RISK, GOVERNANCE AND SOCIETY

Terje Aven
Ortwin Renn

Risk Management and Governance

Concepts, Guidelines and Applications

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Concepts, Guidelines and Applications

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Preface

Today's society seems to be preoccupied with the notion of risk. The examples of the devastating flood in Pakistan in 2010, the hurricane Katrina in 2005, the so called "Mad Cow Disease" (BSE) in Great Britain, the terrorist attack on the World Trade Center in New York, and the major accident of a nuclear power plant in Chernobyl to name just a few, have gained much public attention and have given rise to a growing discontent between the public's desire to see risks reduced and the actual performance of risk management institutions. There is confusion about the potential of risk assessment and risk management. What can society do to reduce risks? What does the term "risk" imply and how is this term understood among engineers and statisticans, natural and social scientists, regulators, social groups and the public at large? What is so special about risk that makes it such an important issue in contemporary politics?

There are more questions than answers when people talk about risks (Short 1984; Aven 2003; Renn 2008). The career of the term "risk" is a rather recent phenomenon, however (Fischhoff et al. 1984). Of course, risk has always been part of human existence and the field of risk research started as early as human beings started to reflect on the possibility of their own death and contemplated actions to avoid dangerous situations. The fundamental mathematical tool for risk assessment, probability theory, was developed centuries before actual risk analyses were performed on technical systems. A systematic scientific attempt to study risks in society and to professionalize risk management agencies is a rather recent addition, however. Several authors claim that systematic studies of risk began with Chauncy Starr's seminal article on risk and voluntariness in 1968 (Starr 1969; Kates and Kasperson 1983; Covello and Mumpower 1985). Others date the beginning in the early 1950s when space exploration programs were designed and probabilistic tools of safety analysis were developed and implemented (Kolluru 1995). Others again associate the first risk assessment studies of chemical or nuclear power plants with the beginning of risk research (Royal Society 1992). Whatever date one chooses, the preoccupation with risk is a rather recent phenomenon in contemporary society and, thus, still an emerging topic in the long tradition of scientific analysis.

The emergence of this topic and its fascinating scope has attracted the two of us to this subject. Why is this topic so fascinating? First of all, risk is paramount to our understanding of human agency. We presume that human beings have agency and that they can choose from a variety of behavioral options (Renn 2008). Agency presupposes that human beings are capable of acting in a strategic fashion by linking decisions with potential outcomes. Humans are goal oriented; they have options for action available and select options that they consider appropriate to reach their goals. Selecting options implies that humans consider and weigh the opportunities and risks that are linked with each option. Thinking about "what could happen" is one of the major distinctions between instinctive and deliberate actions. Hence, in this book we will specifically explore the connections between risk and decision making.

Second, risk plays a major role in most contemporary theories about modern or post-modern societies. Not by chance did Ulrich Beck call his famous book on reflexive modernity *The Risk Society* (Beck 1986, 1992b). Risk has become an essential part of modern society which has been adopted by many scholars and has inspired many analyses about the foundation of modernization and the evolution of governance structures relating to managing uncertainties in a world full of contingencies. This is the reason why we have chosen the concept of governance to describe the societal handling of risk.

Third, risk is not just a fascinating academic subject; it has a direct impact upon our life. People die, suffer, get ill or experience serious losses because they have ignored or misjudged risks, miscalculated the uncertainties or had too much confidence in their ability to master dangerous situations. The institutional means of societies to deal with risks have direct and often painful, consequences for each individual affected by collective actions and arrangements. Risks cannot be confined to the ivory tower of scholarly deliberations. It clearly affects the lives and livelihoods of humans all over the world. Therefore, it is so important that our concept of risk covers both the best technical estimate of the harm as well as an understanding of the social and cultural context in which risks occur. In this book we have tried to give justice to these two sides of risk – the analytical as well as the practical aspects.

Fourth, risk is a truly interdisciplinary, if not transdisciplinary, phenomenon. Risk is a popular topic in many sciences: aspects of risk are studied in the natural, medical, statistical, engineering, social, cultural, economic and legal disciplines. Yet, none of these disciplines can grasp the entire substance of this issue; only if they combine forces can one expect an adequate approach to understanding and managing risks. Investigating risks necessitates a multidisciplinary approach. Risk is like a polished gem with different facets: each facet reflects the light in different colors; but the whole gem can be appreciated only if the images of all the facets are being absorbed. This is the reason why this book has been written jointly by a researcher based on the engineering and statistical tradition and a social scientist. Combining the two major domains of science, the technical/natural and cultural parts of our world, this book should also be seen as an example of the synergies one can accomplish when the two camps meet and cooperate.

Given these four reasons, the main purpose of this book is to illuminate as many of the facets of our polished gem as the two of us were able to detect. In particular, our emphasis is on integration: we attempt to provide an in-depth-understanding of the mathematical and analytical rigor of risk analysis and its outcomes without falling into the usual jargon that may be discomforting to those unfamiliar with mathematical algorithms and formulas. At the same time, we intend to familiarize the more analytically inclined reader with the richness and subtle insights of social science research into risk issues. Our goal is to build bridges between the two science camps. This is not only a desirable goal for its own sake, but, more importantly crucial for improving our performance in risk assessment and risk management. As a physician may be able to understand a mysterious disease only, if he or she investigates all the relevant medical and behavioral facets, so thinking about risk in an integrated fashion helps society to gain more knowledge and expertise in detecting, assessing, evaluating and managing complex risks. There are many textbooks on risk – but usually either seen from a natural science or engineering angle or from a typical social or cultural science perspective. There is a lack of truly integrated approaches to grasp risk from a holistic perspective. This book is meant to meet this challenge.

This first chapter sets the stage for integrated analysis of risk. It provides a description of our understanding of risk, its crucial components and the context in which risk plays a major role. The second chapter is devoted to an overview of risk concepts in different disciplines and traditions. The following chapters introduce the risk governance cycle that we have taken from the model proposed by the International Risk Governance Council (IRGC 2005). The framework builds upon the logical structure of four consecutive phases called reassessment, appraisal, characterization/evaluation and management. In addition, risk *communication* accompanies all four phases. Within each of the boxes, specific activities are listed that are deemed essential for meeting the requirements of good governance. These five phases serve as the main guidance for structuring Chaps. 3–8. Since the term risk communication also includes the important issue of stakeholder involvement and participation, we decided to devote a chapter on its own for this subject (Chap. 9) and another one for stakeholder and public involvement (Chap. 10). Chapters 11–13 illustrate these more abstract steps of risk governance through three distinct case studies. These cases illustrate the need for improvements in risk assessment as well as in risk management. The last Chap. 14 summarizes the main results of our analysis and provides some major lessons for decision and policy makers in economy, politics, and society.

At the end of this preface, we would like to acknowledge the assistance of those individuals who have provided comments, critical remarks, inspirations, ideas and editorial improvements. We are particularly grateful to Key Borschewski, Jörg Hilpert, Brigitte Kugler, Linda March and Sabine Mücke for proofreading the entire manuscript, editing the bibliography and adding an index to the manuscript. We would also like to thank Katharina Wetzel-Vandai from the Springer team for

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Chapter 1
Introduction: Concept of Risk

1.1 The Multidimensionality of Risk

In today's world of globalized trade, travel and communication, an ever larger number of risk-related events have a trans-boundary impact, crossing national and regional frontiers: large-scale electricity blackouts, chemical accidents and risks related to emerging technologies have all affected various parts of the world only recently. Even these risks seem limited, however, when compared to those that can and do go global – and which, as a result of the rapid movement of people, goods and information, do so almost real-time. A highly topical example is that of the potential avian influenza epidemic; other examples include energy supply and price fluctuations and the political and psychological impacts of the 9/11 terror attacks.

The omnipresence of risk has left its mark in public perception and public debate. Risk has become a popular topic in the media. The popular press puts out a constant stream of risk warnings and sensational reports. To give an impression on the variety and diversity of risk issues that have occupied our attention, here are some examples of large scale disasters that have dominated the headline news over the last years:

- The terrorist attack of September 11, 2001
- Natural hazards like the devastating flood in Pakistan in the summer of 2010
- The hurricane Katrina in 2005
- The appearance of new infectious diseases like the severe acute respiratory syndrome (SARS) and avian influenza
- Food scandals like bovine spongiform encephalopathy (BSE)

Risks consequently have to be understood as permanent companions of everyday life. As long as people value certain things or conditions and as long as they take decisions in the presence of uncertainty, they will face risks. Risks are hence a basic constituent of life.

When we talk about risks, we may associate many different things: fears of specific hazards such as a terrorist attack, concerns regarding potential failures of

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complex technological systems like the ones we might face with nuclear energy systems, uncertain projections regarding financial gains or losses that we may experience in the stock market, worries about natural disasters, such as the tsunami in South Asia in 2004, but also the thrill of adventure produced through bungee jumping or other extreme sports. Included in the portfolio of risk may also be worries about the competence and trustworthiness of those who manage these different types of risks (Jaeger et al. 2001:16 f.).

In view of worldwide divergent preferences, variations in interests and values and very few, if any universally applicable moral principles, risks must be considered as heterogeneous phenomena that preclude standardized evaluation and handling. At the same time, however, risk management and policy would be overstrained if each risky activity would require its own strategy of risk evaluation and management. What risk managers need is a concept for evaluation and management that on the one hand ensures integration of social diversity and multidisciplinary approaches, and, on the other hand, allows for institutional routines and standardized practices. The concept of risk is to be understood as a perspective to analyse the uncertain consequences of future developments and changes in societies. Risk is like a pair of "glasses" through which the modern world is looked at. The following sections will explain the approaches of how to conceptualize and understand risks.

1.2 Definitions of Risk

1.2.1 Overview

There is no agreed definition of risk. If we study the risk literature, we find that the concept of risk is used as an expected value, a probability distribution, as uncertainty and as an event. Some common definitions are (Aven and Renn 2009a):

1. Risk equals the expected loss (Willis 2007)
2. Risk equals the expected disutility (Campbell 2005)
3. Risk is the probability of an adverse outcome (Graham and Weiner 1995)
4. Risk is a measure of the probability and severity of adverse effects (Lowrance 1976)
5. Risk is the combination of probability and extent of consequences (Ali 2002)
6. Risk is equal to the triplet (s_i, p_i, c_i), where s_i is the *i*th scenario, p_i is the probability of that scenario, and c_i is the consequence of the ith scenario, $i = 1, 2, \ldots, N$, (Kaplan and Garrick 1981; Kaplan 1991)
7. Risk is equal to the two-dimensional combination of events/consequences and associated uncertainties (will the events occur, what will be the consequences) (Aven 2007a, 2008a, 2009a, 2010)
8. Risk refers to uncertainty of outcome, of actions and events (Cabinet Office 2002)

9. Risk is a situation or event where something of human value (including humans themselves) is at stake and where the outcome is uncertain (Rosa 1998, 2003)
10. Risk is an uncertain consequence of an event or an activity with respect to something that humans value (IRGC 2005)

These definitions can be divided into two categories (1) risk is expressed by means of probabilities and expected values (definitions 1–6) and (2) risk is expressed through events/consequences and uncertainties (definitions 7–10).

Our understanding of risk comes close to the definitions 7–10. The definitions 9–10 represent a subclass of category (2) as they consider risk to be an event (consequence of an event), subject to uncertainties. Uncertainty is an aspect that characterizes or qualifies the events and consequences. The definitions 7 and 8 are different as risk is defined as uncertainty (linked to the events and consequences). The definitions 9 and 10 express a state of the world independent of our knowledge and perceptions (an ontology, cf. Rosa 1998), whereas the other two definitions also include knowledge of that state (epistemology). Our suggestion is to introduce a minor but conceptually important modification of the two risk definitions 9 and 10: *Risk refers to uncertainty about and severity of the consequences (or outcomes) of an activity with respect to something that humans value*. The following sections will provide the arguments and reasons for modifying the definition as we have proposed here.

1.2.2 Risk Defined as an Event Where the Outcome Is Uncertain

Figure 1.1 illustrates shows definitions 9 and 10, which basically express the same intention. The activity considered could produce events and consequences (outcomes) and these are subject to uncertainties. Something of human value is at stake. Risk is defined as an event or a consequence in a specific setting: the consequences (outcomes) are uncertain and something of human value is at stake.

The definition 9: “Risk is a situation or event where something of human value (including humans themselves) is at stake and where the outcome is uncertain”, is introduced and discussed by Rosa (1998, 2003). It expresses an ontological realism that specifies which states of the world are to be conceptualised as risk. As an

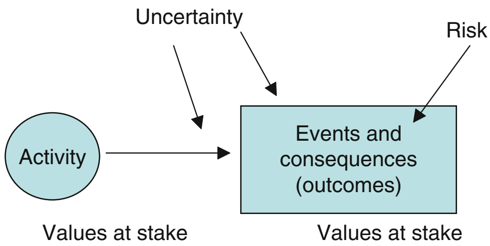

Fig. 1.1 Illustrates of the risk definitions 9 and 10 (Aven and Renn 2009a)

objective state of the world, risk exists independently of our perceptions and our knowledge claims, subjective judgements, about what is at risk and how likely a risk will be realized (Rosa 2008:108f.). Furthermore, by granting risk an ontological status, debates between risk paradigms are placed into an arena of disagreement over questions of knowledge, about our perceptions and understandings of risk, and about our understanding of how groups and societies choose to be concerned with some risks while ignoring others.

Consider smoking. Humans have a stake in their health and well-being, and these values are threatened by events (such as uncontrolled growth of cells) that could lead to lung cancer and death. The events and consequences (outcomes) are subject to uncertainty. Or we could consider lung cancer as the "event" in the definition and reformulate this as: Humans have a stake in their health and well-being, and these values are threatened by lung cancer that could lead to weakened health and death. "Lung cancer" is the risk according to the definition 9. Risk is defined as an event (where . . .). "Lung cancer" is the state of the world. To cite Campbell (2006): "Lung cancer is the risk you run if you smoke". The event is subject to uncertainties and threatens humans' health and well-being.

An analogous definition to 9 is found in reliability theory. Here the term unavailability is normally used as the expected fraction of time the system being considered is unavailable, i.e. is not functioning (Aven and Jensen 1999), but we also see unavailability defined in the sense 9 as a state of the world, expressed by the actual fraction of time the system is unavailable (ISO 2008b). Then we may consider failures in the system as the "events" according to the definition 9 and the fractional downtime as the consequences. The events and consequences are subject to uncertainties.

Risk according to the definition 9 has the following properties:

I. It accommodates both undesirable and desirable outcomes
II. It addresses uncertainties instead of probabilities and expected values
III. It addresses outcome stakes instead of specific consequences

These will be discussed in the following:

Property I: Rosa (1998) makes a point of the fact that the definition (9) can accommodate both undesirable and desirable outcomes. The term "What human values" is the key characteristic. In this way, also economic risks as well as thrills are incorporated, since these domains of human risk action both address losses and gains.

Accommodating both undesirable and desirable outcomes is a requirement for any definition of risk if we search for a widespread agreement. We see from the list of definitions in Sect. 1.2.1 that several of these meet this requirement (all except 1, 3 and 4, definition 2 may also be included in case disutility is restricted to undesirable outcomes). By restricting the risk definition to undesirable outcomes, we need to determine what is undesirable, and for whom? An outcome could be positive for some stakeholders and negative for others. It may not be worth the effort and energy discussing whether an outcome is classified in the right category.

Properties II and III: The definition 9 addresses uncertainties instead of probabilities and expected values and it addresses outcome stakes instead of specific consequences: Addressing uncertainties instead of probabilities and outcome stakes instead of specific consequences are crucial features of definition 9. They point at the challenge of establishing a precise measure of uncertainty as well as a precise measure of stakes involved. Probability is the common tool to express uncertainty, but the transformation of knowledge to probabilities is not straightforward. The probability assignments are conditioned on a number of assumptions and suppositions. The assignments are not expressing objective results. Uncertainties are often hidden in probabilities and expected values, and restricting attention to these quantities could camouflage factors that could produce surprising outcomes (Aven 2008b, 2010).

As uncertainty and outcome stakes are key points of debate among experts, among laypersons, and between experts and laypersons, Rosa (1998) argues that his definition is more robust than the standard technical definition based on expected values. The key point is, however, not that risk is identified by an event but that uncertainty replaces probabilistic quantities, and that specific consequences are replaced by a broader discussion of outcome stakes. In definition 9, Rosa (1998) refers to the two defining features of the risk; the "Outcome stake" and the "Uncertainty", and draws the illustration shown in Fig. 1.2.

Presenting the dimensions of risk in this way, uncovers according to Rosa several important features of the risk concept: First, the definition is consistent with the etymology of the word risk, meaning to navigate among dangerous rocks. Second, the representation is consistent with the standard definition of risk in the technical literature as a function of probability and consequences (or outcomes).

A comment to this statement is in place. The definition 9 and Fig. 1.2 relate to uncertainties, not probabilities. A probability is a measure of uncertainty, but uncertainties exist without specifying probabilities. Furthermore, there is nothing in the definition 9 and Fig. 1.2 saying that we should multiply probabilities and consequences, i.e. consider expected values. In the technical literature, risk is often defined by expected values, but it is equally common to define risk by the combination of probabilities and consequences (outcomes), i.e. the full probability distribution of the outcomes (Ale 2002; Aven 2003).

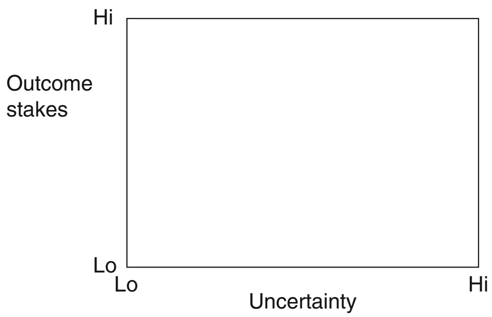

Fig. 1.2 Dimensions of risk (Rosa 1998)

Now let us examine how the definition 9 is to be used in a risk research and/or a risk management context. Suppose you ask some experts on smoking "Is the risk high?" How can risk be reduced? How is the risk compared to other risks? The experts would have to say that such statements have no meaning. He or she may consider the risk to be severe, but without an assessment of uncertainty or probability they cannot conclude on the risk being high or low, and rank the risks.

Instead the experts must use statements like this: The (assigned or estimated) probability of the risk is high, and higher than the (assigned or estimated) probability of another risk. To reflect that uncertainty exists without specifying probabilities, the experts may alternatively use a statement like this: The uncertainties about the occurrence of the risk is rather small, the uncertainties can be reduced by measures so and so, etc. We see that compared to standard terminology used in risk research and risk management, definition 9 leads to conceptual difficulties that are incompatible with the everyday use of risk in most applications.

As a more specific case, consider the ALARP principle, which is an important principle in risk management, expressing that risk should be reduced to a level that is as low as reasonable practicable (HSE 2001; Aven and Vinnem 2007). As it stands, this principle has no meaning according to definition 9, and has to be rephrased. "Risk should be reduced", needs to be changed to "Uncertainties/likelihoods of the risks should be reduced". How this can be operationalized must be defined, but that is not the issue here. The main point we would like to make here is that definition 9 cannot be applied to many risk concepts without making major detours and adding ad hoc assumptions.

As another example, we consider risk perception. The definition 9 means that risk and perception of risk are separate domains of the world (Rosa 1998:33). Risk exists independent of our perceptions. To get lung cancer is a risk (according to 9), and how person A, who is smoking, judges the risk is his/her risk perception. This judgement could for example be that he/she concludes that the risk is strongly undesirable, as the consequences of lung cancer is so severe. However, by looking at the likelihood (uncertainty) of the risk, he could find that this likelihood (uncertainty) is rather low and acceptable. The uncertainties/likelihoods need to be taken into account to reflect his/her perceptions. If we use the term risk perception according to 9, this is not an obvious interpretation, as risk is defined as the event lung cancer. We again see that a detour and adding assumptions are required to apply a basic concept in risk research and risk management.

The other extreme is to say that *risk is the same as risk perception*, as has been suggested by cultural theory and constructivism (Jasanoff 1999; critical comments in Rosa 1998). Risk coincides with the perceptions of it (Douglas and Wildavsky 1982; Freudenburg 1988; Rayner 1992; Wynne 1992b). Beck (1992b:55) concludes that "because risk are risks in knowledge, perceptions of risks and risk are not different things, but one and the same". Beck argues that the distinction between risk and risk perception is central to a scientific myth of expertise, according to which the population "perceives risks" but science determines (i.e. identifies and quantifies) risk (Campbell and Currie 2006:152). A similar viewpoint can be found in an article by S. Jasanoff:

> I have suggested that the social sciences have deeply altered our understanding of what "risk" means – from something real and physical, if hard to measure, and accessible only to experts, to something constructed out of history and experience by experts and laypeople alike. Risk in this sense is culturally embedded in texture and meaning that vary from one social grouping to another. Trying to assess risk is therefore necessarily a social and political exercise, even when the methods employed are the seemingly technical routines of quantitative risk assessments... Environmental regulation calls for a more open-ended process, with multiple access points for dissenting views and unorthodox perspectives... (Jasanoff 1999:150).

This viewpoint of risk being the same as risk perception is, however, not confined to these paradigms and scientists (Rosa 1998). Rosa refers for example to the leading risk psychometrician Paul Slovic who has written: "Human beings have invented the concept of 'risk' ... there is no such thing as 'real risk' or 'objective risk'" (Slovic 1992:119).

But rejecting the idea that there exists a "real risk" or an "objective risk" does not mean that risk is the same as perceived risk. Depending on how a probability is understood, none of the definitions 1–8 needs to be based on the idea of a "real risk" or "objective risk". If probability is a way of expressing uncertainties, seen through the eyes of the assigner (a knowledge-based or subjective probability), there is no "real risk" or "objective risk". However, knowledge-based probabilities and related risk assignments are not the same as risk perception. The main difference is that risk perception is based on personal beliefs, affects and experiences irrespective of their validity. Knowledge-based probabilities used in risk assessments are representations of individual and collective uncertainty assessments based on available statistical data, direct experience, models and theoretical approximations which all need justification that must also be plausible to others. The difference may be a judgment call at the borderline between subjective probabilities and perception, but the need for justification according to intersubjective rules is an important and relevant discrimination point between the two concepts.

Furthermore, if we assume that risk perception does not only cover perceived seriousness of risk but also acceptability of risk the difference becomes even more pronounced. A knowledge-based probability carries no normative weight in terms of acceptability or tolerability of risk. You may assign a probability equal to 0.000000001 for an event to occur, but still find the risk to be intolerable. Our judgments about risk acceptability are as we know from a number of risk perception studies influenced by many factors outside the realm of the probabilistic world. Perception of risk does not discriminate between the "value-free" risk knowledge on the one hand and the value judgment about its acceptability or tolerability on the other hand. The assigned probability and judgments about risk tolerability or acceptability are different dimensions, or separate domains in the world of risk professionals who make a clear distinction between risk assessment and judgment of acceptability.

In the case that the risk perspective is based on the idea that a true risk exists, it is obvious that the thesis "risk = risk perception" is wrong (Campbell 2005). The above analysis showed, however, that this thesis is invalid for all the risk definitions 1–10.

1.2.3 New Risk Definition

As an alternative to the definition 9, we suggest the following definition: *Risk refers to uncertainty about and severity of the events and consequences (or outcomes) of an activity with respect to something that humans value* (Aven and Renn 2009a). In this section we will explain the meaning of this definition and compare it with the definition 9. The main features of the definition are illustrated in Fig. 1.3, analogous to Fig. 1.1.

According to this definition risk refers to uncertainty about events/consequences of an activity, seen in relation to the severity of the events/consequences. Severity refers to intensity, size, extension, scope and other potential measures of magnitude, and is with respect to something that humans value (lives, the environment, money, etc). Losses and gains, for example expressed by money or the number of fatalities, are ways of defining the severity of the consequences. It is important to note that the uncertainties relate to the events and consequences – the severity is just a way of characterising the consequences.

This definition accepts the three properties in Sect. 1.2.2, but contests that risk is a state of the world that exists independently of the assessors. Incorporating the uncertainty dimension into the risk concept as suggested, risks can be judged high or low, and compared to other risks. In the lung cancer example, risk refers first to uncertainty that lung cancer may or may not materialize and second to severity of this disease, i.e. the degree of violation of personal or social value associated to lung cancer. Probabilities may be used as a tool to express these uncertainties, for example by determining a probability of at least x persons dying because of lung cancer next year in a specific population. In the system reliability example, risk refers to uncertainties about and the severity of the consequences of a failure in the system. Probabilities expressing the uncertainties are used to predict the performance of the system. As a third example, consider the risk associated with a terrorist attack. Here risk refers to uncertainties about and the severity of the consequences of a terrorist attack. Again probabilities may be used as a tool to express these uncertainties, related to the event "terrorist attack" and the consequences given that such an event occurs. For specifying the probability of a terrorist attack there is little statistically relevant data available. So we may prefer a qualitative expression of the knowledge and lack of knowledge (or often phrased

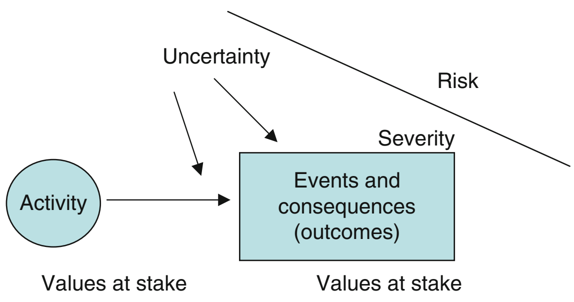

Fig. 1.3 Illustration of the main features of the new risk definition (Aven and Renn 2009a)

non-knowledge) about the underlying phenomena and processes, i.e. about the uncertainties. As stated earlier, the expression of uncertainty does not imply a judgment on risk acceptability or tolerability but it is the pre-condition that such a judgement can be made on the basis of evidence and qualified assessments rather than pure intuition or personal experience.

Our definition is based on the combined dimensions uncertainties and severity, similar to Rosa's perspective presented in Fig. 1.2. Severity of consequences corresponds to outcome stakes. Hence we may consider our definition as a reformulation of Rosa's definition 9. In our view it captures the main intention of 9, but is more precise in terms of what is combined in the risk concept. In this line of argument it is essential that the second dimension is uncertainties and not probabilities. The concept of risk should be based on uncertainties beyond probabilities.

A low degree of uncertainty does not necessarily mean a low risk, or a high degree of uncertainty does not necessarily mean a high level of risk. As risk is defined as the two-dimensional combination of uncertainties and severity of consequences, any judgment about the level of risk, needs to consider both dimensions simultaneously. For example, consider a case where only two outcomes are possible, 0 and 1, corresponding to 0 and 1 fatality, and the decision alternatives are A and B, having uncertainty (probability) distributions (0.5,0.5), and (0.0001, 0.9999), respectively. Think of the outcome 1 in alternative B as the occurrence of a fatal accident in traffic in a specific area next year. Hence, for alternative A there is a higher degree of uncertainty than for alternative B. However, considering both dimensions, we would of course judge alternative B to have the highest risk as the negative outcome 1 is nearly certain to occur.

Vulnerability: In risk assessment it is necessary to distinguish between *the risk agent* (such as a chemical or a technology) *and the risk absorbing system* (such as a building, an organism or an ecosystem). Addressing complex structures of risk agents requires methods for causal modelling and data analysis. With respect to risk absorbing systems the emphasis is on vulnerability (IRGC 2005). The extent to which the risk absorbing system reacts to the stress induced by the risk agent is called vulnerability. More formally, in line with the risk definition we can define vulnerability as uncertainty about and severity of the consequences, given the stress induced by the risk agent (for example an attack) (Aven 2008a).

1.3 Implications for Risk Perception

We concluded in Sect. 1.2 that for none of the risk definitions 1–10, risk is the same as risk perception. Consider our suggested definition and the lung cancer example. If the focus is the risk for an individual, say John (who is smoking), then risk comprises the two dimensions:

(a) Uncertainties about the occurrence of lung cancer and its consequences and
(b) The severity of getting lung cancer and its consequences

The risk perception is the person's judgment about this risk, and could be influenced by the facts (for example showing observed correlations between smoking and lung cancer), scientific risk assessments, the individual's own calculations and assessments, as well as perceptional factors such as dread or personality factors such as a personal preference for risk-averse behaviour.

In our concept, risk does not exist independent of the assessor, as the uncertainties need to be assessed by somebody. Consider the lung cancer example. Would cancer exist if the conditions of cancer – the uncontrolled growth of cells – have not been detected (we may call this state of the person "undetected cancer")? Yes, cancer exists, but this is not a risk according to our definition. Risk according to our definition requires a mental construction of the uncertainty (knowledge) dimension. This construction can be based on observations and/or causal knowledge about dose and effect. Regardless of how this construction is generated, it still relates to a mental construction, of a virtual reality expanding into scenarios of what could happen if John continues to smoke, or smoke less or quit smoking or reduce weight and continue smoking, etc. "Uncertainty" is not real, it is a construct of human imagination to cope with potential future outcomes that can become real. This is in contrast to definition 9 where cancer is the risk, independent of whether it is detected or its uncertainty is assessed or not.

Emphasizing the subjective and constructive nature of uncertainty does not imply however that these constructs are arbitrary or not subject to scientific scrutiny. Returning to the lung cancer example, a risk assessment means first to address (describe) the uncertainties and likelihoods related to the occurrence of lung cancer and its possible consequences such as death, and then make an evaluation of this risk, which could for example mean a comparison of the risk with other activities. This can be done based on the best scientific data available. Perception of risk, on the other hand, is a judgement about risk which includes personal or social attributes such as the degree of perceived personal control and the familiarity of the risk situation. John's risk perception is related to how the risk affects him. Considering such aspects is not irrational or unscientific. However, it is a personal or, if shared by others, social judgment that colors the uncertainty and/or the severity judgment of John or the group he may represent. Therefore, it cannot be generalized in terms of an abstract and encompassing concept of risk.

The fact that both uncertainty and severity imply a reference to the assessor, should not be confused with the postmodern thought that risk knowledge is socially constructed and therefore unrelated to the objective world. Clearly, there are events (dangers) out there even if they have not yet been perceived (new, undiscovered diseases for example). Rosa (1998) writes:

> To argue that no dangers exist beyond those we perceive or beyond our current measurement sophistication is a difficult argument to sustain. It is another version of the "argument from ignorance" fallacy (Shrader-Frechette 1985), meaning that if we are ignorant of some danger there is little basis for claiming the danger exists at all.

The assumption that threats are only real if we perceive them as risks is counterintuitive and easy to refute. Yet does our definition of risk fall prey to this fallacy when it emphasizes the subjective nature of both uncertainty and severity? This is not the case. The concept that we propose does not prescribe the consequences. There could be large uncertainties related to specific consequences or events that may or may never materialize. The uncertainties may be a result of "known uncertainties" – we know what we do not know, and "unknown uncertainties" (ignorance or non-knowledge) – we do not know what we do not know. For a specific activity an undiscovered disease may occur. This risk exists for the assessor provided that the assessor opens up for the possible occurrence of such consequences. See Aven et al. (2010).

1.4 Normative Implications

It is common to distinguish between (a) state of the world (ontology), (b) knowledge about that state (epistemology) and (c) normative judgment (what ought to be done). Our definition covers (a) and (b), but leaves (c) to the risk treatment. Also definition 9 addresses (a) and (b) although the risk itself is defined as a state of the world (a).

There is no normative aspect involved in the merge of uncertainty and severity. We do not propose a specific rule of combining both components such as multiplication. This would have implied a value judgment, for example that the components should receive weights according to an expected value formula.

We may compare our definition with a probability distribution of a quantity X (for example expressing the number of fatalities) based on knowledge-based (subjective) probabilities. This probability distribution exists for the assessor, and covers both dimensions (a) and (b). However, our definition is more general as probability is replaced by uncertainties and the consequences are not restricted to a set of defined random quantities.

The definitions 9 and our new definition both have the following properties:

- They accommodate both undesirable and desirable outcomes
- They address uncertainties instead of probabilities and expected values
- They are not restricted to specific consequences and quantities

We consider these properties essential for the risk concept to provide a foundation for risk research and risk management. The definition 9 represents a state of the world (ontology) whereas our proposed definition also incorporates the epistemological component uncertainty in the risk definition. Our definition combines the two key dimensions of risk (a) uncertainties about events and consequences and (b) severity of these events and consequences (outcome stakes), in line with existing classification schemes (Funtowicz and Ravetz 1985; Rosa 1998; Aven 2003:127, 2007a). It acknowledges the challenge of establishing a precise measure of uncertainty as a well as a precise measure of stakes involved (Rosa 1998). Risk is then not a state of the world, but the events/consequences that are associated with the risk (for example: John gets lung cancer) are states of the world.

For risk research and risk management the difference between definition 9 and our proposed definition has not only academic value but impacts on policies, procedures and practices. If considering risk a state of the world as definition 9 does, the practice of risk assessment would need to be revamped. For example, we cannot talk about high risks and compare options with respect to risk. Our proposed definition provides a conceptually consistent and practically compatible concept of risk without falling into the extreme of total subjectivism and relativism but also not pretending that risk is a measurable object similar to other physical entities.

1.5 Classification of Risk Problems

For a systematic analysis of risks it is helpful to introduce a risk classification system which reflects the knowledge base and its interpretations. We distinguish between different type of situations (risk problems), according to the degree of complexity (Simple – Complex), uncertainty and ambiguity (IRGC 2005; Aven and Renn 2009b).

Simplicity is characterized by situations and problems with low complexity, uncertainties and ambiguities. Examples include car accidents, smoking, regularly reoccurring natural disasters or safety devices for high buildings. Note that simplicity does not mean that the risks are low. The possible negative consequences could be very large. The point is that the values that are exposed are non-controversial and the uncertainties low. It is possible to rather accurately predict the occurrence of events and/or their consequences.

Complexity refers to the difficulty of identifying and quantifying causal links between a multitude of potential causal agents and specific effects. The nature of this difficulty may be traced back to interactive effects among these candidates (synergisms and antagonisms), positive and negative feedback loops, long delay periods between cause and effect, inter-individual variation, intervening variables, and others. It is precisely these complexities that make sophisticated scientific investigations necessary since the dose–effect relationship is neither obvious nor directly observable. Nonlinear response functions may also result from feedback loops that constitute a complex web of intervening variables. The global decrease in biodiversity is an example of a risk situation that is characterised by high complexity. The destruction of natural habits of endangered species, the intrusion of invasive species caused by globalised transport and travels, and environmental pollution are only some influencing factors, of which the interdependencies are unknown to a large extent. Other examples of complexity include synergistic effects of potentially toxic substances and failure of large interconnected infrastructures.

Uncertainty refers to the difficulty of predicting the occurrence of events and/or their consequences based on incomplete or invalid data bases, possible changes of the causal chains and their context conditions, extrapolation methods when making inferences from experimental results, modelling inaccuracies or variations in expert judgments. Uncertainty may results from an incomplete or inadequate reduction of complexity, and it often leads to expert dissent about the risk characterization. Examples of high uncertainty include many natural disasters (such as earthquakes), possible health effects of mass pollutants, acts of violence such as terrorism and sabotage and long term effects of introducing genetically modified species into the natural environment. For terrorism risk, the consequences of an attack can be fairly accurately predicted. However, the time and type of attack is subject to large uncertainties.

The difficulty of predicting the occurrence of events and/or their consequences depend on the models available. If variations in populations are known (for example the proportion of persons suffering a disease), the corresponding probability distributions represent a basis for accurate predictions. Variation in populations is often referred to as stochastic or aleatory uncertainties. In general, the uncertainties can be reduced by improving our knowledge and improving our models. Yet aleatory uncertainty remains fuzzy about the time, the exact location and/or the persons who will suffer.

Ambiguity refers to different views related to

1. The relevance, meaning and implications of the basis for the decision making (interpretative ambiguity) or
2. The values to be protected and the priorities to be made (normative ambiguity)

What does it mean, for example, if neuronal activities in the human brain are intensified when subjects are exposed to electromagnetic radiation? Can this be interpreted as an adverse effect or is it just a bodily response without any health implication? Examples of high interpretative ambiguity include low dose radiation (ionising and non-ionising), low concentrations of genotoxic substances, food supplements and hormone treatment of cattle. Normative ambiguities can be associated, for example, with passive smoking, nuclear power, pre-natal genetic screening and genetically modified food. Normative ambiguity raises the question about the tolerability of the risk. It is based on the idea that there are varying legitimate concepts of what can be regarded as tolerable, "referring e.g. to ethics, quality of life parameters, distribution of risks and benefits etc." (IRGC 2005:31). For example, genetically modified organisms (GMO) encounter a high level of opposition in the area of food, but are widely accepted in the area of medical applications, because they are associated with the hope for great benefits.

Most of the scientific disputes in risk analysis do not refer to differences in methodology, measurements or dose–response functions, but to the question of what all of this means for human health, environmental protection etc. Emission data is hardly disputed. Most experts debate, however, whether a certain emission constitutes a serious threat to the environment or to human health. Ambiguity may come from differences in interpreting factual statements about the world or from differences in applying normative rules to evaluate a state of the world. In both cases, ambiguity exists on the ground of differences in criteria or norms to interpret or judge a given situation. High complexity and uncertainty favour the emergence of ambiguity, but there are also quite a few simple and low uncertainty cases that can cause controversy and thus ambiguity.

1.6 Social Constructivism Versus Realism

There is a major debate among risk professionals about the nature of risks: are risks social constructions or real phenomena? The issue here is whether technical risk estimates represent “objective” probabilities of harm, or reflect only the conventions of an elite group of professional risk assessors that may claim no more degree of validity or universality than competing estimates of stakeholder groups or the lay public. Furthermore, different cultures may have different mental representations of what they consider “risks”, independent of the magnitude or probability of harm. At first glance it is obvious that risks constitute *mental constructions* (OECD 2003a:67). They are not real phenomena, but originate in the human mind. Actors, however, creatively arrange and reassemble signals that they get from the “real world”, providing structure and guidance to an ongoing process of reality enactment. Therefore, risks relate to what people observe in reality, and what they experience. The link between risk as a mental concept and reality is forged through the experience of actual harm (the consequence of risk) in the sense that human lives are lost, health impacts can be observed, the environment is damaged or buildings collapse.

The status of risk as a mental construction has major implications for how risk is perceived. Unlike trees or houses, one cannot scan the environment, identify the objects of interest and count them. Risks are created and selected by human actors. What counts as a hazard to someone may be an act of God to someone else, or even an opportunity for a third party. Although societies have, over time, gained experience and collective knowledge of the potential impacts of events and activities, one cannot anticipate all potential scenarios and be worried about all of the many potential consequences of a proposed activity or an expected event. By the same token, it is impossible to include all possible options for intervention. Therefore, societies have been *selective* in what they have chosen to be worth considering and what to ignore (Douglas 1990; Thompson et al. 1990; Beck 1994:9 ff.). Specialized organizations have been established to monitor the environment for hints of future problems and to provide early warning of some potential future harm. This selection process is not arbitrary. It is guided by cultural values (such as the shared belief that each individual life is worth protecting), by institutional and financial resources (such as the decision of national governments to spend money or not to spend money on early warning systems against highly improbable but high-consequence events), and by systematic reasoning (such as using probability theory for distinguishing between more likely and less likely events or methods to estimate damage potential or determine distributions of hazards in time and space).

Ultimately, whether the evidence, collected for assessing and evaluating risks represents human ideas about reality or depicts representations of reality, is more or less irrelevant for the distinction between evidence and values that is suggested throughout the risk governance framework that forms the basis of this book (IRGC 2005).

Our adopted risk perspective tries to avoid the naive realism of risk as a purely objective category, as well as the relativistic perspective of making all risk judgements subjective reflections of power and interests. We must deal with both the “physical” and “social” dimensions of risk. We refer to the discussion in Sect. 1.2.

Chapter 2
Characteristics of Risks in the Modern World

2.1 New Challenges to Risk Governance

A number of driving forces have been identified that are shaping our modern world and have a strong influence on the risks we face (cf. OECD 2003a:10 ff.): The *demographic development*, including the increase of the world population, the growing population density and visible trends towards urbanisation accompanied by significant changes in the age structure of most industrial populations have lead to more vulnerabilities and interactions among natural, technological and habitual hazards. Demographic changes are also partially responsible for the strong interventions of human beings into the natural environment. Human activities, first of all the emission of greenhouse gases, may cause global warming and, as a consequence, place growing stress on ecosystems and human settlements. In addition, the likelihood of extreme weather events increases with the rise of average world temperatures. Furthermore, these trends towards ubiquitous transformation of natural habitats for human purposes are linked to the effects of economic and cultural *globalization*: The exponential increase in international transport and trade, the emergence of world-wide production systems, the dependence on global competitiveness and the opportunities for universal information exchange testify to these changes and challenges. In terms of risks, these trends create a close web of interdependencies and coupled systems by which small perturbations have the potential to proliferate through all the more or less tightly coupled systems and cause significant damage.

The development of globalization is closely linked to *technological change*. The technological development of the last decades has led to a reduction of individual risk, i.e. the probability to be negatively affected by a disaster or a health threat, yet increased the vulnerability of many societies or groups in society. Among the characteristics of this technological development are the tight coupling of technologies with critical infrastructure, the speed of change and the pervasiveness of technological interventions into the life-world of human beings, all aspects that

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have been described as potential sources of catastrophic disasters (cf. Perrow 1992; von Gleich et al. 2004).

In addition to the technological changes, *socioeconomic structures* have experienced basic transitions as well. In the last two decades efforts to deregulate the economy, privatise public services and reform regulatory systems have changed the government's role in relation to the private sector which had major repercussions on the procedures and institutional arrangements for risk assessment and risk management. Attitudes and policies are increasingly influenced by international bodies with conflicting interests and increasingly by the mass media.

These basic developments have induced a number of consequences:

- An increase of catastrophic potential and a decrease of individual risk, associated with an increased vulnerability of large groups of the world population with respect to technological, social and natural risks
- An increase in (cognitive) uncertainty due to the growing interconnectedness and the fast global changes
- An increased uncertainty about a change in frequency and intensity of natural hazards due to global change
- Strong links between physical, social and economic risks due to the interconnectedness of these systems
- An exponential increase in payments by insurances for compensating victims of natural catastrophes
- The emergence of "new" social risks (terrorism, disenchantment, mobbing, stress, isolation, depression)
- An increased importance of symbolic connotations of risks, and thus a high potential for social amplification and attenuation of risks. Social amplification of risk describes an amplification of the seriousness of a risk event caused by public concern about the risk or an activity contributing to the risk (Jaeger et al. 2001:171)

2.2 The Emergence of Systemic Risks

These recent trends and consequences of risks to society have led to the creation of a new risk concept – the concept of *emerging systemic risks*. These are risks "that affect the systems on which the society depends – health, transport, environment, telecommunications, etc." (OECD 2003a:9). Systemic risk denotes the embeddedness of risks to human health and the environment in a larger context of social, financial and economic risks and opportunities. Systemic risks are at the crossroads between natural events (partially altered and amplified by human action such as the emission of greenhouse gases), economic, social and technological developments and policy driven actions, both at the domestic and the international level. These new interrelated risk fields also require a new from of risk analysis, in which data from different risk sources are either geographically or functionally integrated into one analytical perspective. Investigating systemic risks goes beyond the usual agent-consequence analysis and focuses on interdependencies and spill-overs between risk clusters.

Systemic risks also face specific problems with respect to public perception and risk governance structures. Risk management and governance processes dealing with systemic risks suffer from a loss of credibility and trust; they are often driven by crisis and immediate often non-reflected management actions determined by public opinion. One major reason for this is that decision-making on risk often fails to successfully combine scientific expertise with careful consideration of the socio-cultural aspects of risk issues. Policy makers are often not aware or not willing to accept that risk relates to both the physically measurable outcomes ("facts") and the socio-cultural attributions ("values"). Neither the solution that assumes that scientific knowledge determines political decisions, nor the opposite view that "all knowledge is created equal" provides a promising and reliable basis for prudent risk management.

Systemic risks have evolved from the increased vulnerabilities and interconnections between geographic areas as well as functional dependencies between the various sectors of society such as the physical world, the economy, the social relationships and the political cultures. The potential for systemic risks is likely to become augmented because of:

- Increase of population and population density
- Increase of population exposed to natural hazards and technological risks (dramatic increase in losses due to natural disasters over the last four decades, during the last decade natural hazard disasters have resulted annually in some 79,000 fatalities, with 200 million people affected) (OECD 2003a:14)
- Increased use of hazard-prone land for productive purposes (for example 40 of the 50 fastest growing urban centres in the world are located in earthquake-endangered areas) (Randall et al. 1996)
- Increased interdependencies between technical, social, and cultural hazards
- Expected increase of hazard intensity due to climate change and other human interventions into geo-chemical cycles (IPCC 2001)
- Changes in the social definition of what is being regarded as detrimental or hazardous (Renn and Rohrmann 2000)
- Growing diversity with respect to lifestyles and subcultures within societies (Beck 1992a)

At a time, when the disaster potential increases, the coping mechanisms of many societies appear to become less effective. Vulnerability is likely to increase due to:

- Speed of urbanization (probably two thirds of the world population will live in cities after 2020) (Jones and Kandel 1992)
- Insufficient speed in building infrastructure to cope with it (OECD 2003a:44)
- Coupling of independent risk sources
- Interaction of natural disasters with chemical, technological, lifestyle, and social risks (Perrow 1984; Renn 1997b)

- Increase of mobility and cultural de-rooting
- Loss of traditional management capabilities (WBGU 2000)
- Increase of social pressure and conflicts
- Lack of capacity for mitigation and contingency management, etc. (IFRC 2000)

Given these new challenges the world needs a concerted effort to deal with systemic risks. In particular new methodological as well as institutional solutions involving the different levels of risk governance at the local, national, international and global level are required as a means to provide adequate tools for limiting and managing those risks. Another more down to earth reason for such an integrated approach is the confusion of the public, because, on the one hand, the methodical approach for risk assessment is different for different technologies and, on the other hand, because the risks of the same technology are evaluated differently in different countries, by different interest groups and by different experts; even terms are used differently. A similar confusion exists with respect to the risk management processes themselves and for the policy styles, the regulation principles and the target values applied.

As a result of the emergence of systemic risks, new challenges for risk management, and risk governance have come up. Among the most pressing are:

- Finding more accurate and effective ways to characterize uncertainties in complex systems.
- Developing methods and approaches to investigate and manage the synergistic effects between natural, technological, and behavioural hazards.
- Integrating the natural and social science concepts of risks to deal with both physical hazards and social risk perceptions.
- Expanding risk management efforts to include global and transboundary consequences of events and human actions.

In Chap. 4 we will develop a framework that promises some solutions of how to deal with these challenges.

Chapter 3
Risk Perspectives

3.1 Purpose of a Comparative Review

The purpose of this chapter is to give a brief review and discussion of the variety of concepts of risk in different disciplines and application areas, as a basis for describing the integrated approach taken in this book. In general, the following elements form the essence of the risk concept:

- Possible outcomes (O). We are concerned about outcomes that affect what humans value and in particular undesirable outcomes. It is an issue who determines what undesirable means. We distinguish often between initiating events (undesirable events) (A) and their consequences (C). Example: The occurrence of a terrorist attack (A) and the associated consequences (C).
- Uncertainties (U), and probabilities (P) specifying the likelihood of each outcome.
- Ways of aggregating the possible outcomes allowing for comparisons and the setting of priorities, for example expected value (EV), expected net present value (E[NPV]) and expected utility (EU).

Based on these dimensions –the possible outcomes, uncertainty and the rule of aggregation for practical purposes – we can structure the way risk is conceptualized and used in various disciplines and application areas. See Table 3.1. This structure is based on Renn (1992b, 2008:12ff).

3.2 The Technical Risk Perspective

If large data bases are available, as in the world of the insurance companies, statistical analysis based on large samples can be used for prediction purposes. An application of this approach may be the prediction of fatalities in car accidents for the coming year. From the statistical data about fatal accidents in previous years,

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Table 3.1 Classification of risk perspectives (based on Renn (1992b, 2008:15))

Risk perspective	Integrated approaches						
	Statistical analysis (including the Actuarial approach)	Toxicology, epidemiology	Probabilistic risk analysis	Economics of risk	Psychology of risk	Social theories of risk	Cultural theory of risk
Risk description	Statistics. Large population averages	Probabilities and Expected Values (P & EV)	Probabilities and Expected Values (P & EV)	Outcome uncertainties relative to the expected value, measured by the variance and quantiles (Value at risk). Expected utility (EU) and Expected net present value E[NPV]	Probabilities and expected utility.	Beliefs and feelings that people have about the nature of hazardous events, their features and benefits (e.g. fairness), and their acceptability	Risk is a social construct.
Main scope of risk concept	Universal	Health and environment	Safety	Universal	Individual perceptions	Social interests	Cultural clusters
Predominant theories/ methods	Sampling, estimation, prediction, and testing hypotheses	Hazard identification. Dose–response assessments, exposure assessments. Experiments, health surveys	Basic risk assessments methods such as event trees and fault trees. Consequence modeling.	Statistical analysis. Expected utility theory, Cost benefit analysis, Portfolio theory	Psychometrics	Surveys, structural analyses	Grid-group analysis
Purpose	Monitoring the risk level, identify critical items, prediction. Support decisions on the risk	Identify risk contributors and describe risk, to support decision making on policy selection, risk reducing measures and standard setting.	Identify risk contributors and describe risk, to support decision making on policy selection, arrangements and risk reducing measures	Support decision making on policy selection and resource allocation	Show how people assign probabilities and the factor influencing the assignments. Show how people make decisions and how these	Input to processes on political acceptance, Equity, Fairness Policy making, conflict resolution and risk communication	Cultural identity, political legitimation Policy making, conflict resolution and risk communication

	handling, e.g. about risk sharing in insurance				deviates from e.g. the expected utility theory Individual acceptance, policy making, conflict resolution and risk communication		
Basic problem areas	Predictive power, averaging. Relevancy to sub-populations	Averaging. Transfer to human	Averaging. Precision level. Common mode failures. Human–machine interface	Aggregate utility functions. Preference aggregation. In E[NPV] calculations transform all values to money	Preference aggregation. Social relevance	Social relativism	Social relativism. Empirical validity

this number can be accurately predicted. This perspective of risk relies on two conditions. First, enough statistical data must be available. Second, the causal agents that are producing the effects must remain stable over the time period considered. The resulting risk assessment is reduced to a single dimension representing the population average.

Risk assessment becomes more complex when the adverse effects cannot be observed as an immediate effect of a causing agent (Kolluru 1995; Bedford and Cooke 2001). If we think of environmental risks such as dioxin, benzene or radioactive particles, the link between exposure and effect is often difficult to draw, sometimes not even measurable. In such risk assessments, causal relationships have to be explored through modeling. Models represent plausible and – in an ideal world – empirically confirmed representations of the cause–effect relationships. Models are purpose driven constructions that are built to display the cause–effect pathways. In the field of medical risk such models try to assess the likely impact of a specific agent, for example acrylamide, on human health, i.e. development of cancer. Based on toxicological (animal experiments) or epidemiological studies (comparing a population exposed to a risk agent with a population not exposed to the risk agent), researchers try to identify and quantify the relationship between a potential risk agent (such as dioxin or ionizing radiation) and physical harm observed in humans or other living organisms (NRC 1991; IEC 1993; Graham and Rhomberg 1996). Risk assessments based on toxicological or epidemiological models can serve as early warning signals to inform society that a specific substance may cause harm to humans or the environment, even if the effects are not obvious to an unskilled observer. In addition, dose–effect investigations help risk managers to define standards in accordance with observed or modeled threshold values. If there is no threshold value as in the case of most carcinogens, risk assessments provide probabilities of harm depending on the dose.

Another complication is experienced when facing technological risks: the absence of sufficient data for the system as a whole. Technical malfunctions and/or human errors in handling technological systems can cause these systems to fail and the consequence can be catastrophic. As a tool to analyze and model such failures and their consequences, experts use probabilistic risk assessments (Bedford and Cooke 2001; Modarres 1993; Aven 2003). Using techniques such as fault tree or event tree analyses, the system failure probability is computed. The basis for the calculations is the system structure and the component failure probabilities, determined by models, hard data and/or expert judgments.

The statistical, environmental and technological approaches have much in common and can be grouped together as technical perspectives on risk. They anticipate potential physical harm to human beings, cultural artifacts or ecosystems, and use probabilities and expected values (estimated or assigned) to express uncertainties and frequencies. The normative implication is obvious: since physical harm is perceived as an undesirable effect (at least for most people and society as a whole), technical risk analyses can be used to reveal, avoid, or modify the causes that lead to these unwanted effects. They can also be used to mitigate consequences. Their instrumental functions in society are, therefore, oriented to risk treatment and in particular risk reduction, through mitigation of consequences, standard setting, and improvements in the reliability and safety of technological systems. In addition, the data from technical risk analyses are crucial input for conducting cost–benefit analyses.

The strength of the risk assessments is that they systemize the knowledge and uncertainties about the phenomena, processes, activities and systems being analyzed. What are the possible hazards and treats, their causes and consequences? This knowledge and these uncertainties are described and discussed and this provides a basis for evaluating what is important (tolerable and acceptable) and for comparing options. Risk assessments have been specifically valuable to detect deficiencies in complex technical systems and to improve the safety performance of the technical system under consideration. Examples are chemical plants, power plants, or liquid gas installations.

The traditional technical risk assessments provide a rather narrow definition of hazards, threats and consequences (by for example restricting attention to the number of fatalities), and confine uncertainties to probabilities. However, this narrowness is a virtue as much as it is a shortcoming. Focusing on some defined quantities, such as the number of fatalities, it is possible to obtain methodological rigor, and separate data, risk descriptions and value judgments.

The main weaknesses and limitations of technical risk assessments are their lack of precision level and their narrowness as indicated above. The probability assignments are often based on averaging and are not reflecting the specific factors influencing the uncertainties. This applies in particular to human, organisational, social and cultural impacts. It is also difficult to model human–machine interactions, and common mode failures, i.e. the simultaneous failures of components. Uncertainties are often hidden in the assigned probabilities and expected values, and restricting attention to these quantities could camouflage factors that could produce surprising outcomes. It is therefore essential that results of the assessments are evaluated in the light of the premises, assumptions and limitations of these assessments. The assessments are based on background information that must be reviewed together with the results of the assessments (Aven 2008b, 2009a, b, c; Flage and Aven 2009).

Taleb (2007) makes a similar conclusion, using the black swan logic. The inability to predict outliers (black swans) implies the inability to predict the course of history. An outlier lies outside the realm of regular expectations, because nothing in the past can convincingly point at its occurrence. The standards tools for measuring uncertainties are not able to predict these black swans.

Risk assignments are often based on historical data, fitted to some probability distributions like the normal distribution. In practice it is a problem to determine the appropriate distribution. Our historical data may include no extreme observations, but this does not preclude such observations to occur in the future. Statistical analysis, including Bayesian statistics, is based on the idea of similar situations and if "similar" is limited to the historical data, the population considered could be far too small or narrow. However, by extending the population, the statistical framework breaks down. There is no justification for such an extended probability model. The statistician needs a probability model to be able to perform a statistical analysis, and then he/she will base his/her analysis on the data available. Taleb (2007) refers to the world of *mediocristan* and *extremistan* to explain the difference between the standard probability model context and the more extended population required to reflect surprises occurring in the future, respectively. Without explicitly formulating the thesis, Taleb (2007) is saying that we have to see beyond the historically based probabilities and expected values.

The weaknesses and limitations of the technical analyses of risk have been pointed out by a number of researchers and in particular by many social scientists (Hoos 1980; Douglas 1985; Beck 1992b; Freudenburg 1988; Shrader-Frechette 1991; Reiss 1992; Adams 1995; Tierney 1999; Zinn and Taylor-Gooby 2006:24ff.; Fischhoff 1995; Perrow 1984; Aven 2003). Much of the criticism goes back to the 1970–1980s where risk assessment was in its early stage as a scientific discipline and its use was characterized by a positivistic approach: risk assessment provides an objective, value-free way of quantifying risk and non-experts are biased. A critic to such a “naïve” perspective certainly is in place, but fortunately many assessments today are based on a more balanced perspective in the sense that it is acknowledged that the assessments need to be considered as an input to a broader evaluation and judgment process, taking into account the weaknesses and limitations of the assessments. Such evaluations and value judgments go beyond the realm of the risk assessments. See e.g. Vinnem et al. (2006) and Gheorghe et al. (2006).

Risk assessments are often used in combination with risk acceptance criteria. Such criteria cannot be derived from the data but requires a threshold on a value-based dimension. For example, a threshold for human lives lost and expected number of human life lost could be the level that society has accepted as tolerable in the past (revealed preference). Or one could ask all affected persons if they can negotiate a tolerable risk level in exchange for some social benefit (expressed preference). Sometimes the term risk tolerability is also used in this context. While acceptability refers to a morally satisfactory situation, the term tolerability entails that the risk should be further reduced if possible but not banned. For both, acceptability and tolerability limits, society needs ethical criteria to determine the required thresholds. Analytic studies are essential to find out if the threshold has been met or surpassed; but the determination of the threshold is not a question of scientific inquiry but of ethical reasoning. The need for risk reducing measures is thus assessed with reference to these ethically derived criteria. In some industries and countries, it is a requirement in regulations that such criteria should be explicitly defined.

Two examples of such criteria are:

- The individual probability that a person is killed in an accident during 1 year (Individual risk – IR) should not exceed 0.1%.
- The probability that a specific valuable environmental component is damaged due to an accidental event during 1 year should not exceed 0.01%.

Note that in the following, when using the term “risk acceptance criteria” we always have in mind such upper limits. Following the traditional text-book use of such criteria, they should be specified before the risk numbers are calculated.

First, one needs to define the criteria, then, follow with the calculations to see if these criteria are met, and according to this evaluation, the need for risk reducing measures is determined. Such an approach is intuitively appealing, but a closer look reveals some problems:

- The introduction of pre-determined criteria may give the wrong focus – meeting these criteria rather than obtaining overall good solutions and measures.
- The risk assessments – the tools used to check whether the criteria are met – are not generally sufficiently accurate to allow a clear and unambiguous allocation on the scale that the criterion defines.

Consider as an example a case where the criterion of 0.01% is formulated as stated above to control the environmental risk in relation to the possible start-up of some industrial activities. The formal decision about start-up is political. A risk assessment is performed and a probability equal to 0.04% is computed. The conclusion is that the risk is not tolerable, and hence the industrial activities are not allowed to commence.

Such a risk management approach means that the risk assessment results dictate the solution. The politicians are out. They have delegated the judgments about risk tolerability and acceptance to the risk assessment experts and the mechanics of the risk assessment tool. But the calculated risks are based on a set of assumptions and suppositions, meaning that the precision level of the risk numbers produced could be poor – other reasonable assumptions and suppositions would significantly change the results. Furthermore, the number 0.01% is arbitrary – it is difficult to find arguments supporting the use of 0.01% in stead of 0.05% – and the results of the assessment are conditional on a predefined limit without reasonable justification. If the threshold was determined at a different level, the acceptability judgment would also change and the activities would be either tolerated or banned. Making a judgment on the basis of one criterion only may hence be misleading or at least problematic. Should we isolate the environmental risk from other concerns? Would it not be better to first describe risk and then make the judgment about tolerability and acceptance? Different political parties would certainly give different weight to the importance of the environmental risk compared to the benefits gained by the industrial activities. Risk management is about balancing a variety of values and concerns. A practical approach for determining risk acceptability or tolerability is presented and discussed in Chap. 8, which is based on more than one criterion and which allows for trade-offs between the criteria so that a violation of one criterion can be offset by positive performance on another criterion (within limits).

Using the criterion 0.01%, the activities may be judged tolerable subject to the implementation of some risk reducing measures, such that the computed risk meets the criterion 0.01%. In this case, a common interpretation of the regime and the results is that there is no need for further risk reduction. It has been "proven" that the safety or security level is satisfactory. The risk assessment is used to show that there is no need for risk reducing measures. Such an interpretation is often seen in practice (Aven and Vinnem 2007), even if the ALARP principle applies, i.e. the risk should be reduced to a level that is as low as reasonably practicable. According to the ALARP principle a risk reducing measure should be implemented, provided it cannot be demonstrated that the costs are grossly disproportionate relative to the gains obtained (this principle is often referred to as "reversed onus of proof"). In our example this means that measures should be considered for reducing the risk even if the calculated probability is below the limit 0.01%.

Risk acceptance criteria and the ALARP principle are thoroughly discussed in the literature, see e.g. Hokstad et al. (2004); Aven and Vinnem (2005); Abrahamsen and Aven (2008); Aven (2007b); Ersdal and Aven (2008); Fischhoff et al. (1981); Melchers (2001); Schofield (1998); Lind (2002); Rimington et al. (2003) and Skjong and Ronold (2002).

3.3 The Economic Perspective

The perspective closest to the technical approach is the economic perspective. The major difference here is the incorporation of values and utilities, expressed through the expected utility and expected net present value.

The theoretical economic framework for decision-making is the expected utility theory. The theory states that the decision alternative with highest expected utility is the best alternative. The expected utility approach is attractive as it provides recommendations based on a logical basis. If a person is coherent both in his preferences amongst consequences and in his opinions about uncertain quantities, it can be proved that the only sensible way for him to proceed is by maximizing expected utility. For a person to be coherent when speaking about the assessment of uncertainties of events, the requirement is that he follows the rules of probability. When it comes to consequences, coherence means adherence to a set of axioms including the transitive axiom: If b is preferred to c, which is in turn preferred to d, then b is preferred to d. What we are doing is making an inference according to a principle of logic, namely that implication should be transitive. Given the framework in which such maximization is conducted, this approach provides a strong tool for guiding decision-makers. Starting from such "rational" conditions, it can be shown that this leads to the use of expected utility as the decision criterion, see e.g. Lindley (1985) and Bedford and Cooke (2001).

In practice the expected utility theory to decision-making is used as follows. One assesses probabilities and a utility function on the set of outcomes, and then uses the expected utility to define the preferences between actions. These are the basic principles of what is referred to as rational decision-making.

The expected utility theory has a strong position as a prescriptive theory, but the utility concept is difficult to implement in practical decision-making as all preferences need to be specified. The expected utility theory applies when decisions are being made by individuals and in which decision consequences are confined to the decision-maker. In the risk area these two conditions are rarely met. Most decisions on risks are collective decisions (public or meritocratic goods), and it is not obvious how to define societal welfare based on individual utilities. Furthermore, many transactions between individuals imply the imposition of risks on third parties, who may not benefit or only marginally benefit from the transaction itself.

It is also worth noting that even if it were possible to establish practical procedures for specifying utilities for all possible outcomes, decision-makers would be sceptical to reveal these as it would mean reduced flexibility to adapt to new situations and circumstances. In situations with many parties, as in political decision-making, this aspect is of great importance.

Although the expected utility theory is the ruling theoretical paradigm for decision-making under uncertainty among economists and decision analysts, experimental studies on decision-making under uncertainty have revealed that individuals tend to systematically violate the theory (i.e. the independence axiom which the theory is based on). A decision-maker would in many cases not seek to optimize and maximize his utility, but he would look for a course of action that is satisfactory. This idea, often known as bounded rationality, is just one of many ways to characterize how people make decisions in practice.

For many decision analysts the practical solution is to use cost–benefit analyses based on expected net present value calculations, E [NPV]. The ultimate goal is to use this approach to allocate resources so as to maximize the total welfare in the society.

A traditional cost–benefit analysis is an approach to measure benefits and costs of a project. The common scale used to measure benefits and costs is money. The main principle in transformation of goods into monetary values is to find out what the maximum amount the society is willing to pay for the project. Market goods are easy to transform to monetary values since the prices on the market goods reflect the willingness to pay. The willingness to pay for non-market goods is on the other hand more difficult to determine, and special methods are required (Hanley and Spash 1993); see examples below.

We also refer to work related to the Life Quality Index (LQI) (Nathwani et al. 1997). From this index, Skjong and Ronold (1998) and others have derived the amount of money which should be invested to avert a fatality, see e.g. Rackwitz (2000).

Although cost–benefit analysis was originally developed for the evaluation of public policy issues, the analysis is also used in other contexts, in particular for evaluating projects in firms. The same principles apply, but using values reflecting the decision-maker's benefits and costs, and the decision maker's willingness to pay. In the following when using the term cost–benefit analysis, we also allow for this type of application.

To calculate the net present value the relevant cash flows (the movement of money into and out of the business) are specified and the time value of money is taken into account by discounting future cash flows. When the cash flows are uncertain, which is usually the case, they are represented by their expected values, and the E[NPV] results. The discount rate used to calculate the E[NPV] is adjusted to compensate for the uncertainties (risk). However, not all types of uncertainties are considered relevant when determining the magnitude of the risk-adjusted discount rate, as shown by the portfolio theory (Levy and Sarnat 1990). This theory justifies the ignorance of unsystematic risk and states that the only relevant risk is the systematic risk associated with a project. The systematic risk relates to general market movements, for example caused by political events, and the unsystematic risk relates to specific project uncertainties, for example accident risks.

The method implies transformation of goods into monetary values for example using the value of a "statistical life": What is the maximum amount the society (or the decision-maker) is willing to pay to reduce the expected number of fatalities by 1? Typical numbers for the value of a statistical life used in cost–benefit analysis are €1–10 million.

To determine a value of a statistical life, different methods can be used. Basically there are two categories of methods, the revealed approach and the expressed approach. In the former category, values are derived from actual choices made. A number of studies have been conducted to measure such implicit values of a statistical life (also referred to as "implied cost of averting a fatality" – ICAF). The costs differ dramatically, from net savings to costs of nearly $100,000 million. The latter category, the expressed approach, is used to investigate individual tendency towards risk taking and willingness to pay under different hypothetical situations, see Nas (1996).

The method is not trivial to carry out, as it requires the transformation of non-economic consequences such as expected loss of lives and damage to the environment, to monetary values. To avoid the problem of transformation of all consequences to one unit, it is common in many situations to calculate cost-effectiveness indices, such as the expected cost per expected saved lives (ICAF).

The cost–benefit approach has been subject to strong criticism, due to both philosophical objections and formal treatment of values and weights (Adams 1995; Bedford and Cooke 2001; Fischhoff et al. 1981; Ackerman and Heinzerling 2004; Aven and Abrahamsen 2007; Aven and Vinnem 2007). The main problem is related to the transformation of non-economic consequences to monetary values. What is the value of future generations? How should we determine a "correct" discount rate? It is argued that the value of safety and security is not adequately taken into account by the approach. This argumentation relates to the willingness to pay methods being used, as well as the use of expected values to compute the criterion. Investments in safety and security are justified by risk and uncertainty reductions, but cost–benefit analyses to large extent ignore these risks and uncertainties. A cost–benefit analysis calculating expected net present values do not take into account the unsystematic risks (uncertainties) and the use of this approach to determine the right level of investments in safety and security is therefore problematic (Aven and Abrahamsen 2007). To explain this in more detail, consider the following example.

In an industry, two risk reducing measures A and B are considered. For measure A (B) the computed expected reduced number of fatalities equals 1 (2). The costs are identical for the two measures. Hence the cost–benefit approach would guide the decision-maker to give priority to measure B. But suppose that there are large uncertainties about the phenomena and processes that could lead to fatalities. Say for example that measure B is based on new technology. Would that change the conclusion of the cost–benefit analysis? No, as this analysis restrict attention to the expected value. We conclude that there is a need for seeing beyond the expected value calculations and the cost–benefit analysis when determining the best alternative.

Modifications of the traditional cost–benefit analysis have been suggested to solve this problem, see e.g. Aven and Flage (2009). In these methods, adjustments are made to either the discount rate or the contribution from cash flows. This latter case could be based on the use of certainty equivalents for uncertain cash flows (the payoffs that are required to be indifferent between the payoffs and the uncertain outcomes). Although arguments are provided to support these methods, their rationale can be questioned. There seems to a significant element of arbitrariness associated with the methods.

In the economic literature a distinction has traditionally been made between certainty, risk and uncertainty, based on the availability of information. Certainty exists if the outcome of a performance measure is known in advance. Risk and uncertainty relate to situations in which the performance measures have more than one possible outcome, and are not known in advance. Under risk the probability distribution of the performance measures can be assigned objectively, whereas under uncertainty these probabilities must be assigned or estimated on a subjective basis (Douglas 1983). This definition goes back to Knight (1921). It is often referred to in the literature but it is not much used in practice. It is recognised that we seldom have objective probability distributions. Hence the use of the risk term in this way becomes too restrictive. Risk should not be separated from uncertainties.

We may ask what the economic analysis of risk has contributed to our understanding of risk and the improvement of risk policies. *First,* the treatment of risk in economics has sharpened our vision for conceptualizing risk as a cost factor that can be exchanged, treated or mitigated just like any other cost factor. The mental processing of uncertainty is not confined to calculating probabilities and expected values, but is part of a utility/cost–benefit analysis in which measures related to risk avoidance, prevention, reduction and mitigation can be systematically compared to each other. In addition, the economic concept includes risk attitudes such as risk aversion or risk proneness. Economic rationality implies that different risk attitudes are legitimate elements of risk management (Luce and Weber 1986). This is true for speculating on the stock market as well as for coping with natural hazards.

Second, economic studies on risk have demonstrated the opportunities and limits of exchanging different types of costs and offering compensation (Kunreuther 1995). Risks to one's health or even life are almost impossible to compensate with monetary compensation, at least in an industrial country with a high income level. At the same time, however, risk insurance as well as liability laws act as powerful incentives for risk managers to avoid future damages as a means to save money. A large portion of the legal activities in the United States is devoted to ex post compensation of victims for being involuntarily exposed to risk.

3.4 The Psychological Perspective

The psychological perspective on risk addresses people's perception of risk, i.e. their subjective judgment or appraisal of risk. Risk perceptions belong to the aspects that risk managers need to consider when deciding whether or not risk should be taken as well as when designing risk reduction measures. The perception may be influenced by the technical risk assessment and the individual's own risk assessment, as well as perceptional factors such as dread. Often the third point is the most important one. Scientific assessments influence the individual response to risk only to the degree that they are integrated in the individual perceptions (Covello 1983). Furthermore, relative frequencies are substituted by the strength of belief that people have about the occurrence of any undesirable effect to occur (Fischhoff et al. 1981). Both aspects are combined in a formula that normally puts more weight on the magnitude of the effects than on the probability of their occurrence. The main insight is, however, that effects and likelihood are enriched by the perceived presence of situational and risk specific characteristics that depend on properties such as the degree of perceived personal control, the perception of a social rather than an individual risk, or the familiarity of the risk situation (Slovic et al. 1981; Slovic 1992; Vlek and Stallen 1981; Gould et al. 1988; Vlek 1996; Boholm 1998; Renn and Rohrmann 2000). Most cognitive psychologists believe that perceptions are formed by common sense reasoning, personal experience, social communication and cultural traditions (Brehmer 1987; Drottz-Sjöberg 1991; Pidgeon et al. 1992; Pidgeon 1998). In relation to risk it has been shown that humans link certain expectations, ideas, hopes, fears and emotions with activities or events that have uncertain consequences.

The psychological risk research has identified a set of biases (heuristics) in people's ability to draw inferences from probabilistic information (Festinger 1957; Kahneman and Tversky 1974; Ross 1977; Renn 1990, 2008:20f.; Rohrmann and Renn 2000; Dawes 2001a). Risk managers and public health professionals should be aware of these biases because they are found in public perception and may be one of the underlying causes for the observed public response. For example, the frequent media coverage about the "Mad Cow Disease" (BSE) and a potential link to a certainly fatal human disease has alarmed the public and promoted a response of outrage based on the availability bias. Yet the question remains, why most people seem to assign a low probability of contracting such a disease while amplifying the dread associated with the individual suffering from the disease. In order to understand this response, one needs to understand the semantic images that govern people's risk perception (Streffer et al. 2003:265ff.).

Psychological risk research has also revealed different meanings of risk depending on the context in which the term is used (Slovic 1987; Drottz-Sjöberg 1991; Boholm 1998; Renn 2004a). Whereas in the technical sciences the term risk is based on the probability of the effect and the magnitude of the effect, the everyday use of risk has different connotations among individuals, groups and cultures.

Some of the important elements influencing the perceptions of risks are (Rohrmann and Renn 2000):

– Intuitive heuristics and judgments processes with respect to probabilities and damages
– Contextual factors relating to the perceived characteristics of the risk (for example familiarity or naturalness) and to the risk situation (for example voluntariness, personal controllability)
– Semantic associations relating to the risk source, the people associated with the risk and the circumstances of the risk-taking situation
– Trust and credibility of the actors involved in the risk debate

Within the psychological domain of investigating risk perception, two major methodological approaches have been pursued: one through psychometric scaling exercises by which individuals rate risks on attributes such as voluntary, dread, familiar or known to science (Slovic 1992; Rosa et al. 2000) and the other one by mental models that reconstruct the mental associations of respondents between the risk and related subjects such as actors involved, context, and attitudes towards the source of risk (Bostrom et al. 1992; Atman et al. 1994; Morgan et al. 2001). Regardless which of the two major methodological routes had been pursued there has been a clear consensus in the literature that the intuitive understanding of risk refers to a multidimensional concept that cannot be reduced to the product of probabilities and consequences (Kahneman and Tversky 1979; Lopes 1983; Luce and Weber 1986). Risk perceptions differ considerably among social and cultural groups. However, it appears to be a common characteristic in almost all countries, in which perception studies have been performed, that most people form their judgments by referring to the nature of the risk, the cause of the risk, the associated benefits, and the circumstances of risk-taking (Renn and Rohrmann 2000).

The focus on the individual and his/her subjective assessments may also be considered as the major weakness of the psychological perspective (Mazur 1987; Plough and Krimsky 1987; Thompson et al. 1990; Wynne 1992b; Jasanoff 1999, 2004). The broadness of the dimensions that people use to make judgments and the reliance on intuitive heuristics and anecdotal knowledge make it hard, if not impossible, to aggregate individual preferences and to find a common denominator for comparing individual risk perceptions. Risk perceptions vary among individuals and groups. Whose perceptions should be used to make decisions on risk? At the same time, however, these perceptions reflect the real concerns of people and include the undesirable effects that the technical analyses of risk often miss. Facing this dilemma, how can risk perception studies contribute to improving risk policies? They can (Fischhoff 1985):

- Reveal public concerns and values
- Serve as indicators for public preferences
- Document desired lifestyles
- Help to design risk communication strategies

- Represent personal experiences in ways that may not be available to the scientific assessment of risk

In essence, the psychological studies can help to create a more comprehensive set of decision options and to provide additional knowledge and normative criteria to evaluate them (Fischhoff 1994). There may be good reasons that evolution has provided human beings with a multidimensional, sophisticated concept of risk. This concept favors cautious approaches to new risks and induces little concerns about risks to which everyone is already accustomed (Shrader-Frechette 1991; Kasperson 2005a). It places relevance to aspects such as control and possibility for mitigation, both aspects that have been proven helpful in situations where predictions went wrong (Gigerenzer and Selten 2001).

3.5 The Social Science Perspective

The risk world becomes even more complex with the sociological or cultural concepts of risks. The sociological perspectives include undesirable events that are socially defined and (in some cases) socially constructed. “Real” consequences are always mediated through social interpretation and linked with group values and interests (Bradbury 1989; Dietz et al. 1989; Short 1989; Shrader-Frechette 1991; Wynne 1992b; Luhmann 1993; O’Malley 2004; Sjöberg 2006:693). Possibilities for future events are not confined to the calculation of probabilities, but encompass group-specific knowledge and vision. Furthermore, possibilities are shaped by human interventions, social organizations, and technological developments (Freudenburg 1988; Short and Clarke 1992). Lastly, reality is seen as both a system of physical occurrences (independent of human observations) and constructed meanings with regard to these events and to abstract notions, such as fairness, vulnerability, and justice (Kasperson and Kasperson 1983; MacLean 1986; Linnerooth-Bayer and Fitzgerald 1996).

The importance of social and cultural factors for risk experience is undisputed. What is missing, however, is a clear concept of how these factors influence social judgements about risks, individual behaviour and institutional responses (see, for example, Hutter 2006; Sjöberg 2006). The multitude of social science perspectives are illustrated in Fig. 3.1 (based on an earlier version of this analysis in Renn 1992b, 2008:13ff. and a similar approach in Zinn and Taylor-Gooby 2006). This taxonomy orders sociological and anthropological approaches with regard to two dimensions: individualistic (x-axis) versus structural, and realist versus constructivist (y-axis) approaches.

There are five predominant *social science based theoretical approaches to risk* (see a similar suggestion in Zinn and Taylor-Gooby 2006): the rational choice approach (Jaeger et al. 2001; Renn et al. 1999); the reflexive modernization approach by Beck (1986) and Giddens (2000); the post-modern perspective, introduced by Foucault (1982) and further developed by Dean (1999) and others; the systems theory approach of Luhmann (1993), and the critical theory approach,

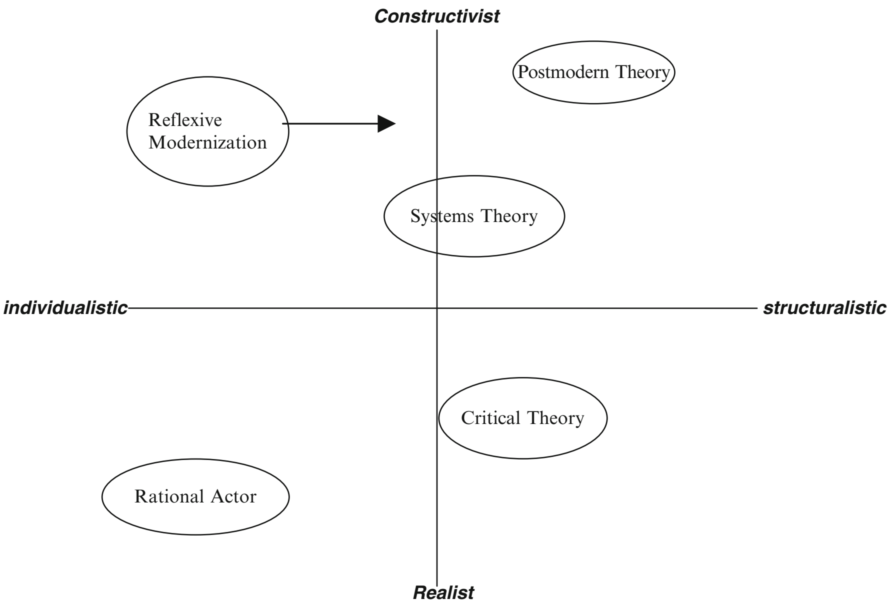

Fig. 3.1 Review of sociological approaches to risk.
Source: modified from Renn (1992b, 2008:24)

based on the seminal work of Juergen Habermas (1984, 1987). These approaches are described in more detail in the following paragraphs.

The rational choice approach: The notion of rational choice forming the philosophical basis for explaining risk has become the most popular and important theory of risk in economics and many social sciences (Jaeger et al. 2001:20 ff.). In its widest form (as a global view), it parts from the assumption that human beings are capable of acting in a strategic fashion by linking decisions with outcomes. In terms of risk, the rational choice approach addresses outcomes as expectations that individuals link with different consequences of decision options. The uncertainty of these outcomes is captured by the strength of belief that these outcomes may or may not materialize. The aggregation of likelihood and outcome is modified by personal preferences or values of organizational culture. The rational choice perspective comes closest to the economic understanding of risk but is also compatible with most psychological models of risk taking.

The theory of reflexive modernization and the "risk society": The reflexive modernization approach combines the macro and micro levels and goes back to the seminal works of Beck (1986) and Giddens (1990). The theory of reflexive modernization rests on the assumption that the meta-rationality of modernity (i.e. instrumental rationality, efficiency, justice through economic growth, and steady improvement of individual living condition through scientific and technical progress) has lost its legitimizing power. This new development of disenchantment rests on several developments within the transition from classic to reflexive modernity including individualization of lifestyles, pluralisation of knowledge and values and increase of uncertainty in one's life planning (cf. Giddens 1994; Lash 2000; Knight and Warland 2005; Zinn and Taylor-Gooby 2006:39 ff.).

What does the theory of reflexive modernization add to our understanding of risk? Most notably, individuals respond to the trends of individualization, pluralization, and globalization by searching for genuine orientation (Jaeger et al. 2001; Knight and Warland 2005). This orientation is constantly threatened by risk producers who impose risks on all members of society (without their consent) and, hence, threaten to destroy the basis of their own livelihood. Beck does not offer a solution to this problem other than the suggestion of placing more trust in sub-political civil society actors and refusing to license any technical facility that cannot ensure its maximum losses (Beck 1997, 1999).

Systems theory: In a system theory perspective, risk is understood as a fundamental social construct that is closely linked to the particular rationality of sub-systems in society. According to this theory (in particular, referring to Luhmann (1984, 1989, 1993)), human societies are organized as a variety of self-referential or autopoietic (self-organizing) systems, which define their own reality as well as an image of the world outside (Luhmann 1984). Systems include functional entities such as the law, the economy and the political hierarchy. Over time, social systems have increasingly internalized external threats – i.e. dangers – and have, thereby, transformed them from external dangers into risks. Since those who create risks expose others to hazards, there is always the potential for incongruence between the risk takers and risk bearers in Luhmann's perspective. To deal with this systemic dilemma, risk creators (and, as a means for exculpation, public risk managers) use formal tools of risk analysis to justify and legitimate the acceptance of risks, while risk bearers use perceptions of dread and consequences, cultural interpretations or competing professional judgements as a justification for rejecting dangers. Each line of reasoning is incompatible with the other, and there is no communication medium available for reconciling these opposing positions on risk taking.

Critical theory: Critical theory, particularly Habermas (1984, 1987) theory of communicative action and of communicative competence respectively (1984, 1987), comprises a body of thought based on an extended criticism of modernity that emphasizes the contradictions and untoward consequences of advanced or late capitalism. Risks have emerged as dominating phenomena demanding political intervention and management. Decisions by the political system, based as they are on the exercise of power – rather than, e.g. a fairness doctrine – perpetuate an inequitable distribution of risks. The only viable solution to overcome this imbalance is to create a forum for open discourse, where all actors have the opportunity to argue their interests and to resolve their conflicts in an equitable and rational manner. The process of discourse must be fair, transparent and truthful (Renn 2004b).

Post-modernism: Post-modern theorists have developed the most radical view on constructivism. Knowledge, moral norms and aesthetic values represent nothing more than power-induced constructions of groups who abuse claims of universality for reasons of influencing or manipulating others (Lyotard 1984; Smart 1996; Dean 1999; see overview in Jaeger et al. 2001:221 ff.). Risk is not at the centre of post-modern thinking. Many post-modernists are radical individualists who believe that the individual is able to cope with contingencies and to arrive at the most appropriate balance of expected positive and negative outcomes. However, what is seen as risks and what as benefits, and to what degree, depends upon the framing of social forces (for an explanation of framing, see Tversky and Kahneman (1987); adjustment to post-modern theory is explained in Tagg 1992:170 ff.). Post-modern theory has eluded risk analysts to the importance of framing and cultural biases in assessing and evaluating risks.

All five social science perspectives on risk include a multitude of undesirable or desirable effects that people associate with a specific cause, leading to consequences for something that people value (Kasperson and Pijawka 2005:31). Individuals or social/cultural groups respond according to their perception of risk and not according to an historical based risk levels or the scientific assessment of risk (Sjöberg 2006:694). The main insight is, however, that focusing on effects and likelihood alone is merely of limited use for social orientation.

First, maximizing outcomes may not be the main objective of social actions in situations where overarching social goals – such as building solidarity, demonstrating empathy or strengthening one's identity – are pursued. *Second,* even if the individual perceives the situation as one of personal choice, the inability to predict outcomes, the interferences of one's own action with the actions of others, and the presence of competing and conflicting values and preferences make it difficult, if not impossible, to base one's own decisions on the evaluation of expected utility (Jaeger et al. 2001:247 ff.). *Third,* even if evaluation of expected utility is the preferred strategy, this optimization is not only governed by magnitude and probability, but is also enriched by the perceived presence of situational and risk-specific characteristics, such as the degree of perceived personal control, the perception of a social rather than an individual risk or the familiarity of the risk situation, the experience of equitable risk–benefit distribution and others (Boholm 1998). Risk evaluation by individuals can, hence, be characterized by a functional relationship representing perceived violations of what humans value, perceived patterns of occurrence and social context variables. *Fourth,* most people rely on information from third parties when they are faced with unknown risk consequences. In this situation, they can either trust the information or not, since they have no (empirical) way of proving one side wrong or the other. They have no lab at their disposal in order to investigate the risks of BSE, acrylamid, electromagnetic fields, or genetically modified plants. They rely on trustworthy information from experts or risk managers. For risk professionals, it is, therefore, essential to build a trusting relationship with their target audiences. Trust, however, relies more on institutional arrangements, cultural traditions, and symbolic interactions than on factual evidence (Löfsedt 2005). As post-modern theory assumes trust is a powerful instrument for persuading people to accept decisions without having the capability to control the motivation and the level of evidence put forth by organisation that demands trust. Even if one does not accept the cynical world view of post-modern thinkers, it seems obvious that in complex and uncertain situations assigning trust to elites is on one hand unavoidable but on the other hand risky when judging the actual competence and good will of these elites.

In particular, the social science perspectives on risk can enrich and inform risk management in the following manners (Fischhoff 1994):

- Identify and explain public concerns associated with the risk source
- Explain the context of risk-taking situations
- Identify cultural meanings and associations linked with special risk arenas
- Help to articulate objectives of risk policies in addition to risk treatment (minimization), such as enhancing fairness and institutional trust and reducing inequities and vulnerability
- Design procedures or policies to incorporate these cultural values into the decision- making process
- Design programs for participation and joint decision making
- Design programs for evaluating risk management performance and organizational structures aiming at identifying, monitoring, and controlling risks

Another major insight from the social science studies on risk has been the importance of procedure or due process for making decisions (Renn et al. 1993; Renn 2004b; Lidskog 2005; Kasperson 2005b). People are not only concerned about the risks that are imposed on them but also about the process by which the decision has been made. In particular, they demand that those affected by a decision will also have the opportunity to be involved in the decision-making process. While in many European countries, the legal process of involvement is structured by law and does not leave many choices in the selection of processes or participants, the American tradition of participation is less rigid in structure and encourages public expectations that, without prior consent, decisions cannot be implemented. Insufficient public involvement is often a cause for litigation and political protest. Litigation, however, is not only costly and time-consuming, it also results in often unsatisfactory resolutions of the conflict, since the legal system is not prepared to adequately cope with problems, in which highly technical aspects are at the center of the controversy. In the United States and recently also Europe, procedures of mediation have gained more and more popularity as a means to incorporate public concerns into the decision process without sacrificing technical expertise or rational reasoning (Amy 1987). Mediation is also less expensive and time-consuming than litigation. Risk managers should therefore be aware that risk reduction may not be at the heart of a risk controversy but rather the process by which decisions on risks were made. In democratic societies, people demand procedural fairness and expect risk management institutions to demonstrate that fair procedures have been used (Linnerooth-Bayer and Fitzgerald 1996).

3.6 Cultural Theory of Risk

Cultural theories of risk treat risks as social constructs that are determined by structural forces in society. Issues such as health threats, inequities, fairness, control, and others cannot be determined by scientific analysis, but only reconstructed from the beliefs and rationalities of the various actors in society (Douglas and Wildavsky 1982; Rayner 1987, 1992; Schwarz and Thompson 1990; Thompson et al. 1990; Dake 1991; Grendstad 2000). The fabric and texture of these constructions reflect both the interests/values of each group or institution in the various risk arenas and the shared meaning of terms, cultural artifacts, and natural phenomena among groups. Risk policies result from a constant struggle of all participating actors to place their meaning of risk on the public agenda and impose it on others. The need to compromise between self-interest, i.e. constructing one's own group-specific reality, and the necessity to communicate, i.e. constructing a socially meaningful reality, determines the range and limitations of possible constructs of reality. Technical risk analyses are not necessarily superior to any other construct of risk because they are also based on group conventions, specific interests of elites, and implicit value judgments.

The cultural perspective on risk identifies different patterns that are supposed to determine individual and social responses to risk (Overview in Jaeger et al. 2001:183 ff.; Zinn and Taylor-Gooby 2006:37 f.). Organizations or social groups belonging to the *entrepreneurial* prototype perceive risk taking as an opportunity to succeed in a competitive market and to pursue their personal goals. They are less concerned about equity issues and would like the government to refrain from extensive regulation or risk management efforts. This group contrasts most with organizations or groups belonging to the *egalitarian* prototype, which emphasizes cooperation and equality rather than competition and freedom. Egalitarians focus on long term effects of human activities and are more likely to abandon an activity (even if they perceive it as beneficial to them) than to take chances. They are particularly concerned about equity. The third prototype, i.e. the *bureaucrats,* relies on rules and procedures to cope with uncertainty. As long as risks are managed by a capable institution and coping strategies have been provided for all eventualities, there is no need to worry about risks. The fourth prototype, the group of *atomized or stratified individuals,* principally believes in hierarchy, but they miss group identity and a system of social bonding. These people trust only themselves, are often confused about risk issues, and are likely to take high risks for themselves, but oppose any risk that they feel is imposed on them. At the same time, however, they see life as a lottery and are often unable to link harm to a concrete cause.

There has been an intensive debate in the social science community about the validity of these prototypical descriptions in terms of theoretical reasoning and empirical evidence (Nelkin 1982; Johnson 1987; Funtowicz and Ravetz 1985; Bellaby 1990; Shrader-Frechette 1991). *First,* many critics claim that cultural theory does not distinguish between individuals as carriers of cultural convictions and as social aggregates. *Second,* the relationship between cultural prototype and organizational interest is seen as unclear and problematic. If cultural affiliation precedes interest, then what determines to which cultural prototype individuals, groups or organizations belong? *Third,* the selection of four (and occasionally five) prototypes as the only relevant cultural patterns in modern society needs more evidence than the reference to tribal organizations (Douglas 1985) or generic models of human interactions (Wildavsky and Dake 1990). Furthermore, if prototypes are mixed in organizations, then the perspective (similar to many sociological concepts) is not falsifiable. Any observed behavior is compatible with some mix of prototypes. *Fourth,* the cultural perspective has not provided sufficient empirical evidence of its validity (Sjöberg 1997).

As valuable as cultural studies on risk have been in showing the relativity of scientific reasoning in the social and cultural context of processing risk information, they also carry the danger of solipsism, i.e. the belief that all knowledge about the state of the world is relative to its spectator and thus not applicable to anyone else (Rayner 1987:6 f.; Searle 1995; Rosa 1998). This view of collective knowledge is not only theoretically difficult to defend, it is also empirically invalid. Even everyday experience tells us the opposite daily. Almost all cultures are concerned about avoiding physical harm and, without any doubt, modern societies are strongly concerned about health impacts and ecological damage.

The cultural theory of risk has its shortcomings and its merits. The reduction of cultural clusters to a set of prototypes may be a valid and intuitively plausible hypothesis in analyzing risk responses, but it should be treated as a model rather than the exclusive explanation. The emphasis on values and world views rather than interests and utilities (which in themselves are reflections of one world view) is a major accomplishment of this theory. Whatever the "real" cultural patterns may be, cultural analysis has demonstrated to the risk professionals that the concept of risk assessment as well as the rationale behind it cannot claim universal validity and legitimizing power among all groups and cultures. There are different worldviews that determine how different groups cope with the universal experience of potential outcomes of actions and events. Different worldviews include different knowledge structures and value systems. For example, the selection of physical harm as the basic indicator for risk may appear as being irrelevant for a culture in which violations of religious beliefs are perceived as main risks to society.

3.7 Integrated Perspectives

The dual nature of risk as a potential for physical change and as a social construction demands a dual strategy for risk management. Public values and social concerns may act as the driving agents for identifying those topics for which risk assessments are judged necessary or desirable. The central task, of balancing the opportunities and risk of modern technologies and other human activities in accordance with the needs and visions of those who ought to be served requires a plural but integrated attempt to have the technical and the social sciences join forces to shape a humane future in line with best available knowledge and a consensus on social expectations.

Several integrated perspectives, linking the various discipline oriented perspectives, have been suggested, including:

3.7.1 Social Amplification of Risk

The first approach covered in this review of integrated risk concepts refers to the social amplification analogy developed by Kasperson et al. (1988). The concept of social amplification of risk is based on the thesis that the social and economic impacts of an adverse event are determined by a combination of the direct physical consequences of the event and the interaction of psychological, social, institutional and cultural processes (Kasperson et al. 1988, 2003; Renn 1991; Breakwell 2007:224 ff.). The authors were motivated to develop this framework due to the lack of integrative theories of risk and the inadequacy of the two main approaches at the time – psychometrics within the psychological risk concepts and cultural theory among the social science perspectives – to capture the complex risk experience of individuals and social entities. The framework of social amplification should include these alternative approaches and provide a consistent analytic structure for investigating psychological, social and cultural factors of risk perception and risk responses. Amplification in this framework includes both intensifying and attenuating signals about risk. Thus, alleged overreactions of target audiences receive the same attention as alleged “downplaying”.

Social interactions can heighten or attenuate perceptions of risk. By shaping perceptions of risk, they also influence risk behaviour. Behavioural patterns, in turn, generate secondary consequences that extend far beyond direct harm to humans or the environment. Liability, insurance costs, loss of trust in institutions or alienation from community affairs are a few such examples. Secondary effects such as these are important because they can trigger demands for additional institutional responses and protective actions. They can also – in the case of risk attenuation – impede the installation of protective actions.

The amplification process starts with either a physical event (such as an accident) or the recognition of an adverse effect (such as the discovery of the ozone hole). In both cases, individuals or groups will select specific characteristics of these events or aspects of the studies and interpret them according to their perceptions and mental schemes. These interpretations are formed into a message and communicated to other individuals and groups (Renn 1991). Individuals in their role as multipliers or representatives of groups collect and respond to information about risks and act as “amplification stations” through behavioural responses or communication. Amplification stations can be individuals in socially exposed positions, groups or institutions.

The behavioural and communicative responses are likely to evoke secondary effects that extend beyond the people directly affected by the original hazard event. Secondary impacts are, in turn, perceived by social groups or institutions so that another stage of amplification may occur to produce third-order impacts. The impacts may spread or “ripple” to other parties, distant locations or other risk arenas. Each order of impact will not only disseminate social and political impacts, but may also trigger (in risk amplification) or hinder (in risk attenuation) positive changes for risk reduction.

In the framework, risk is conceptualized partly as a social construct and partly as an objective property of a hazard or event (Short 1989:405). This avoids the problems of conceptualizing risk in terms of total relativism or technological determinism. The experience of risk is not only an experience of physical harm, but also the result of a process by which individuals or groups learn to acquire or create interpretations of hazards. These interpretations provide rules for selecting, ordering and explaining signals from the physical world. Both processes may have physical consequences. Hazards may directly impact upon health. Communication about risks may result in changes in technologies, methods of land cultivation, or the composition of water, soil and air.

The social amplification concept is useful for selecting, ordering and classifying social phenomena and for suggesting causal relations that can be investigated empirically. It provides a heuristic tool for the analysis of risk experience. One can also think of it as a dynamic framework that allows systematic interpretation of empirical data while attempting to integrate different perspectives on risk. Several empirical applications have been reported, and the results have been used to refine the framework (Kasperson et al. 1988, 2003; Machlis and Rosa 1990; Burns et al. 1993; Frewer et al. 2002; Rosa 2003; Masuda and Garvin 2006). One review described it as a "framework that, like a net, is useful for catching the accumulated empirical findings, and that, like a beacon, can point the way to disciplined inquiry" (Machlis and Rosa 1990:164).

The intuitive attractiveness of the metaphor "amplification" demonstrates the merits, but also the limitations, of using a metaphor common to the description of electronic signal theory. Although each of the social amplification effects can be expressed in terms of familiar control actions, such as volume, filtering, equalizing, mixing, muting, and stereo (Renn 1991), they make only sense if the denotations of each term are adjusted to the social context. In particular, transmitters in social communication have hardly any resemblance with electronic amplifiers. Instead, social transmitters are active actors in the communication process, with their own independent agendas, rules and goals.

The social amplification metaphor has evolved as an umbrella framework that provides ample space for social and cultural theories (Kasperson 1992; Kasperson et al. 2003). It is not based on a nomological theoretical concept, but rather on the simple insight that social experiences of risk are only partially determined by the experience of harm or even expected harm. The distinction between individual, social or institutional amplification stations corresponds with the two traditions in risk perception: the individual processing of information and the social responses to risk based on experience of (dis)trust, the political arena conditions and cultural affiliations. It provides a more holistic picture of the risk perception process and takes into account psychological, sociological and cultural aspects. Yet it fails to provide a synthesis of the technical, natural science, economic, psychological and social science approaches to risk.

3.7.2 The Concept of Risk Types According to the WBGU

The central categories of the technical and natural science approaches to risk are as described above the extent of harm and the probability of occurrence. The economic, psychological and social science approach to risk adds to this list context-related factors and subjective or cultural frames that shape the extent of harm as well as the articulation of probabilities. In 1998, the German Advisory Council on Global Change (WBGU) made an attempt to combine both perspectives to come up with a set of criteria for evaluating risk as well as with a set of risk classes or patterns that would be a step forward in integrating the different perspectives of risk.

The main question for the Council was: What kind of criteria can science offer to risk assessment and evaluation, and what criteria can be derived from the revealed concerns of the people who might be, or will be, affected by the consequences of the risk?

While, within the field of risk assessment, the criteria of damage, probability and remaining uncertainties seem to be the crucial yardsticks for evaluating risks, it proved to be much more difficult to find a common set of criteria reflecting additional public concerns. Empirical research has shown that people tend to evaluate risks based on a large set of evaluative criteria, of which only a few may claim universal validity (Renn and Rohrmann 2000). The council organized several expert surveys on risk criteria (including experts from the social sciences) and performed a meta-analysis of the major insights from risk perception studies. The council also consulted the literature on similar approaches in countries such as the UK, Denmark, The Netherlands and Switzerland (WBGU 2000).

Nine criteria were finally chosen to represent most of the experts' and public concerns as the result of a long exercise of deliberation and investigations (see Table 3.2). The category of "mobilization" was the only criterion aimed at describing public response (or outrage) that found approval by all experts. After the WBGU proposal had been reviewed and discussed by many additional experts and risk managers, two of the authors (Klinke and Renn 2002) decided to unfold the compact "mobilization index" and divide it into four major elements:

- Inequity and injustice associated with the distribution of risks and benefits over time, space and social status (thus covering the criterion of equity)
- Psychological stress and discomfort associated with the risk or the risk source (as measured by psychometric scales)
- Potential for social conflict and mobilization (degree of political or public pressure on risk regulatory agencies)
- Spill-over effects that are likely to be expected when highly symbolic losses have repercussions for other fields, such as financial markets or loss of credibility in management institutions (OECD 2003a)

A similar division was proposed by the UK government (Environment Agency 1998; Kemp and Crawford 2000; Pollard et al. 2000; HSE 2001).

Table 3.2 Criteria for evaluating risks

Criteria	Description
Extent of damage	Adverse effects in natural units, such as fatalities, injuries, production losses, etc.
Probability of occurrence	Estimate/assignment of the relative frequency of an event
Incertitude	Overall indicator for different uncertainty components
Ubiquity	Defines the geographic dispersion of potential damages (intra-generational justice)
Persistency	Defines the temporal extension of potential damage (intergenerational justice)
Reversibility	Describes the possibility of restoring the situation to the state before the damage occurred (possible restoration – e.g. reforestation and cleaning of water)
Delay effect	Characterizes a long time of latency between the initial event and the actual impact of damage; the time of latency could be of physical, chemical or biological nature
Violation of equity	Describes the discrepancy between those who enjoy the benefits and those who bear the risks
Potential of mobilization	Is understood as a violation of individual, social or cultural interests and values, generating social conflicts and psychological reactions by individuals or groups who feel affected by the risk consequences; they could also result from perceived inequities in the distribution of risks and benefits

Source: adapted from WBGU (2000:56)

Theoretically, a huge number of risk classes could be deduced from various combinations of these nine criteria. Such a substantial number of cases would not be useful for the purpose of developing a comprehensive risk concept. In reality, some criteria are tightly coupled and other combinations are theoretically possible; but there are no, or only a few, empirical examples. Considering the task of setting risk regulation priorities, risks with several extreme qualities required special attention (WBGU 2000; Klinke and Renn 2002). Therefore, the Council developed a framework where similar risk candidates are classified into risk classes in which they reach or exceed one or more of the possible extreme qualities with regard to any one of the criteria. This classification leads to six genuine risk classes that were given names from Greek mythology. Their definition are based on a characterization of probability, magnitude and the criteria of Table 3.2, see Table 3.3. By an uncertain probability we mean difficulties in establishing a rationale for a specific probability figure. The various mythological figures demonstrate the complex issues associated with the new self-awareness of creating manageable risks rather than just being exposed to fate.

Risk class "*sword of Damocles*": According to Greek mythology, Damocles was invited for a banquet by his king. At the table, he had to sit under a sharp sword hanging on a wafer-thin thread. Chance and risk are tightly linked for Damocles, and the sword of Damocles is a symbol of impending danger. The myth does not tell about a snapping of the thread with its fatal consequences. The threat, rather, comes from the possibility that a fatal event could, at any time, happen to Damocles, even

Table 3.3 Overview of the risk classes, their criteria and typical representatives

Risk class	Probability	Magnitude (extent of damage)	Other criteria	Typical examples
Damocles	Low	High		Nuclear energy, dams and large-scale chemical facilities
Cyclops	Uncertain	High		Nuclear early warning systems, earthquakes, volcanic eruptions, and new infectious diseases
Pythia	Uncertain	Uncertain		Greenhouse gas effect on extreme weather events, BSE, some GMOs, and some applications of nanotechnology
Pandora	Uncertain	Uncertain	High persistency	POPs and endocrine disruptors
Cassandra	High	High	Long delay	Anthropogenic climate change, destabilization of terrestrial ecosystems, threat to biodiversity
Medusa	Low	Low	High mobilization	Electromagnetic fields

Source: adapted from WBGU (2000:62)

if the probability is low. Accordingly, this risk class relates to risk sources that have a very high potential for damage and, at the same time, very low probability of occurrence. Many technological risks, such as nuclear energy, large-scale chemical facilities and dams, belong to this category.

Risk class "*Cyclops*": The ancient Greeks knew of enormous giants who were punished, despite their strength, by only having a single eye. They were called Cyclops. Having only one eye, the cyclope can only perceive one side of reality and is unable to develop a three-dimensional perspective. Applied to risks: One can ascertain either the probability of occurrence or the extent of damage. One of the sides will remain uncertain. In the risk class Cyclops, the probability of occurrence is largely uncertain, whereas the maximum damage can be estimated. Some natural events, such as floods, earthquakes and volcanic eruptions (but also the appearance of AIDS and nuclear early warning systems) belong to this category.

Risk class "Pythia": The Greeks of the antiquity consulted their oracles in cases of uncertainty. The most known is the oracle of Delphi with the blind prophetess Pythia. Pythia's prophecies were always ambiguous. It certainly became clear that a great danger might be impending; but the probability of occurrence, the extent of damage, the allocation and the way in which the damage manifested itself remained uncertain. Human interventions in ecosystems, technical innovations in biotechnology and the greenhouse effect belong to this risk class, where the extent of changes is still not predictable.

Risk class "Pandora's box": The old Greeks explained many evils and perils through the myth of Pandora's box – a box that was sent to the beautiful Pandora by Zeus, the king of the gods. As long as the evils and perils stayed in the box, no damage whatsoever was to be feared. However, when opening the box, all evils and perils were released, which then irreversibly, persistently and ubiquitously struck the Earth. This risk class is characterized by both uncertainty in the criteria of probability of occurrence and the extent of damage (only presumptions) and high persistency. Here, persistent organic pollutants and endocrine disruptors are modern examples.

Risk class "Cassandra": Cassandra was a prophetess of the Troys who certainly predicted the victory of the Greeks correctly; but her compatriots did not take her seriously. The risk class Cassandra describes a paradox: probability of occurrence and extent of damage are known; but there is no imminent concern because damage will only occur in the future. Of course, Cassandra-type risks are only interesting if the potential of damage and the probability of occurrence are relatively high. This is why this class is located in the intolerable area. A high degree of the delay effect is typical for this risk class (i.e. a long period between the initial event and the impact of the damage). An example of this effect is anthropogenic climate change.

Risk class "Medusa": Ancient mythology tells that Medusa was one of three snake-haired sisters of the Gorgon, whose appearance turns the beholder to stone. Similar to the Gorgon, who spread fear and horror as an imaginary mythical figure, some new phenomena have an effect on modern people. Innovations are occasionally rejected, although they are hardly assessed scientifically as threat. Such phenomena have a high potential of mobilization in public. Medusa was the only sister who was mortal – if we transfer the picture to risk policy; Medusa can be confronted with effective debate, further research and public communication. According to the best knowledge of risk experts, risks of this class are located in the "normal" area. Because of specific characteristics, these risk sources frighten people and lead to strong denial. Often, a large number of people are affected by these risks; but harmful results cannot be proven statistically. A typical example comprises electromagnetic fields.

The Council used the six risk classes to develop class-specific strategies for risk management and risk communication. These strategies are meant to address the specific criterion that dominates the respective risk class. For example, for risks belonging to the class of Damocles the Council advised risk managers to reduce the catastrophic potential rather than the probability of occurrence since public concerns centered around the possibility of catastrophes while the probability was already perceived as extreme low. For risks belonging to the class of Medusa the Council developed risk-communication strategies and stakeholder involvement concepts as a means to bring expert judgments and public perceptions closer together.

The risk classification scheme of the German Advisory Council on Global Change succeeded in developing criteria that combined the scientific concepts of the risk professionals with the public concerns revealed by social scientists. Notwithstanding that such an integration was long overdue, it does not provide a synthesis of mathematical/natural and cultural approaches to understanding risk. The starting point is the mathematical/natural science perspective of risk enriched with public concerns to form a broader concept for evaluating and managing risks. Responsive risk evaluation and management is well advised to take the broader set of criteria into account. Based on these assumptions, this integrative approach provides a classification scheme that can assist risk evaluators and managers to focus on the main problem of the risk under investigation and to go through a set of questions that help to allocate risk and to make a prudent judgement on risk tolerability or acceptability. In terms of the three guiding questions, this approach adds criteria for selecting outcomes as relevant and for specifying the criteria needed for aggregating risk information and evaluating their relevance with respect to risk management requirements.

A modification of the above criteria and classification system has been suggested by Kristensen et al. (2006). It is based on characterizations of potential consequences, uncertainty and the criteria of Table 3.2.

3.7.3 The UK Cabinet Office Approach

This approach sets out how government should think about risk, and practical steps for managing it better (Cabinet office 2002). It proposes principles to guide handling and communication of risks to the public. Risk refers to uncertainty of outcome, of actions and events, and risk management is about getting the right balance between innovation and change on the one hand, and avoidance of shocks and crises on the other. The Cabinet approach is based on the thesis that the handling of risk is at heart about judgement. Judgement in the context of government decision-making can, and should, be supported by formal analytical tools which themselves need enhancing. But these cannot substitute for the act of judgement itself. The approach frames how far formal risk analysis can be usefully enhanced and made systematic, so that there is greater clarity about where analysis ends – and judgement begins. It also explores and suggests what else we need to do to enhance our handling of risk and innovation.

3.7.4 The Consequence–Uncertainty Framework

This framework is presented in Aven (2003, 2008a, 2010). Risk is defined as the two-dimensional combination of events/consequences and associated uncertainties. The focus is on the events and consequences (referred to as observables quantities) such as the number of fatalities and costs, and these are predicted and assessed using risk assessments. Probabilities and expected values are used to express the uncertainties, but it is acknowledged that they are not perfect tools for expressing the uncertainties. To evaluate the seriousness of risk and conclude on risk treatment, a broad risk picture needs to be established, reflecting also aspects such as risk perception and societal concern. Formal decision analyses, such as cost–benefit analyses and utility-based analyses, provide decision support, not hard decisions. The analyses need to be put into a wider decision-making context, which is referred to as a management review and judgment process. Also this perspective can accommodate both undesirable and desirable outcomes.

3.7.5 The Risk Governance Framework of the IRGC

Drawing on an analysis of a selection of well-established approaches to what has traditionally been called “risk analysis” or “risk management”, the International Risk Governance Council (IRGC) has made an attempt to develop an integrative framework of risk based on the concept of risk governance (IRGC 2005, 2007). This framework promises to offer both a comprehensive means of integrating risk identification, assessment, management and communication, and a tool that can compensate the absence of (or a weaknesses in) risk governance structures and processes (Bunting et al. 2007:15).

As much as the IRGC framework promises to integrate over a large selection of risk perspectives it is not more than a framework. It offers a taxonomy of interrelated activities that include a step-by-step procedure for dealing with risk. It does, however, provide neither a theoretical analysis of how risk issues develop in society nor a normative guideline of how to deal with risk. It represents a first important step towards integration but is does not constitute a perspective of its own. *This framework will be used as the main reference to what will follow in this book.*

Chapter 4
Risk Governance: An Overview

4.1 Key Concept: Governance

4.1.1 Definition

In the last decade the term "governance" has experienced tremendous popularity in the literature on international relations, comparative political science, policy studies, sociology of environment and technology as well as risk research. On a national scale, *governance describes structures and processes for collective decision making involving governmental and non-governmental actors* (Neye and Donahue 2000). Governing choices in modern societies is seen as an interplay between governmental institutions, economic forces and civil society actors (such as NGOs). At the global level, *governance embodies a horizontally organized structure of functional self-regulation encompassing state and non-state actors bringing about collectively binding decisions without superior authority* (cf. Rosenau 1992; Wolf 2002). In this perspective non-state actors play an increasingly relevant role and become more important, since they have decisive advantages of information and resources compared to single states.

It is useful to differentiate between *horizontal and vertical governance* (Benz and Eberlein 1999; Lyall and Tait 2004). The horizontal level includes the relevant actors in decision making processes within a defined geographical or functional segment (such as all relevant actors within a community, region, nation or continent); the vertical level describes the links between these segments (such as the institutional relationships between the local, regional and state levels). Figure 4.1 provides a more explicit portrayal of the interactions between the horizontal and vertical levels of governance in the framework (Renn 2008:9).

The vertical governance axis defines the political arena which ranges from the local to the global level. For example, any federalist government structure is designed along similar vertical governance lines. On each vertical level different actors from the horizontal axis (governments, economic interests, academic

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Horizontal levels

Vertical Levels	Governments / Agencies	Industries	Science and Academia	Civil Society / NGOs
Local				
Regional				
National				
Supra-national				
Global				

Fig. 4.1 Levels of vertical and horizontal governance

expertise, and civil society actors) can join the governance process and contribute either knowledge or values to the process.

"Risk governance" involves the "translation" of the substance and core principles of governance to the context of risk and risk-related decision-making (Renn 2008). In IRGC's understanding, risk governance includes the totality of actors, rules, conventions, processes, and mechanisms concerned with how relevant risk information is collected, analyzed and communicated and management decisions are taken. Encompassing the combined risk-relevant decisions and actions of both governmental and private actors, risk governance is of particular importance in, but not restricted to, situations where there is no single authority to take a binding risk management decision but where, instead, the nature of the risk requires the collaboration of and co-ordination between a range of different stakeholders. Risk governance however not only includes a multifaceted, multi-actor risk process but also calls for the consideration of contextual factors such as institutional arrangements (e.g. the regulatory and legal framework that determines the relationship, roles and responsibilities of the actors and co-ordination mechanisms such as markets, incentives or self-imposed norms) and political culture, including different perceptions of risk.

4.1.2 The "Traditional" Understanding of Risk Governance

Traditionally, three components of risk governance are differentiated (Lyall and Tait 2004):

- Risk assessment
- Risk management
- Risk communication

Risk assessment describes the tasks of identifying and exploring (preferably in quantitative terms) the types, intensities and likelihood of the (normally undesired) consequences related to a hazard or a threat. Consequently, risk assessment can be defined as a tool of gaining knowledge about possible events and their consequences, and is mainly located in the scientific area. The main challenges during the risk assessment phase are high levels of complexity and scientific uncertainties.

For example, in the case of pesticide residues in food, the assessment of the health risk of the residues of a single pesticide is comparatively unproblematic – through the characterization of dose–response-relationships. But the concomitance of the residues of multiple pesticides together with additional multiple stressors from the environment and the assessment of their combined effects on human health poses a problem to risk assessors because of the complexity of the dose–response-relationships of multiple residues. As a consequence, the measurement, statistical description and modelling of such types of risks can pose serious problems to the risk assessors.

Risk management, on the other side, describes the task to prevent, reduce or alter the consequences identified by the risk assessment through choosing appropriate actions. Accordingly, it can be defined as a tool for handling risks by making use of the outcomes of the risk assessment process. This task is located in the area of decision-makers – often in the field of politics, but in the economic sector as well. The main challenge to risk management is the existence of ambiguity (related to the relevance, meaning and implications of the decision basis; or related to the values to be protected and the priorities to be made), as it concerns the interpretation of the scientific findings and judgements about the tolerability or acceptability of risk.

The obvious distinction between risk assessment and risk management often becomes blurred, if one takes a closer look into the risk governance processes. This could, for example, be the case if the assessment of the health effects of a specific pesticide results in the finding that it is genotoxic already in very low doses, and the only option for preventing harmful health consequences is a complete ban of the product. If this is the case, decision-making is already included in the risk assessment phase. However, risk management does not only have to consider risk assessment outcomes, but also might, for example, have to alter human wants and needs, e.g. to prevent the creation or continuing of the risk agent, or to suggest alternatives or substitutes to a specific risk agent. It can also comprise activities to prevent exposure to a risk agent by isolating or relocating it or take measures to increase the resilience of risk targets. Resilience in this context means a protective strategy to strengthen the whole system against consequences of a certain hazard or threat, to decrease its vulnerability. This means, the issues that have to be taken into account by risk managers are often going far beyond the direct consequences of a hazard or threat.

The case of the regulation of genetically modified organisms illustrates this complex task: The risk managers do not only have to consider the possible negative health effects that might be a consequence of, e.g. the consumption of genetically modified food, but also indirect consequences like possible losses in biodiversity due to the spread of genetically modified species, ethical concerns raised by religious or moral beliefs regarding the principle of a fundamental manipulation of living organisms, or effects of the ban (or public funding on the other hand) on the competitiveness of the national economy.

Risk communication is the third, but key element in the traditional understanding of risk governance. Its task was initially defined as bridging the tension between expert judgement and the public perceptions of risks, which often vary to a large extent. Four major functions of risk communication can be identified (cf. Morgan et al. 1992; Renn et al. 2002; IRGC 2005:55 ff.). All these functions aim at helping all affected actors, i.e. stakeholders as well as the general public, to make informed choices when facing risks:

- *Education and enlightenment* (informing the public about risks, including risk assessment results and the handling of the risks according to risk management strategies).
- *Risk training and inducement of behavioural changes* (helping people to cope with risks).
- *Promotion of confidence in institutions responsible for the assessment and management of risks* (giving people the assurance, that those responsible for risk assessment and risk management act in an effective, efficient, fair and acceptable manner).
- *Involvement in risk-related decisions and conflict resolution* (giving stakeholders and representatives of the public the opportunity to participate in the risk related decisions).

These major functions pose a number of challenges to those responsible for risk communication (cf. IRGC 2005:57). It has to explain the concept of probability and stochastic effects to a broad audience. Otherwise, wrong interpretations of probabilities or exposure effects might lead to overreactions up to the stigmatization of a risk source (or to the opposite as well, as can be illustrated by the comparison of the risks of driving a car, which is often judged as low, and to travel by plane, which is most of the times judged as high). Dealing with stigmatized risk agents or with highly dreadful consequences is another challenge for risk communication. Such risks, like nuclear energy, can produce high levels of mobilization and very emotional reactions in the public. The example of the stigmatization of genetically modified food illustrates, that risk communication also has to take into account much more general convictions as well, such as ethical, religious and cultural beliefs.

Risk communication has to deal with long-term and delay effects of risks, which often compete with short term advantages in the view of different actor groups. Similar challenges are to provide an understanding of synergistic effects with other lifestyle factors or other risks and to address the problem of remaining uncertainties and ambiguities. The communication of such complex coherences demands a great deal of social competence, as it has to face the differing concerns, perceptions and experiential knowledge of the different audiences addressed. On an international level, risk communication has additionally to cope not only with inter-cultural differences but with differences between various nations and cultures as well.

4.2 The New Concept of Risk Governance

4.2.1 Motivation and Major Innovations of the Framework

Recent tendencies have shown that the three "generic" categories of risk assessment, management and communication are not sufficient to analyse and improve the risk governance processes. The characteristics of modern systemic risks require new concepts, which are able to deal with the described challenges. This means, that besides the "factual" dimension of risk (which can be measured by risk assessors) the "socio-cultural" context has to be included as well, as systemic risks are characterized by affecting the whole "system" that humans live in.

As a consequence, the different risk governance components and their interfaces have to be adequately designed to be able to deal with the "factual" as well as the "socio-cultural" context, i.e. to include the varying values and perceptions of pluralist societies. Another challenge is the need to deal with a variety of risks that differ in their level of complexity, uncertainty, and ambiguity. These differences have to be kept in mind in the structure of the risk governance process. Different risks require different governance procedures. Therefore, a categorization of risks according to these characteristics can help to better adapt the components of governance to the specific needs. The need for new approaches to deal with systemic risks has resulted in various efforts to design such new integrative risk governance frameworks. The International Risk Governance Council (IRGC) is currently developing a framework for risk governance to help analyze how society could better address and respond to such risks. To this end, the IRGC's framework maps out a structured approach which guides its user through the process of investigating global risk issues and designing appropriate governance strategies. This approach combines scientific evidence with economic considerations as well as social concerns and societal values and, thus, ensures that any risk-related decision draws on the broadest possible view of risk. The approach also states the case for an effective engagement of all relevant stakeholders.

The framework is currently being tested for efficacy and practicability – i.e. can the framework help ensure that all relevant issues and questions are being addressed, and, does it support the development of appropriate risk governance strategies. Tests are conducted in the form of short case studies applying the framework to different risks, including those related to genetically modified organisms, stem cells, nature-based tourism and the European gas infrastructure. The results from these tests will serve as input to any necessary revisions to the framework.

The framework offers two major innovations to the risk field: the inclusion of the societal context and a new categorization of risk-related knowledge.

Inclusion of the societal context: Besides the generic elements of risk assessment, risk management and risk communication, the framework gives equal importance to contextual aspects which, either, are directly integrated in a risk process as lined out below as well as additional elements or, otherwise, form the basic conditions for making any risk-related decision. Contextual aspects of the first category include the structure and interplay of the different actors dealing with risks, how these actors may differently perceive the risks and what concerns they have regarding their likely consequences. Examples of the second category include the policy-making or regulatory style as well as the socio-political impacts prevalent within the entities and institutions having a role in the risk process, their organizational imperatives and the capacity needed for effective risk governance. Linking the context with risk governance, the framework reflects the important role of risk–benefit evaluation and the need for resolving risk–risk trade-offs.

Categorization of risk-related knowledge: The framework also proposes a categorization of risk which is based on different states of knowledge and interpretations, distinguishing between "simple", "complex", "uncertain" and "ambiguous" risk problems. This we already explained in the introduction. For each category, a strategy is then derived for risk assessment, risk management as well as the level and form of stakeholder participation, supported by proposals for appropriate methods and tools. The IRGC framework has been further developed in this book by implementing the risk perspective described in the introduction section, and by providing new insights on and substance to the various elements of the framework.

4.2.2 Scope of the Framework

The risk framework covers a wide range of both risks and governance structures. We consider human activities, natural events or a combination of both. In line with our definition of risk, the consequences can be positive or negative, depending on the values that people associate with them. As for IRGC our focus is on (predominantly negatively evaluated) risks that lead to physical consequences in terms of human life, health, and the natural and built environment. Included are also impacts on financial assets, economic investments, social institutions, cultural heritage or psychological well-being as long as these impacts are associated with the physical consequences. In addition to the strength and likelihood of these consequences, the framework emphasizes the distribution of risks over time, space and populations. In particular, the timescale of appearance of adverse effects is very important and links risk governance to sustainable development (delayed effects).

Table 4.1 provides a systematic overview of hazards and threats that potentially fall within the scope of our analysis. The purpose of this overview is to lay out the variety of hazards and threats, rather than to claim that the categories proposed are exhaustive or mutually exclusive (see a review of classification in Morgan et al. 2000).

We place most attention on risk areas of global relevance (i.e. transboundary, international and ubiquitous risks) which additionally include large-scale effects (including low-probability, high-consequence outcomes), require multiple stakeholder involvement, lack a superior decision-making authority and involve the potential to cause wide-ranging concerns and outrage.

Table 4.1 Risk taxonomy according to hazardous agents (adapted from IRGC 2005:20)

Physical agents • Ionizing radiation • Non-ionizing radiation • Noise (industrial, leisure, etc.) • Kinetic energy (explosion, collapse, etc.) • Temperature (fire, overheating, overcooling)
Chemical agents • Toxic substances (thresholds) • Genotoxic/carcinogenic substances • Environmental pollutants • Compound mixtures
Biological agents • Fungi and algae • Bacteria • Viruses • Genetically modified organisms (GMOs) • Other pathogens
Natural forces • Wind • Earthquakes • Volcanic activities • Drought • Flood • Tsunamis • (Wild) fire • Avalanche
Social-communicative hazards/threats • Terrorism and sabotage • Human violence (criminal acts) • Humiliation, mobbing, stigmatizing • Experimentation with humans (such as innovative medical applications) • Mass hysteria • Psychosomatic syndromes
Complex hazards/threats (combinations) • Food (chemical and biological) • Consumer products (chemical, physical, etc.) • Technologies (physical, chemical, etc.) • Large constructions such as buildings, dams, highways, bridges • Critical infrastructures (physical, economic, social-organizational and communicative)

The framework is especially adapted to dealing with systemic risks (see Sect. 2.2). This term denotes the embeddedness of any risk to human health and the environment in a larger context of social, financial and economic consequences and increased interdependencies both across risks and between their various backgrounds. Systemic risks are at the crossroads between natural events (partially altered and amplified by human action such as the emission of greenhouse gases), economic, social and technological developments and policy-driven actions, both at the domestic and the international level. These new interrelated and interdependent risk fields also require a new form of handling risk, in which data from different risk sources are either geographically or functionally integrated into one analytical perspective. Handling systemic risks requires a holistic approach to hazard identification, risk assessment, concern assessment, tolerability/acceptability judgments and risk management. Investigating systemic risks goes beyond the usual agent-consequence analysis and focuses on interdependencies and spill-overs between risk clusters.

Although the framework focuses on physical risks and their secondary implications, the framework may also be extended to allow for the investigation of financial, social or political risks as primary risk consequences.

The decision-making structure of a society is highly complicated and often fragmented. Apart from the structure itself – the people and organizations that share responsibility for assessing and managing risk – one must also consider the need for sufficient organizational capacity to create the necessary knowledge and implement the required actions, the political and cultural norms, rules and values within a particular societal context and the subjective perceptions of individuals and groups. These factors leave their marks on the way risks are treated in different domains and socio-political cultures. To place risk within a context of – sometimes closely interwoven – decision making structures such as those prevalent in governments and related authorities, in the corporate sector and industry, in the scientific community and in other stakeholder groups is of central concern to the framework.

When looking at risk governance structures there is no possibility of including all the variables that may influence the decision making process; there are too many. Therefore it is necessary to limit one's efforts to those factors and actors that, by theoretical reasoning and/or empirical analysis, are demonstrably of particular importance with respect to the outcome of risk governance. The IRGC has highlighted the following aspects of risk governance which extend beyond risk assessment and risk management:

- The structure and function of various actor groups in initiating, influencing, criticizing and/or implementing risk policies and decisions
- Risk perceptions of individuals and groups
- Individual, social and cultural concerns associated with the consequences of risk
- The regulatory and decision-making style (political culture)
- The requirements with respect to organizational and institutional capabilities for assessing, monitoring and managing risks (including emergency management)

In addition to these categories, one may include best practice and normative aspects of what is needed to improve governance structures and processes (European Commission 2001b). With respect to best practice it is interesting to note that often risk creators, in particular when directly affected by the risk they generate, engage in risk reduction and avoidance out of self-interest or on a voluntary basis (e.g. industry "gentleman's agreements", self-restriction, industry standards). Other stakeholders' efforts in risk governance therefore have to be coordinated with what is tacitly in place already.

4.2.3 The Components of the Risk Governance Framework

The framework's risk process, or risk handling chain is illustrated in Fig. 4.2. It breaks down into three main phases: "pre-assessment", "appraisal", and "management". A further phase, comprising the "characterization" and "evaluation" of risk, is placed between the appraisal and management phases and, depending on whether those charged with the assessment or those responsible for management are better equipped to perform the associated tasks, can be assigned to either of them – thus concluding the appraisal phase or marking the start of the management phase. The risk process has "communication" as a companion to all phases of addressing and handling risk and is itself of a cyclical nature. However, the clear sequence of phases and steps offered by this process is primarily a logical and functional one and will not always correspond to reality.

The framework starts with the first step called *Pre-Assessment*. It includes four elements: *Problem framing* describes the different perspectives on the conceptualisation of the issue: the question of what the major actors (e.g. governments, companies, the scientific community, and the general public) select as risks. For example, is the global warming through climate change a hazard/threat, an opportunity or just fate? This element defines the scope of all the subsequent elements. *Early warning* comprises the institutional arrangements for the systematic search for hazards and threats. Phenomena like, e.g. the increase in extreme weather situations are taken as indicators for the emergence of new risks. *Screening* (or monitoring) describes the action of allocating the collected risk-related information

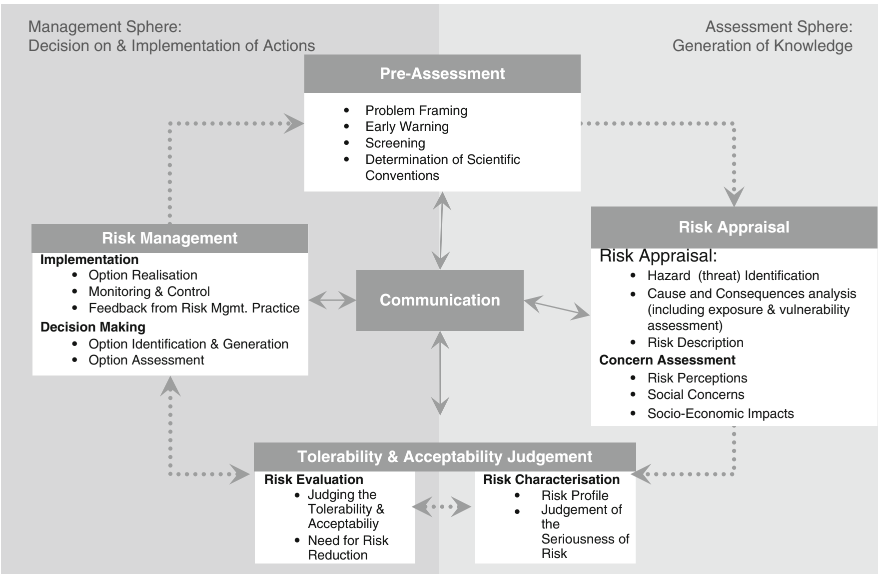

Fig. 4.2 The IRGC risk governance process (adapted from IRGC 2005:13)

into different assessment and management routes. This means, criteria like hazard potential, ubiquity, persistence etc. are identified, systematically analysed and amalgamated (Is the geographic dispersion of the potential damage large? Is the potential temporal extension of the potential damage large?) and then related to potential social concerns. Finally, scientific conventions for risk assessment and concern assessment are defined (What methods will be used to assess the risk? etc.). The pre-assessment step is more thoroughly discussed in the coming chapter.

The next step in the cycle is *Risk Appraisal.* It contains the traditional scientific risk assessment, but additionally the assessment of social concerns. The purpose of Risk assessment is the generation of knowledge linking specific risk agents with uncertain but possible consequences (Lave 1987; Graham and Rhomberg 1996). This element consists of three generic components: H*azard (threat) identification,* which covers potential events that could lead to adverse effects. *Cause and consequence analysis*, including assessments of exposures and vulnerabilities, establishes cause–effect relationships and explores the diffusion plus the exposure pathways and the effects on the risk targets. For example, in this step, those people are identified, that are (especially) affected by the risk, e.g. people with a compromised immune system, very old and very young people, are vulnerable related to an influenza pandemia. The third component *risk description* can be divided into two parts: quantitative description expressing the probability distribution of adverse effects as well as expected effects, while qualitative description comprises accident scenarios, exposures and qualitative factors.

Concern Assessment is part of the appraisal stage and is understood as an additional source of knowledge and includes the varying risk *perceptions and concerns* of all affected actors in the risk context. *Socio-economic impacts* and possible *economic benefits* are also considered in this step. The risk appraisal and concern assessment is discussed in more detail in Chap. 6.

Like the first step, *Tolerability and Acceptability Judgement* is situated in between the two generic spheres. On the side of the assessment sphere, *Risk Characterization* is situated. This element serves for collecting and summarising all the evidence, which is necessary to make an informed choice on tolerability and acceptability of the risk. The term t*olerability* means that the activity is seen as worth pursuing (for the benefit it carries) yet requires additional efforts for risk reduction within reasonable limits. *Acceptability* means that the risks are deemed to be adequately controlled. There is no pressure to reduce acceptable risks further, unless cost-effective measures become available. In many ways, acceptable risks are equivalent to those everyday risks which people accept in their lives and take little action to avoid. The risk characterization includes the creation of a *risk profile (to large extent expressed by probabilities and expected values)*, the *judgement on the seriousness of the risk* (including questions like: Are there effects on the equity of risk and benefits? Does public acceptance exist?) and *conclusions and risk reduction options*. In the *Risk Evaluation* step, societal values and norms are applied to the judgement on tolerability and acceptability. In this step, the need for risk reduction measures is determined. This includes the choice of a specific technology, the determination of the potential for substitution, risk benefit comparisons, the identification of political priorities and compensation potential, conflict management strategies and the assessment of the potential for social mobilisation. In this step in between scientific and policy-making contexts, the options for risk management are generated.

One approach for classifying the risks is the "*traffic light model*", a figure that is often used for classifying different natural and human-made risk areas. It supports assessment and management processes (Fig. 4.3). This figure locates tolerability and acceptability in a risk diagram, with probabilities on the y-axis and extent of consequences on the x-axis. In this variant of the model the red zone signifies intolerable risk, the yellow one indicates tolerable risk in need of further management actions (in accordance with the "as low as reasonably practiable") ALARP – principle and the green zone shows acceptable or even negligible risk. The tolerability and acceptability judgement step is the topic of Chap. 7. Here the practice of specifying risk tolerability limits and risk acceptance criteria is discussed.

The *Risk Management* phase, which is addressed in Chap. 8, is confronted with three possible outcomes of the aforementioned steps: an intolerable situation, a tolerable situation or an acceptable situation. Depending in these outcomes, risk management has to fulfil two tasks: *Implementation* of the generated options includes the *option realisation*, the *monitoring and control* of the consequences and the collection of *feedback from risk management practice*. The *Decision Making* includes option identification and generation and option assessment, and is accordingly interdependent with the tolerability and acceptability judgement step. The arrow between "Tolerability and Acceptability Judgement" and "risk management" goes both directions. After the analysis of the measures a second judgement might be necessary, in order to check if the risk is now acceptable.

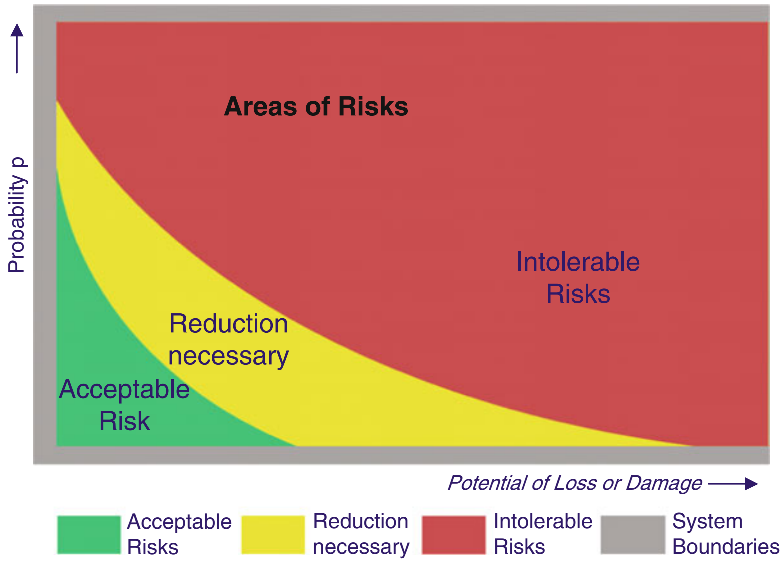

Fig. 4.3 Acceptable, tolerable and intolerable risks (Traffic Light Model)

As can be seen from the scheme (Fig. 4.2), *Risk Communication* is placed in the centre of the whole governance cycle. This central position is due to the important role of risk communication within the presented framework. Risk communication does not stand at the end of the risk governance process, but is an important element of all phases of the cycle. It is to be understood as a mutual leaning process. The perceptions and concerns of the affected parties are meant to guide to risk assessors and risk managers in their selection of topics. We refer to Chap. 9 for a detailed discussion.

It is important to expand the set of criteria for assessing, characterizing, evaluating and managing risks beyond the largely technologic or scientific factors that have dominated earlier models of risk governance. Public values, concerns, and perceptions of risk are often equally important for identifying, understanding and managing risks and must be included. Whether these perceptions have a direct correspondence with the physical world is irrelevant, as long as people feel that these perceptions matter to them, or to the objects and persons whom they care about. Addressing these concerns may include changes in the physical world, such as adding an additional safety layer; but very often it may be more effective to improve trust in the risk operating systems, or to provide more personal control over the extent of the risk. If specific perceptions are clearly in violation with the best scientific knowledge about the likely effects of events, technologies, or human actions, it is the task of risk managers to provide evidence-based information that help people to understand the causal relationships that they may have misjudged. A vast majority of studies on risk perception and concerns tend to show, however, that most of the worries are not related to blatant errors or poor judgement, but to divergent views about the tolerability of remaining uncertainty, short-term versus long-term impacts, the trustworthiness of risk regulating or managing agencies, and the experience of inequity or injustice with regard to the distribution of benefits and risks. All of these concerns are legitimate in their own right and valid for the respective policy arena. They cannot be downplayed by labelling concerns as irrational fears. This is why the framework emphasizes the need for both risk assessment and concern assessment in the *risk appraisal* phase as explained in Chap. 6.

Risk assessments are based on observations and perceptions or social constructions of the world that can be justified by logical reasoning (e.g. that reflect varying degrees of knowledge and are consistent with fundamental axioms of mathematics and probability), or can be verified by comparisons with what actually happens. Public values, perceptions, and social concerns can act as the driving agents for identifying those topics for which risk assessments are judged necessary or desirable, and for ultimately evaluating the acceptability or tolerability of those risks. Whether based on scientific predictions or public perceptions, conclusions about the magnitude of risks, however, should reflect technical expertise as best as possible since the implications of taking action – for health, the environment, or the economy – may be very real.

From there it follows that managing risks will inevitably be directed by relevance claims (e.g. what matters to society and what are important phenomena that should receive our attention?); evidence claims (e.g. what are the causes and what are the effects?) and normative claims (e.g. what is good, acceptable and tolerable?). Identifying what is relevant and worth further investigation is clearly a task that demands both sufficient knowledge about impacts, and a broad understanding of the basic values and concerns that underlie all procedures of selection and priority setting. This important stage of selection and framing forms a separate first phase of the risk governance framework. After this first preliminary phase, the framework distinguishes between knowledge acquisition and evaluative judgements. This distinction is done in spite of the common understanding that providing evidence is always contingent upon existing normative axioms and social conventions. Likewise, normative positions are always enlightened by assumptions about reality (Ravetz 1999). The fact, however, that evidence is never value-free and that values are never void of assumptions about evidence, does not compromise the need for a functional distinction between the two. In managing risks one is forced to distinguish between, what is to be expected when selecting option X rather than option Y, on the one hand, and what is more desirable or tolerable: the consequences of option X or option Y, on the other. As a result, it is highly advisable to maintain the classic distinction between evidence and values, and to affirm that justifying claims for evidence versus values involves different routes of legitimization and validation. We maintain this distinction in the framework by having both *risk characterization* and *risk evaluation* as inputs to judgements about tolerability and acceptability.

4.3 Wider Governance Issues

When considering the wider environment of risk handling in modern societies, many classes of influential factors come into play. Only a few can be mentioned here. For example, the distinction between horizontal and vertical governance as introduced in Sect. 4.1.1 can be helpful in describing and analyzing cases of risk handling in different countries and contexts (Zürn 2000). In addition, the interplay between economic, political, scientific and civil society actors needs to be addressed when looking beyond just governmental or corporate actions. Further, looking at organizational capacity opens a new set of wider risk governance issues which relate to the interplay between the governing actors and their capability to fulfill their role in the risk governance process.

Figure 4.4 shows external influencing factors that cannot be placed within the risk framework itself. The IRGC has published several case studies in which broader governance issues are addressed. These case studies analyzed by the IRGC are placed within this figure. Whereas the risk of listeria can be resolved completely within the core risk governance framework, it is different for the issue of gas transportation from Russia to Western countries. Here the question can be posed in terms of tolerability within the framework, and additionally in terms of organizational capacity outside of the core risk governance framework. The case

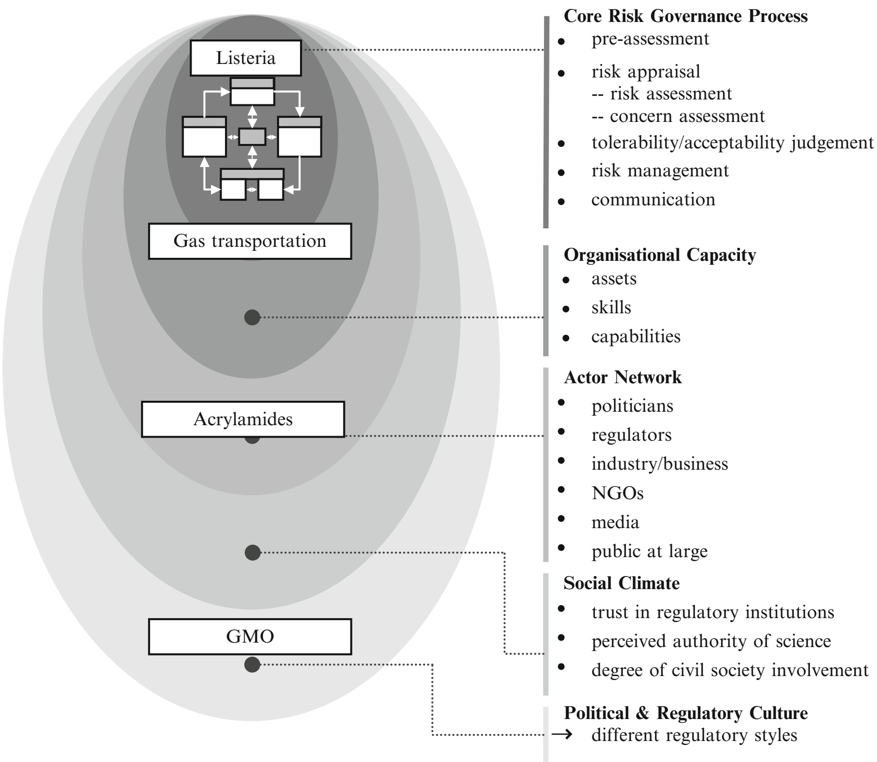

Fig. 4.4 Wider governance issues

studies of acrylamide shows a strong dependency of this issue on the cooperation of different societal actors. Finally, the case of genetically modified organisms (GMO) shows how the social climate and the political culture influence this process.

It is certainly idealistic to assume that societies, when they face new and emerging risks, have developed the institutional and organizational capacity that is needed to perform the tasks described in the governance framework. The realities of the political context can be exemplified by the very first step in the governance cycle, the process of risk framing (cf. IRGC 2005:58 f.): Bringing specific risk issues on the political agenda and consequently to the media as well, is a common means to wield power or to collect votes during election campaigns. In this manner it influences the governance process from the beginning. Public dissent due to varying risk perceptions or media hypes in the context of a specific risk are often used to push individual interests (of political parties, for example) (cf. Shubik 1991). Such influences together with the potential of mobilisation of the wider public, can lead into the playing up of some risks while other risks might be concealed or downplayed due to individual motivations.

As a consequence, many political systems have reacted by establishing independent risk assessment and sometimes management agencies, in order to prevent such exertions of influence. The establishment of numerous national and the European food standards agencies is the most cited example for the institutional restructuring of risk governance. In the mid-1990s, when the transmission of the cattle disease Bovine Spongiform Encephalopathy (BSE) to man was discovered in the UK, in the shape of a new variant of the Creutzfeldt-Jakob disease (vCJD), a policy of reassurance and inadequate scientific attention led to the biggest food scandal in the twentieth century, as measured by its consequences: "no debate inside the European Union (EU) was more influential to everyday life than BSE; no other food scandal had a bigger impact on the public discourse of eating habits or regarding questioning conventional farming practices" (Dressel 2002:60). This scandal led to several institutional changes within the EU and was the motor of the establishment of the European Food Standards Agency (EFSA) and several national food standards agencies or independent risk assessment agencies, like the Federal Institute for Risk Assessment (Bundesinstitut für Risikobewertung, BfR) in Germany, and the Food Standards Agency (FSA) in the UK (cf. Dressel 2002; Dreyer et al. 2009; Ely et al. 2009; Stirling et al. 2009).

4.4 Prerequisites of Good Governance

What lessons can be learned from this and other failings in the governance of risks? First, it is important to make sure that the governance process is based on the best available knowledge and practice. Second, institutions and organizations have to be strengthened so that they are empowered and have the resources to perform their tasks in the most possible effective, efficient and fair manner (IRGC 2005:58). To make sure, that the responsible institutions and organisations are able to act in that way, three analytic categories can be used to assess institutional capacity (cf. ibid; Paquet 2001):

– The knowledge bases and the structural conditions for effective risk management build the *assets* of the governance institutions. This category includes r*ules, norms and regulations*, available *resources* (financial as well as infrastructure, but also access to and processing of information), *competencies and knowledge* (in terms of education and training), and the level of *organisational integration* of the aforementioned types. Organisational integration can be understood as the prerequisite for the effective use of the other types and in a mathematical sense as a multiplying factor.
– *Skills* describe the quality of the institutional and human performance in exploring, anticipating and dealing with existing and emerging risks, here understood as often unpredictable external conditions. They should enable political, economic and civic actors to use effectively, and enhance the impact of, the described assets. Skills include *flexibility* (i.e. openness to make use of new ways in dynamic situations), *vision* (making use of new methods, that are normally used in other contexts, e.g. foresight, scenario planning etc.) and

directivity (expand the risk context into a reframing of the whole perception if the way of life and thus driving change that impacts on the outside world instead of restricting oneself to the prevention or mitigation if external effects).

– The framework, in which assets and skills can be exploited for the development and exploitation of successful policies of risk governance is built by the last category, the *capabilities*. Consequently they build the structure and include *relations* (manage the inclusion through linking users and sources of knowledge; those carrying the authority and those bearing the risk), *networks* (constitute close co-operative structures between self-organisation and hierarchy between and among groups of principally equal actors) and *regimes* (establish the rules, the frameworks and are formed through the two types above).

As a prerequisite for the building and functioning of these three categories, *risk education and training* have to be seen as fundamental resources for making use of the "human capital" in order to handle global, emerging and systemic risks. Such education and training measures should aim at a broad and multidisciplinary knowledge base instead of specialised in depth knowledge, to be able to deal with the challenges of interdependencies, complexity and uncertainty and ambiguities. The often predominating technical focus in scientific education therefore needs to be expanded to health, safety and environmental aspects, i.e. enabling to actors to take up a "bird's eye perspective" (IRGC 2005:61).

4.5 Principles of Good Governance

The term risk governance, as it has been set out in this chapter, denotes not only the governmental actions taken towards the mitigation or prevention of risk consequences, but the whole interplay of all relevant actors – and all actions that are undertaken to handle risks. The integration of so many different views and interests, values and norms creates a very complex structure, which is difficult to comprehend for the public and large parts of the affected groups as well. In order to ensure the functioning of such a complex and interdependent formation, where direct links between the different parties and tasks are often absent or too weak due to international or global dimensions of the risk problems, some general principles have to be set up to support a governance process with outcomes that are accepted or at least tolerated.

On the European level, the Commission has carried out this task in order to strengthen its democratic structures while working on solutions to the major problems confronting European societies, like demographic changes, health risks like smoking, food safety scares, crime and unemployment. Anyway, interest as well as confidence and trust into the work of the European institutions have decreased during the last years. At the same time, the Europeans expect the governments and the European Union to take the lead in reducing risks which emerge in the context of globalization, growth of the population and the economic development. This is particularly true for the handling of international systemic risks. For the improvement of people's trust and confidence into the performance of the European institutions, the European Commission has worked out a White paper (European Commission 2001b), in which a number of principles of good governance are described, which should help them to carry out the task needed for the governance of e.g. systemic risks (cf. European Commission 2001b:10 f.):

- *Openness:* The institutions responsible for the assessment and management of risks should work in an open and transparent manner. This means they should actively communicate to the affected and interested parties and the stakeholders about their tasks, lay open their structures and what and how decisions are taken. This includes the use of a language that is accessible and understandable for the general public, in order to improve the confidence in complex structures and decisions.
- *Participation:* Inclusion of stakeholders and the affected and interested public is set as a crucial task of risk governance. Acceptance in decisions about the handling of risks, and confidence in the outcomes of governance processes depend on the inclusion of the interested parties throughout the whole governance chain.
- *Accountability:* Roles and responsibilities of the different actors in the governance process have to be made clear. From a European point of view, it has to be made clear, which institutions carry out which tasks and where they have responsibility on national and international level. Additionally, the specific tasks of the involved parties in the different stages of the risk governance process have to be made clear.
- *Effectiveness:* Risk governance policies have to be effective and timely, have to deliver what is needed on the basis of clear objectives, an evaluation of future impact and, where available, of past experience. Time and effort have to be treated as spare resources. Measures have to follow the principles of proportionality and appropriateness.
- *Coherence:* Policies and actions have to be coherent and easily understood. As the range and complexity of institutions is constantly growing, interdependencies between different sectors are increasing, regional and local authorities are increasingly involved in European policies etc. These tendencies require political leadership, including a strong responsibility from institutional side, to guarantee consistent procedures within this complexity.
- *Proportionality and Subsidiarity:* Throughout the whole governance process, the choice of the level at which the action is taken (from European to local level) and the selection of the instruments used must be considered in the proportion to the objectives pursued.

The compliance with these principles poses high challenges to those who design and those who carry out the different steps of the risk governance process. It is possible that the adherence to one principle complicates the adherence to another. So, for example, more inclusion and participation might be seen as compromising the scientific accuracy by some actors. The main challenge is hence to find a balance, i.e. to decide how much participation is really necessary and what participatory measures are proportionate to the achievable objectives.

The following chapters include a more refined description of each step of our risk governance model and show how these criteria for good governance can be met and accomplished.

Chapter 5
Pre-assessment and Framing of Risk

A systematic review of risk-related actions needs to start with an analysis of what major societal actors, such as governments, companies, the scientific community and the general public, select as risks and what types of problems they label as risk problems (rather than opportunities or innovation potentials, etc.). In technical terms, this is called "framing". Framing in this context encompasses the selection and interpretation of phenomena as relevant risk topics (Tversky and Kahneman 1981; van der Sluijs et al. 2003; Goodwin and Wright 2004). The process of framing is already part of the governance structure since official agencies (e.g. food standard agencies), risk and opportunity producers (such as the food industry), those affected by risks and opportunities (such as consumer organizations) and interested bystanders (such as the media or an intellectual elite) are all involved and are often in conflict with each other when framing the issue. What counts as risk may vary among these actor groups. Consumers may feel that all artificial food additives pose risk, whereas industry may be concerned about pathogens that develop their negative potential due to the lack of consumer knowledge about food storage and preparation. Environmental groups may be concerned with the risks of industrial food versus organic food. Whether a consensus emerges on what requires consideration as a significant risk depends upon the legitimacy of the selection rule.

The acceptance of selection rules rests on two conditions: first, all actors need to agree with the *underlying goal* (often legally prescribed, such as prevention of health detriments or guarantee of an undisturbed environmental quality – for example, purity laws for drinking water); second, they need to agree with the *implications derived from the present state of knowledge* (whether, and to what degree, the identified hazard affects the desired goal). Even within this preliminary analysis, dissent can result from conflicting values, as well as conflicting evidence, and, in particular, from the inadequate blending of the two. Values and evidence can be viewed as the two sides of a coin: the values govern the selection of the goal, whereas the evidence governs the selection of cause–effect claims. Both need to be properly investigated when analyzing risk governance; but it is of particular

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importance to understand the values shaping the interests, perceptions and concerns of the different stakeholders, as well as to identify methods for capturing how these concerns are likely to influence, or impact upon, the debate about a particular hazard/threat. The actual evaluation of these impacts should then be effected in the most professional manner, including the characterization of uncertainties (Keeney 1992; Gregory 2004; Pidgeon and Gregory 2004).

A second part of the pre-assessment phase concerns the institutional means of *early warning and monitoring*. This task refers to institutions of government, business or civil society identifying unusual events or phenomena (e.g. disease registries, biodiversity indices, climate indices, environmental quality monitoring) in order to detect hazards and threats, in particular new emerging risk events. This task also provides some initial insight into the extent or severity of these hazards/threats and risks. Furthermore, public efforts are needed to monitor the environment for recurring risk events (such as infectious diseases) or newly evolving risk events. Many countries face problems in monitoring the environment for signals of risks. This is often due to a lack of institutional efforts to collect and interpret signs of risk and deficiencies in communication between those looking for early signs and those acting upon them. The 2004 tsunami catastrophe in Asia provides a more than telling example of the discrepancy between the possibility of early warning capabilities and the decision to install or use them. It is therefore important to look at early warning and monitoring activities when investigating risk governance.

In many risk governance processes risk related information are pre-screened and then allocated to different assessment and management routes. In particular, industrial risk managers search for the most efficient strategy to deal with risks. This includes prioritization policies, protocols for dealing with similar causes of risk events, and optimal methods combining risk reduction and insurance. Public risk regulators often use pre-screening activities to allocate risks to different agencies or to predefined procedures. Sometimes hazards and threats may seem to be less severe, and it may be adequate to cut short risk or concern assessment. In a pending crisis situation, risk management actions may need to be taken before any assessment is even carried out. A full analysis should, therefore, include provisions for *risk screening* and the selection of different routes for selection, prioritization, assessment and management of risks. This aspect has been called "risk assessment policy" by the Codex Alimentarius Commission (2001). It is meant to guide the assessment process in terms of risk selection, defining priorities, and determining assessment and management protocols, including methods of investigation, statistical procedures and other scientific conventions used in assessing risks or selecting risk reduction options. A screening process may also be employed when characterizing risks according to complexity, uncertainty and ambiguity, as introduced in Chap. 1.

Another major component of pre-assessment is the *selection of conventions and procedural rules* needed for a comprehensive appraisal of the risk (i.e. for assessing the risk and the concerns related to it). Such conventions cover existing scientific, legal, policy, social, or economic conventions. Any such assessment is based on prior informed, yet subjective, judgements or conventions articulated by the scientific, legal or user community, or other policy-related bodies. Of particular importance are conventions that govern the risk assessment process. These judgements refer to the following (Pinkau and Renn 1998; van der Sluijs et al. 2004:54 ff.):

- The social definition of what is to be regarded as adverse – e.g. by defining the no-observed-adverse-effect-level (NOAEL), for example for contaminants or additives in food
- The selection rule determining which potentially negative effects should be considered in the risk governance process, knowing that an infinite number of potential negative outcomes can theoretically be connected with almost any substance, activity, or event
- The aggregation rule specifying how to combine various effects within a one-dimensional scale (e.g. early fatalities, late fatalities, cancer, chronic diseases and so on)
- Selection of the testing and detection methods, which are currently used in risk assessment (e.g. the use of genomics for calculating risk from transgenic plants)
- Selection of valid and reliable methods for measuring perceptions and concerns
- Determination of models to extrapolate high-dose effects to low-dose situations (e.g. linear, quadro-linear, exponential or other functions or assumptions about thresholds or non-thresholds in dose–response relationships)
- The transfer of animal data to humans
- Assumptions about the exposure or definition of target groups
- The handling of distributional effects that may cover inter-individual, inter-group, regional, social, time-related and inter-generational aspects

These judgements reflect the consensus among experts or are common products of risk assessment and management (e.g. by licensing special testing methods). Their incorporation into guiding scientific analyses is unavoidable and does not discredit the validity of the results. It is essential, however, that risk managers and interested parties are informed about these conventions and understand their rationale. On the one hand, knowledge about these conventions can lead to a more cautious appraisal of what the assessments mean and imply; on the other hand, they can convey a better understanding of the constraints and conditions under which the results of the various assessments hold true.

In summary, Table 5.1 provides a brief overview of the four components of pre-assessment. It also lists some indicators that may be useful as heuristic tools when investigating different risk governance processes. The choice of indicators is not exhaustive and will vary depending upon risk source and risk target. Listing the indicators serves the purpose of illustrating the type of information needed to perform the task described in each step. The title "pre-assessment" does not mean that these steps are always taken before assessments are performed. Rather, they are logically located at the forefront of assessment and management. They should also not be seen as sequential steps, but as elements that are closely interlinked. As a matter of fact, and depending upon the situation, early warning might precede

Table 5.1 Components of pre-assessment in handling risks (adapted from IRGC 2005:26)

Pre-assessment components	Definition	Indicators
1. Problem framing	Different perspectives of how to conceptualize the issue	• Dissent or consent on the goals of the selection rule • Dissent or consent on the relevance of evidence • Choice of frame (risk, opportunity, fate)
2. Early warning	Systematic search for detecting hazards and threats, in particular new emerging risk events	• Unusual events or phenomena • Systematic comparison between modelled and observed phenomena • Novel activities or events
3. Screening (risk assessment and concern assessment policy)	Establishing a procedure for screening hazards/threats and risks, and determining an assessment and management route	• Screening in place? • Criteria for screening: – Hazard potential – Persistence – Ubiquity, etc. • Criteria for selecting risk assessment procedures for different type of risk problems • Criteria for identifying and measuring social concerns
4. Scientific conventions for risk assessment and concern assessment	Determining the assumptions and parameters of scientific modelling and evaluating methods and procedures for assessing risks and concerns	• Definition of no-observed-adverse-effect-levels (NOAELs) • Validity of methods and techniques for risk assessments • Methodological rules for assessing concerns

problem framing and could benefit from “non-systematic” findings and incidental/accidental reporting. Pre-assessment can be viewed as an opportunity for early prevention of more serious threats. Careful framing, screening and selection of rules are essential for reducing overall risk by preventing decision-makers from neglecting key risks or concerns and facing unpleasant surprises later on.

Chapter 6
Risk Appraisal

6.1 Concept of Risk Appraisal

The term *risk appraisal* is used to include all knowledge elements necessary for risk characterization and evaluation as well as risk management (Stirling 1998, 2003). For society to make prudent choices about risk, it is not enough to consider only the results of (scientific) risk assessment. In order to understand the concerns of the various stakeholders and public groups, information about both risk perceptions and the further implications of the direct consequences of the activity – including its social mobilization potential (i.e. how likely is it that the activity will give rise to social opposition or protest) – is needed and should be collected by risk management agents. In addition, other aspects of the risk causing activity that seem to be relevant for characterizing and evaluating the risk and selecting risk reduction options should be pulled together and fed into the process. Based on such a wide range of information, risk managers can make more informed judgements and design the appropriate risk management options (Clark 2001).

Risk appraisal thus includes the scientific assessment of the risk to human health and the environment and an assessment of related concerns as well as social and economic implications. The appraisal process is and should be clearly dominated by scientific analyses – but, in contrast to the traditional risk governance model, the scientific process includes both the natural/technical as well as the social sciences, including economics. We envision risk appraisal as having two process stages: first, natural and technical scientists use their skills to identify risk sources (hazards/threats) and analyse the consequences (for example physical harm) that these risk sources could induce (as described in the section below on risk assessment); secondly, social scientists and economists identify and analyze the issues that individuals or society as a whole link with a specific risk source and its direct consequences.

For this purpose the repertoire of the social sciences such as survey methods, focus groups, econometric analysis, macro-economic modelling, or structured hearings with stakeholders may be used. Based on the results of risk assessment

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and the identification of individual and social concerns this second process stage also investigates and calculates *the social and economic implications of risk sources and their immediate consequences*. Of particular interest in this context are financial and legal implications, i.e. economic losses and liabilities, as well as social responses such as political mobilisation. These secondary implications have been addressed by the concept of social amplification of risk (Kasperson et al. 2001, 2003) (Sect. 2.6). This concept is based on the hypothesis that events pertaining to hazards interact with psychological, social, institutional, and cultural processes in ways that can heighten or attenuate individual and social perceptions of risk and shape risk behaviour. Behavioural patterns, in turn, generate secondary social or economic consequences that extend far beyond direct harm to human health or the environment, including significant indirect impacts such as liability, insurance costs, loss of confidence in institutions, or alienation from community affairs (Burns et al. 1993). Such amplified secondary effects can then trigger demands for additional institutional responses and protective actions, or, conversely (in the case of risk attenuation), place impediments in the path of needed protective actions. Secondary impacts, whether amplified or not, are of major concern to those who are obliged to take over the costs or cope with the consequences of being accountable.

Risk appraisal intends to produce the best possible scientific assessments of the physical, economic and social consequences of a risk source. It should not be confused with direct stakeholder involvement which will be covered later. Involvement by stakeholders and the population is only desirable at this stage if knowledge from these sources is needed to improve the quality of the assessments.

6.2 Appraising Complexity, Uncertainty and Ambiguity

The term complexity is often used to address the entire portfolio of highly intertwined causal relationships, uncertainty about cause–effects, and plurality of interpretations. We are convinced that such an overarching concept is too broad to have any real value in risk governance other than saying that the world is more complex than we think. We therefore assign specific meanings to the terms: simplicity, complexity, uncertainty, and ambiguity. These four characteristics of risk related knowledge were already introduced in Chap. 1. For using these terms for risk appraisal, we need to revisit these terms and discuss their relevance for identifying and characterizing risks.

When we talk about complexity we envision a spectrum of risks that range from obvious cause–effect relationships (such as falling from a bicycle and breaking a leg) to a sophisticated and totally invisible connection between an exposure to some mixture of chemicals and the occurrence of a disease 20 years later. In principle, if we know all the causal factors that contribute to this disease, understand the mechanisms of how these chemicals work, have enough data about dose–response-relationships and exposure and are confident about the limits of interindividual variability and the validity of our extrapolation method, if all of this is more or less given, scientific modelling exercises can resolve this complexity to a mutually satisfying degree of certainty (Graham and Rhomberg 1996). This means: that we end up with dose–response-relationships that can be used to obtain accurate predictions of the quantities of interest. We can construct similar scenarios for technical failures or even acts of terrorists assuming we know their preferences and strategies in advance.

If we are unable to reconstruct the causal connections with a high degree of confidence and reliability, we end up with scientific uncertainty. It is an empirical question of how often we encounter a highly complex problem that we can resolve almost completely or to a large degree. But there is sufficient evidence that in particular for toxic substances, many accident scenarios, and leisure type activities we can decompose complex cause–effect relationships and reduce the remaining uncertainties to a degree that we can be sure that the puzzle is being solved (Cullen and Small 2004). The less confidence we have in this resolution the more we encounter uncertainty. Here uncertainty refers to the degree of confidence in the predictions after we have done everything to reduce and understand the complexity.

This understanding of uncertainty echoes the more recent interest of scholars in non-knowledge (van Asselt 2005). If we have no knowledge about causes and effects and the relationship is not obvious, we can only assume randomness or some hidden causal connection or a combination of both. The more we gather knowledge about this relationship the better we can characterize what the relationships might be but also better describe what we do not know. Japp (1999) distinguishes two kinds of unknowns: the ones that we can characterize to some degree and the other representing true ignorance. The more we collect knowledge the more we will find evidence about the potential gaps in our knowledge in addition to the uncertainties (variations) that we can statistically model.

To make an illustration of this, suppose that you are making a random drawing of some balls from an urn, not knowing how many balls are inside the urn or what colour the balls have. Having drawn 100 red, 20 blue and 1 green ball(s) out of an urn believed to contain 2,000 balls we can estimate the true distribution of balls in the urn. The uncertainties are however large. The one green ball that we collected during the last drawing provides us with a hint that other colours may be represented in addition to the three that we found. So we should not be surprised to even get a purple ball once we continue the sampling effort. If we knew the distribution of balls in the urn, there would be no unknowns, but still some uncertainties exist. We cannot predict the outcome of the drawing of the next ball. However, when making many drawings we will be able to make accurate predictions.

Why is this important? If we experience high complexity we should try to reduce this complexity by applying scientific risk assessment methods to the best degree possible. If this analysis concludes that there is a large degree of uncertainty and unknowns, we should use different criteria of evaluation, different methods of balancing risks and benefits and certainly different strategies for risk management compared to a situation where the risk is either simple from the beginning or where our scientific analysis can resolve the complexity to a large degree (Stirling 2003).

It is certainly a judgment call whether the remaining uncertainties are judged as being high or low (they will never be zero) yet this judgment can be based on fairly simple rules of thumb that will be context-specific and unique for each class of risks (for example accidents, food safety, carcinogens, etc.).

The situation gets even more sophisticated when we require that the risk assessors should take into account the *levels of uncertainties* when choosing risk assessment methods. Our framework advises risk professionals to use different assessment tools depending on whether we face a highly complex but resolvable risk problem or a highly complex risk problem that even after assessing its complex nature to the best degree possible will remain highly uncertain. Since we propose different assessment methods, we recommend an initial screening exercise during the pre-assessment phase using hazard-related indicators for identifying risks where the assessment will likely result in high uncertainty (cf. Mueller-Herold et al. 2005). In this case it would be advisable from the beginning to place more emphasis on vulnerability and resilience assessment (are we able to cope with surprises?), inclusion of less uncertain alternatives in the assessment, and using more refined and comprehensive methods for characterizing unknowns and uncertainties (for example by selecting experiential knowledge from people who have experience with the risk). Of course, no screening board can foresee what results the assessment will finally produce but indicators have been developed that can guide the screening board to anticipate high or low uncertainty (cf. Mueller-Herold et al. 2005).

Among these indicators are novelty, dissimilarity to other known risk events, realization of an innovative procedure, ignorance about exposure, etc. In the course of the assessment phase these preliminary judgments need to be constantly revised and only at the end one can be sure about the degree of remaining uncertainties. Yet, it is wise to include strategies for early indication of uncertainties already during the pre-assessment phase.

Whereas complexity and uncertainty are sequentially linked, ambiguity adds another dimension to the characterization process. Ambiguity refers to the degree of controversy that is associated with the interpretation of the assessment results and the evaluation about the tolerability or acceptability of the risk. In principle even simple risks or complex risks without much uncertainty can cause a high degree of controversy, for example when passive smoking is evaluated or the risk of riding a bicycle without helmet is considered. Often highly complex and uncertain risk problems are more likely to trigger controversy but this is not necessarily the case. The effects of many natural ingredients such as many pathogens in food are highly complex and uncertain in their effects but they do not raise much controversy in society.

Again we should know as early as possible if the risk is associated with much ambiguity. The degree of ambiguity will be better understood after the required concern assessment has been conducted. Yet the degree to which a concern assessment is necessary depends on the assumption about the potential power for controversy. As Löfstedt and van Asselt (2008) point out, if there is little ambiguity there is no need for performing a full-fledged concern assessment. Again we need a screening prior to the appraisal stage to make a preliminary judgment about the degree of ambiguity that this risk or the cause of risk will likely induce. Similar to our discussion on uncertainty, a high degree of ambiguity would trigger another set of assessment tools, evaluation considerations and management options.

The risk appraisal starts with the process of screening and makes an assumption about the degree to which complexity, uncertainty and ambiguity is present. Depending on the outcome of the screening either a conventional risk assessment (simple, complex) or an expanded assessment including a more thorough uncertainty characterization will follow. If during the assessment it becomes clear that the complexity of the risk cannot be reduced by scientific analysis, the assessment process will be augmented by an expanded risk and uncertainty characterization process. In addition, depending on the degree of ambiguity a range of simple to highly sophisticated tools for concern assessment is required. Those tools may range from a survey among social scientists to methods of representative surveys, focus groups, concern mapping with groups, and other techniques.

6.3 Risk Assessment

6.3.1 Generic Steps and Features of Risk Assessment

A risk assessment is a methodology to determine the nature and extent of risk. It comprises the following three main steps:

- Identification of relevant sources (threats, hazards, opportunities)
- Cause and consequence analysis, including assessments of exposures and vulnerabilities
- Risk description

Note that the term *risk analysis* is often used to describe the same process (Aven 2003). However, in this book we have avoided the term "risk analysis" as there are so many different interpretations of it.

Exposure refers to the contact of the source agent with the target (individuals, ecosystems, buildings, etc.). Vulnerability refers to uncertainty about and severity of the consequences (or outcomes) as a result of the source occurring (cf. Sect. 1.2.3). We may be concerned about the vulnerability of a building when it is exposed to a structural damage. Understanding vulnerabilities – whether it is related to a system, an individual, a community, etc. – is an important part of assessing risk. The issue of vulnerability necessitates a clear distinction between an "agent" (risk source) such as an earthquake or a chemical and the "risk absorbing system" such as a building or an organism. Vulnerability refers to the quality of the risk absorbing system to withstand or tolerate different degrees or compositions of the agent to which it may be exposed. For example, a building may be constructed in a way that it can withstand seismic pressures up to an intensity of x. Or an organism can be vaccinated so that the outbreak of a specific virus would not harm its health. A risk absorbing system may include a complex chain of interacting elements starting with a physical entity such as a complex of buildings and ending with the availability of effective disaster relief organizations.

The basis of risk assessment is the systematic use of analytical – largely probability-based – methods which have been constantly improved over the past years. Probabilistic risk assessments for large technological systems, for instance, include tools such as fault and event trees and Bayesian networks. The processing of data is often guided by inferential statistics and organised in line with decision analytic procedures. These tools have been developed to generate knowledge about cause–effect relationships, express the strength of these relationships, characterize remaining uncertainties and ambiguities and describe, in quantitative or qualitative form, other risk or hazard related properties that are important for risk management (IAEA 1995; IEC 1993). In short, risk assessments specify what is at stake, assess uncertainties and calculate probabilities for (un)wanted consequences, to produce a risk picture.

A number of approaches and methods exist for assessing risks. We distinguish between two main categories:

(a) *Statistical methods:* Data are available to predict the future performance of the activity or system analyzed. These methods can be based on data extrapolation or probabilistic modelling, see below.
(b) *Systems analysis methods:* These methods are used to analyse systems where there is a lack of data to accurately predict the future performance of the system. Insights are obtained by decomposing the system into subsystems/ components for which more information is available. Overall, probabilities and risk are a function of the system's architecture (Paté-Cornell and Dillon 2001). Examples of such methods are FMEA (failure mode and effect analysis), FTA (fault tree analysis), ETA (event tree analysis), QRA (Quantitative risk analysis) and PRA (probabilistic risk assessment). Our main focus will be the PRA. The other methods can be viewed as tools being used in a PRA.

Systems analysis also includes tools such as scenarios, which show different plausible pathways from release of an agent to the final outcome (loss). Often such scenario analysis is based on extreme cases, such as "worst scenario" and "best scenario".

6.3.2 The Meaning of Probabilities in Risk Assessment

A key term in risk assessment is the concept of probability. A probability can be interpreted in different ways (Bedford and Cooke 2001):

(a) In the classical statistical sense as the relative fraction of times the events occur if the situation analyzed were hypothetically "repeated" an infinite number of times. The underlying probability is unknown, and is estimated in the statistical analysis.

(b) As a measure of uncertainty about unknown events and outcomes (consequences), seen through the eyes of the assessor and based on some background information and knowledge. Probability is a knowledge-based (subjective) measure of uncertainty, conditional on the background knowledge (the Bayesian perspective).

A knowledge-based (subjective) probability can be given two different interpretations. Among economists and decision analysts, and the earlier probability theorists, a subjective probability is linked to betting. According to this perspective the probability of the event A, $P(A)$, is the price at which the person assigning the probability is neutral between buying and selling a ticket that is worth one unit of payment if the event A occurs, and worthless if not (Singpurwalla 2006).

Alternatively, a knowledge-based is interpreted with reference to a standard. Following this interpretation the assessor compares his/her uncertainty (degree of belief) about the occurrence of the event A with the standard of drawing at random a favourable ball from an urn that contains $P(A)$ 100% favourable balls (Lindley 2000; Aven 2003).

The betting interpretation of the knowledge-based probability should be used with care, as it extends beyond the realm of uncertainty assessments – it reflects the assessor's attitude to money and the gambling situation which means that analysis (evidence) is mixed with values. The scientific basis for risk assessment is based on the idea that professional analysts describe risk separated from how we (the assessor, the decision-maker or other stakeholders) value the consequences and the risk. The distinction between professional risk assessment and the value judgment process constitutes a basic pillar of the risk framework in this book.

A probability can also be given other interpretations (Singpurwalla 2006, Sect. 2.3), but for practical use in a risk context we see no alternatives to (a) and (b).

The rules of probability apply to all these interpretations. They are deduced from a set of reasonable axioms, including the additivity axiom expressing that the probability of a union of mutually exclusive events equals the sum of the individual event probabilities. A probability cannot easily be "verified". Scientists can only judge whether the predictions based on probability assignments correspond with what one can observe (with all the difficulties of incomplete testing associated with uncertainty). Probabilistic analysis assists us in the identification of patterns of regularities that do not follow deterministic cause–effect pathways. Whether this observation of indeterminate relationships is due to our lack of knowledge, our inability to select the appropriate boundaries between what we include in our model and what we exclude or whether it represents the true nature of the phenomenon remains unknown to us. Probability is the best approach we have to cope with these events and situations that are neither truly random nor deterministic.

In this respect, risk analysts have introduced a crucial distinction between *aleatory* and *epistemic uncertainty* (Rosa 2008:109 ff.):

- *Aleatory uncertainty*: Decision and risk analysts refer to aleatory uncertainties as "those that stem from variability in known (or observable) populations and, therefore, represent randomness in samples" (Paté-Cornell 1996; Aven and Vinnem 2007:39 ff.). A simple example of this type of variability is represented by the distribution of possible values from the roll of a fair die. A random process gives rise to any possible value at any point in time; but in the long run, with a large enough sample (or rolls of the die in our example), the distribution of possible values can be well characterized. Increasing the sample size can help to characterize this distribution more precisely but not reduce its fundamental parameters.
- *Epistemic uncertainty*: Epistemic uncertainty arises from "basic lack of knowledge about fundamental phenomena" (Paté-Cornell 1996). The impacts of global warming have been considered to be very uncertain for precisely these reasons. Epistemic uncertainty can, in principle, be reduced by the generation of additional knowledge, the collection of samples, or other forms of research appropriate to the particular issue. As scientists have begun to better understand some of the fundamental phenomena underlying climate change, many have become less uncertain about its potential impacts.

The epistemic uncertainties are expressed by knowledge-based probabilities, whereas aleatory uncertainty is reflected in a relative frequency-interpreted probability. Bayesian theorists would not refer to the "relative frequency-interpreted probabilities" as probabilities, but chances or propensities (Singpurwalla 2006). However, from a practical point of view, an analyst would not see much difference between the Bayesian theorist view of a chance and the relative frequency-interpreted probabilities.

Many researchers have argued that there is only one kind of uncertainty and this uncertainty stems from our lack of knowledge concerning the truth of a proposition or the value of an unknown quantity (Winkler 1996; Lindley 2006). Winkler (1996) uses a coin example to illustrate his point:

> Consider the tossing of a coin. If we all agree that the coin is fair, then we would agree that the probability that it lands heads the next time it is tossed is one-half. At first glance, our uncertainty about how it lands might be thought of as aleatory, or irreducible. Suppose, however, that the set of available information changes. In principle, if we knew all of the conditions surrounding the toss (the initial side facing up; the height, initial velocity, and angle of the coin; the wind; the nature of the surface on which the coin will land; and so on), we could use the laws of physics to predict with certainty or near certainty whether the coin will land heads or tails. Thus, in principle, the uncertainty is not irreducible, but is a function of the state of knowledge (and hence is epistemic).
>
> In practice, of course, measuring all of the initial conditions and doing the modelling in the coin-tossing example are difficult and costly at best and would generally be viewed as infeasible. (However, if a billion dollars was riding on the toss of the coin, we might give serious consideration to some modelling and measurement!). Our uncertainty about all of the initial conditions and our unwillingness to spend time to build a detailed model to relate the initial conditions to the ultimate outcome of the toss translate into a probability of one-half for heads. Even uncertainty about just the initial side that faces up could translate into a probability of one-half for heads. At a foundational level, as noted above, our uncertainty in a given situation is a function of the information that is available.

Winkler (1996) concludes that all uncertainties are epistemic uncertainties, a result of lack of knowledge. However, for the purpose of analyzing uncertainties and risks it may be useful to introduce models – and aleatory uncertainty represents a way of modelling the phenomena studied. In the case of a coin, the model is defined as follows: if we throw the coin over and over again, the fraction of heads will be p. When throwing a die we would establish a model expressing that the distribution of outcomes is given by (p_1, p_2, . . ., p_6), where p_i is the fraction of outcomes showing *i*. These fractions are parameters of the models, and they are referred to as probabilities in a traditional classical statistical setting and as chances in the Bayesian setting.

The models are often referred to as probability models or stochastic models. They constitute the basis for statistical analysis, and are considered essential for assessing the uncertainties and drawing useful insights (Winkler 1996; Helton 1994). All analysts and researchers acknowledge the need for decomposing the problem in a reasonable way, but many would avoid the reference to different types of uncertainties as they consider all uncertainties to be epistemic.

To further reflect on the difference between aleatory and epistermic uncertainty, we return to the urn example introduced in beginning of this section. Suppose that you are making a random drawing of ten balls from an urn, not knowing how many balls are inside the urn or what colour the balls have. The true distribution of balls expresses the aleatory uncertainty. From your sample you may estimate this distribution. The more balls we take and the more confident we are that we know the total amount of balls (by judging the size of the urn and the relative size of each ball) the more accurate will be our estimates of this distribution. With growing knowledge about the composition of the urn the statistical confidence intervals for judging the relative composition for all balls will become smaller. This is based on a standard statistical analysis and the use of relative frequency-interpreted probabilities. Alternatively, using knowledge-based probabilities we assess the uncertainties of the distribution (chance distribution) using Bayes theorem. Starting from a prior knowledge-based probability distribution of the true chance distribution of balls, we are led to the posterior knowledge-based probability distribution when we observe the results of the drawings. The posterior probability distribution will be narrower than the prior probability distribution as it is based on more information. The posterior distribution may reflect different type of epistemic sources; we may have information about similar urns and use expert judgments. This knowledge is expressed thorough the prior probability distribution; we may also do experiments as above.

In a risk assessment context, what is often loosely referred to as "uncertainty" is some combination of the contribution of aleatory uncertainty (variation) and epistemic uncertainty. For the risk assessor, these distinctions can be helpful in developing an approach for characterizing uncertainty. If the assessor knows that some fundamental random process gives rise to an outcome – huge populations of similar items or situations can be generated (modelled) – as in the case of the role of a die or in the combinatorics that predict genetic variability in some trait, this may be a starting and ending point for characterizing uncertainty (in the case that he or she is certain that aleatory uncertainty or variability tells the whole story). If such populations can be generated (modelled), the assessor's epistemic uncertainties would be based on a probability model representing the variation (a chance is such a model). The framework used is the Bayesian analysis as explained above. Subjective probabilities (degrees of belief) are here used to express the epistemic uncertainties. If such populations cannot be generated (modelled), the epistemic uncertainties need to be expressed without the use of an underlying probability model.

When conducting risk assessments an important step of the analysis is to introduce probability models and chances whenever appropriate. Care should be shown when such models and chances have to be introduced based on fictional populations that cannot be given meaningful interpretations. Consider the following example related to terrorism risk. Should we introduce the chance of a terrorist attack? To understand what this concept means, we need to construct an infinite large population of thought-constructed repeated experiments, similar to the one studied. This is however difficult to do. What is the meaning of a large set of "identical" independent attack situations, where some aspects (for example related to the potential attackers and the political context) are fixed and others (for example the attackers' motivation) are subject to variation? Say that the specific probability is 10%. Then in 1,000 situations, with the attackers and the political context specified, the attackers will attack in about 100 cases. In these situations the attackers are motivated, but not in the remaining ones. Motivation for an attack in one situation does not affect the motivation in another. For independent random situations such "experiments" are meaningful, but not for unique situations like this. We conclude that the chance in this example should not be introduced – a meaningful interpretation cannot be given.

6.3.3 Statistical Methods: Overview

In the following we present two simple examples to illustrate the main ideas of the use of statistical methods. We refer to text-books in statistical analyses for further details (Bedford and Cooke 2001; Meeker and Escobar 1998; Vose 2008).

Dose–response analysis: We consider a population of units (e.g. human beings) subject to an adverse effect (the response) of exposure (dose) to an agent (e.g. radiation, a chemical, drug, etc). Suppose the dose is x. Then the response is y. We may think of y as normalized per unit of the population, for example the relative proportion in the population that will die or the average reduced life length, etc. Since y is depending on x, it is a function of x, we write $y = f(x)$ for a function f. An example of such a function is $y = f(x) = vx,$ for a constant v.

We may refer to $f(x) = vx$ as a model as it is a representation of the real world, the link between the dose and the response in this population. The relationship between the dose and the response could be very complex but we simplify and establish the model $y = vx$, which is easy to analyze and use in a practical setting. Now, suppose that we have the data shown by Table 6.1 and Fig. 6.1:

Based on these data we see that a good fit is obtained by $y = 4x$. If we use this model, we predict for example $y = 10.0$ for $x = 2.5$. This is a deterministic data analysis. Next we introduce probabilistic quantities.

Let $Y_1, Y_2, \ldots, Y_n$ represent the response of a sample based on the doses $x_1, x_2, \ldots, x_n$, respectively. The response Y_i is unknown, it is a random variable (random quantity), with expected value $E[Y_i] = f(x_i)$ and variance $\sigma^2 = Var(Y_i)$ (say). The interpretation is that $E[Y_i] = f(x_i)$ represents the average response in a large population of units when the dose is x_i, and $\sigma^2 = Var\ Y_i$ represents the empirical variance in the same population, i.e. $\sum(Y_i - E[Y_i])^2/k$, where the sum is taken over all the units in the population, and k is the number of units in the population.

The response Y_i can be expressed by the following equation:

$$Y_i = E[Y_i] + \varepsilon_i = \nu x_i + \varepsilon_i,$$

where ε_i is a random error term with expected value equal to 0 and variance equal to σ^2, and v is a parameter that needs to be specified. Hence the response is $E[Y_i]$ on average, but because of noise we could observe an Y_i higher or lower than $E[Y_i]$. The variation or uncertainty is determined by the probability distribution of ε_i, denoted $F(\cdot)$. The parameter v represents the mean rate at which the response increases as a function of the dose (dose quantities between 0 and 6 in our example). To determine the parameter v we need a statistical analysis, either a traditional statistical analysis or a Bayesian analysis, as briefly explained in the following.

Table 6.1 Data for X (the dose) and Y (the response)

X	0	1	2	3	4	5	6
Y	0	4	7	11	17	18	23

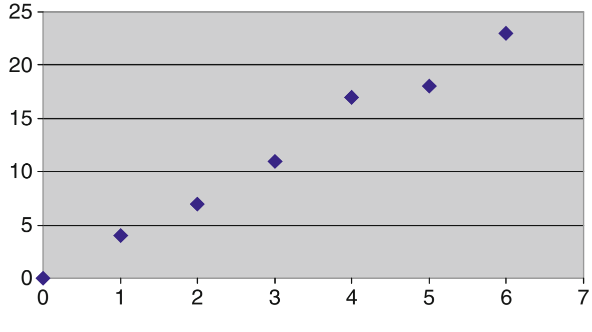
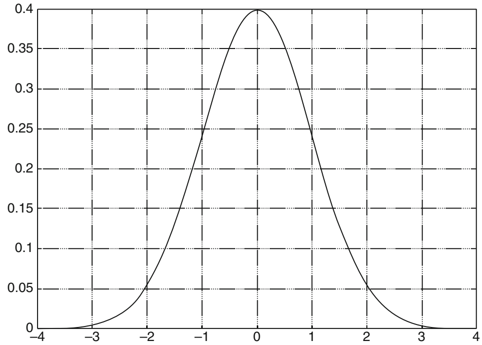


Fig. 6.1 The response as a function of the dose for the data of Table 6.1

6.3.4 Traditional Statistical Analysis

We assume that the error terms $\varepsilon_1, \varepsilon_{1,\ldots,} \varepsilon_n$ are independent and Gaussian (normally) distributed, with mean 0 and variance σ^2. Hence the distribution (i.e. the associated probability density) has the bell shaped form as shown in the figure below.



Based on the data $Y_1, Y_2, \ldots Y_n$ we establish an estimator for the parameter ν. A common estimator for ν is the least square estimator, minimising $\sum(Y_i - \nu\, x_i)^2$, i.e.

$$\nu* = \sum Y_i x_i \Big/ \sum x_i{}^2.$$

As an estimator for σ^2 we use the empirical variance: $S^2 = \sum(Y_i - \nu^* x_i)^2/(n - 1)$.

Then we may construct a confidence interval $[\nu_L, \nu_U]$ for ν, with confidence say 90%, such that $P(\nu_L \le \nu \le \nu_U) = 0.90$. Introducing $z_{0.05}$ as the 5% quantile of the standard normal distribution (i.e. $z_{0.05} = 1.65$), the confidence interval for ν can be written

$$\left[\nu^* - z_{0.05}\frac{S}{\sqrt{t}}, \nu^* + z_{0.05}\frac{S}{\sqrt{t}}\right],$$

where $t = \sum x_i{}^2$. We interpret the interval as follows: If we have a large number of similar samples, the parameter ν will be contained in this interval in 90% of the cases.

From this estimator $\nu^* x$ we can predict a response Y for a dose x, by the equation

$$Y = \nu^* x.$$

The probability distribution of Y is given by

$$P(Y \leqslant y) = P(\nu^* \leqslant y/x)$$

and using that ν^* has a normal distribution with mean ν and variance σ^2/t, we find an approximate expression for the distribution of Y by the formula

$$P(Y \leqslant y) \approx G\big((y/x - v^*)/(S/\sqrt{t})\big),$$

where G is the distribution of the standard normal distribution with mean 0 and variance 1. From this distribution we can construct an approximate 90% prediction interval [L,U] for Y, i.e. an interval [L,U] such that $P(L \leq Y \leq U) \approx 0.90$.

6.3.5 Bayesian Analysis

In the Bayesian case, the analyst uses knowledge-based (subjective) probabilities to express uncertainties, as explained in Sect. 6.3.2. All probabilities are conditional on a background information, the data available and the models being used. Let us return to the example above, and let $Y_1, Y_2, \ldots, Y_n$ represent the responses of a sample based on the doses $x_1, x_2, \ldots, x_n$, respectively. The response Y_i is given by the equation

$$Y_i = \nu x_i + \varepsilon_i,$$

where the parameter ν represents the mean rate at which the response increases as a function of the dose (dose quantities between 0 and 6), assuming that the population considered is very large.

The rate ν is unknown, and the variance σ^2 (standard deviation σ) is unknown. Before the data $Y_1, Y_2, \ldots, Y_n$ are observed, the analyst assigns a prior distribution (density), $p(\nu, \sigma)$ say, expressing his or her uncertainties (degree belief) about ν and σ. Based on the observations $Y_1 = y_1$, $Y_2 = y_2, \ldots, Y_n = y_n$, a posterior distribution (density) $p(\nu, \sigma|\text{data})$ is established using the standard Bayesian updating procedure:

$$p(\nu, \sigma|\text{data}) = c p(\nu, \sigma) f(y_1, y_2, \ldots, y_n|\nu, \sigma)$$

where c is a constant such that the density $p(\nu, \sigma|\text{data})$ has integral 1, and $f(y_1, y_2, \ldots, y_n|\nu, \sigma)$ is the probability density for the observations given ν and σ. From $Y_i = \nu x_i + \varepsilon_i$, we can deduce that

$$f(y_1, y_2, \ldots, y_n|\nu, \sigma) = [g((y_1 - \nu x_1)/\sigma) g((y_2 - \nu x_2)/\sigma) \ldots g((y_n - \nu x_n)/\sigma)]/\sigma^n,$$

where g is the density of the standard normal distribution.

From this posterior distribution we can calculate a 90% credibility interval [a, b] for ν by the equation $P(a \leq \nu \leq b \mid \text{data}) = 0.90$. Furthermore we can establish a predictive distribution for a new Y given a dose x, by

$$P(Y \leqslant y) = \int P(Y \leqslant y|\nu, \sigma)\, p(\nu, \sigma|\text{data})\, d\nu\, d\sigma = \int G((y - \nu x)/\sigma)\, p(\nu, \sigma|\text{data})\, d\nu\, d\sigma,$$

where G is the distribution of the standard normal distribution with mean 0 and variance 1. Using this expression we can also establish a prediction interval for Y.

6.3.6 Risk Assessment for Accident Risks

Consider two production units in a company C. Table 6.2. and Fig. 6.2 show the number of accidents (properly defined) for the two units the last 12 months. For the sake of simplicity we assume that these two units have the same number of hours of accident exposure.

Based on these data, we calculate the mean number of accidents and empirical standard deviations:

Unit	Mean (M)	Empirical Standard deviation (S)
1	13.42	2.06
2	13.50	1.55

We see that the number of accidents for the two is about the same, but the standard deviation is much larger for unit 1. It seems that the number of accidents in unit 1 has an increasing trend.

What about risks? What are the accident risks? The above numbers do not show the risks, just the historical numbers. The data may be used to say something about the future and the risks.

If we use the data as a basis, we obtain the following risk picture: Let X(1) and X(2) be the number of accidents for the two units next month. Then using the means as predictors we obtain the following predictions for the Xs:

$$X(1)^{*} = 13.4$$

$$X(2)^{*} = 13.5.$$

Table 6.2 Number of accidents for two production units over the last 12 months

Month Unit	1	2	3	4	5	6	7	8	9	10	11	12
1	10	11	13	12	13	12	14	13	14	15	17	17
2	12	11	12	14	14	14	16	15	16	13	12	13

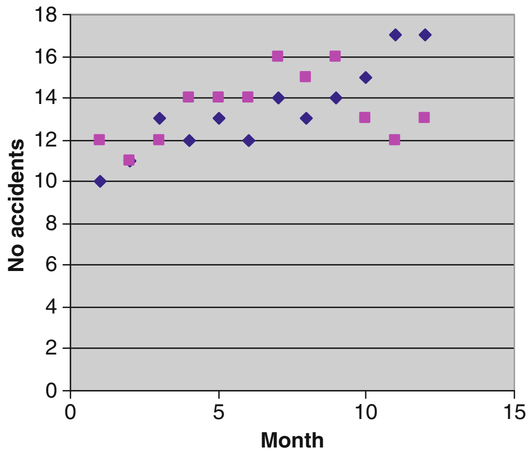


Fig. 6.2 Number of accidents as a function of time for two production units, based on the data of Table 6.2

Furthermore, 90% prediction intervals can be specified as:

$$X(1) : [11, 17]$$

$$X(2) : [12, 16].$$

These numbers are derived simply by requiring 90% of the observations to be in the interval.

Can we rely upon the above predictions? Consider Unit 1. If we assume that there is a trend for the number of accidents for unit 1, we would predict a number of accidents of about 17 and not 13.4. If we use the same variance as above, we obtain a prediction interval [13, 21]. Of course, only the future can tell which prediction is the best, but it is obvious that a pure transformation from the historical data can give poor predictions.

By trying to understand the data, by taking into account trends and performing regression analysis, we may improve the predictions. But we could also overdo the analysis and interpretations in the sense that we attempt to find all kinds of explanations why the historical data are as they are. We may analyse the underlying factors that could influence the number of accidents, but it is not easy to identify what are important factors and what are random noise and arbitrariness.

An analysis based on the historical numbers could easily become to narrow and imply that extreme outcomes are ignored. Surprises occur from time to time, and suddenly an event could occur that dramatically changes the development, with the consequence that the number of accidents jumps up or down. In a risk analysis such events should be identified. However, the problem is that we do not always have the knowledge and insights to be able to identify such events, because they are extremely unexpected (cf. the discussion in Taleb (2007)).

6.3.7 Probabilistic Risk Assessments

To explain the main ideas of probabilistic risk assessment (PRA) we will look into the three main steps of risk assessment again:

- Identification of relevant sources (threats, hazards, opportunities)
- Cause and consequence analysis
- Risk description

The level of depth of the various analysis steps would of course depend on the purpose and scope of the assessment.

A simple example will be used to illustrate the basic steps of the assessment and some of the common methods used in the assessment. The example is to large extent based on Garrick et al. (2004) and Aven (2007a). We refer to the former reference for the technical details. Various aspects of the approach adopted by Garrick et al. (2004) are discussed.

The system is a hypothetical electrical grid. The electrical infrastructure is critical to the nations's well being. The analysis covers assessments related to cyber attacks and physical attack on a hypothetical electric power grid.

The system has many functions, but the main function is the delivery of electric power to the consumers. The following damage levels are defined:

1. No damage
2. Transient outage (4–24 h) to network 1
3. Transient outage to the region and network 1
4. Long-term outage (more than 24 h) to network 1
5. Long term outage to network 1 and transient outage to the region (a transient outage is an outage which is automatically restored with no human intervention)
6. Long term outage to the region and network 1

In addition the assessment focuses on:

(a) The number of attacks (suitably defined) and
(b) The proportion of attacks being "successful"

Step 1: Identify relevant sources (threats and hazards): As a basis for this activity an analysis of the system is carried out, to understand how the system works, so departures from normal, successful operation can be easily identified. Once the system is understood, vulnerabilities that require special analysis can be identified. The electrical grid has four main elements; substations, transmission lines, supervisory control and data acquisition (SCADA) systems and energy management systems (EMSs). A first list of sources is normally identified based on this system analysis, experience from similar type of analyses, statistics, brainstorming activities and specific tools such as Failure mode and failure effect analysis (FMEA) and Hazards and operability studies (HAZOP).

The FMEA was developed in the 1950s and was one of the first systematic methods that was used to analyse failures in technical systems. If we describe or rank the criticality of the various failures in the failure mode and effect analysis, the analysis is often referred to as an FMECA (Failure Modes, Effects and Criticality Analysis). The criticality is a function of the failure effect and the frequency/probability.

FMEA is a simple analysis method to reveal possible failures and to predict the failure effects on the system as a whole. The method is inductive; for each component of the system we investigate what happen if this component fails. The method represents a systematic analysis of the components of the system to identify all significant failure modes and to see how important they are for the system performance. Only one component is considered a time, the other components are then assumed to function perfectly. FMEA is therefore not suitable for revealing critical combinations of component failures.

A HAZOP study is a systematic analysis of how deviation from the design specifications in a system can arise, and an analysis of the risk potential of these deviations. Based on a set of guidewords, scenarios that may result in a hazard or an operational problem are identified. The following guidewords are commonly used:

NO/NOT, MORE OF/LESS OF, AS WELL AS, PART OF, REVERSE, and OTHER THAN. The guidewords are related to process conditions, activities, materials, time and place. For example, when analysing a pipe from one unit to another in a process plant, we define the deviation “no throughput” based on the guideword NO/NOT, and the deviation “higher pressure than the design pressure” based on the guideword MORE OF. Then causes and consequences of the deviation are studied. This is done by asking questions, for example for the first mentioned deviation in the pipe example above:

- What must happen to ensure the occurrence of the deviation “no throughput” (cause)?
- Is such an event possible (relevance/probability)?
- What are the consequences of no throughput (consequence)?

As a support in the work of formulating meaningful questions based on the guidewords, special forms have been developed.

Normally the source identification is strongly integrated with step 2, as source identification quickly leads to discussions of scenarios, causes, uncertainties and likelihoods.

For the case, we restrict attention to potential terrorist attacks. Further detailing is carried out in Step 2.

Step 2: Cause and consequence analysis: The second step is performed to assess consequences from a set of causes. We focus on the following threats:

(1) A physical attack on the electrical grid
(2) A complementary simultaneous cyber attack on the electrical grid

Now starting from the events (1) and (2), a standard analysis can be performed using event trees and fault trees to identify the possible consequences of the initiating events (1) or (2) and possible scenarios leading to the events based on a backward approach. This process leads to a number of specified scenarios. We first look at the backward analysis, asking how the initiating events (1) and (2) may occur.

Numerous physical methods could be used to damage equipment at each substation with varying degrees of damage to the network. For example carbon fibers could be sprayed over buses and transformers to cause severe short circuits, and explosives could be used to destroy key transformers, circuit breakers and bus sections. Without going into more details, we see the contours of an analysis establishing possible scenarios that can lead to the event (1). This analysis could be structured by using fault trees, see the simple example in Fig. 6.3. The attack occurs if either the basic event A occurs or B (or both).

A fault tree is a logical diagram which shows the relation between a top event – often a system failure (the attack in this case), and events that may cause this undesirable event (often failures of the components of the system), referred to as basic events. The graphical symbols showing the relation between these events are called logical gates. The two most common logical gates are the Or-gate (see Fig. 6.3) and the And-gate. The output from an And-gate is true if the input-events

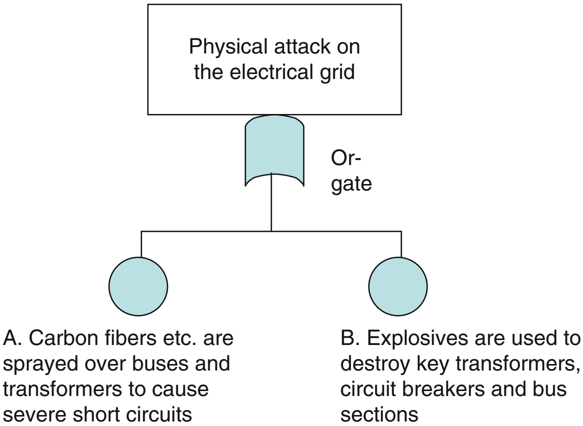


Fig. 6.3 A simple example of a fault tree

are all true. In the case of an Or-gate, the output is true if at least one input event is true.

The fault tree (FTA) method was developed by Bell Telephone Laboratories in 1962 when they performed a safety evaluation of the Minuteman Launch Control System. The Boing Company further developed the technique and made use of computer programs for both quantitative and qualitative fault tree analysis. Since the 1970s fault tree analysis has become very widespread and is today one of the most used risk analysis method. The applications of the method include most industries. The space industry and the nuclear power industry have perhaps been the two industries that have used fault tree analysis the most.

A fault tree that comprises only And- and Or-Gates can alternatively be represented by a reliability block diagram. This is a logical diagram which shows the functional ability of a system. Each component in the system is illustrated by a rectangle as shown in Fig. 6.4. If there is connection from a to b in Fig. 6.4, this means that the system is functioning. Usually “functioning” means absence from one or more failure modes.

The diagrams in Figs. 6.3 and 6.4 represent alternative ways of representing the same activity or system. The next stage in the analysis would be to perform a resource attacker’s analysis, which addresses the following points:

– The need for resources to carry out the attack
– Possible attackers
– Their motivation, competence, resource basis, and ability in general to perform the attack
– Knowledge, access and target vulnerabilities, as well as non-retribution and the ability to assess the success of an attack (cf. Anton et al. 2003)

A comprehensive analysis would also address factors that would influence the performance of the attackers, and the systems and barriers to withstand the attacks

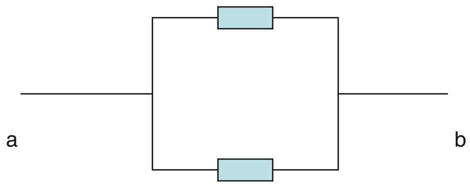


Fig. 6.4 A reliability block diagram (parallel system)

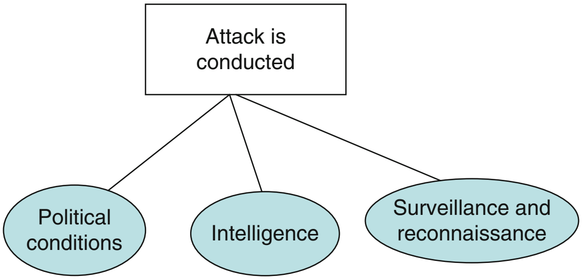


Fig. 6.5 Factors influencing the possible occurrence of an attack

and reduce their consequences. Examples of such performance influencing factors are political conditions, intelligence, surveillance and reconnaissance, and self-awareness. An influence diagram (Bayesian belief network) could be used to show the influencing factors. A simple example is shown in Fig. 6.5.

Now, if an attack occurs, what are the consequences? To analyze these, event trees are used. They produce scenarios starting from the initiating events, in our case (1) and (2). A simple event tree based on (2). is shown in Fig. 6.6.

The Network 1 event represents the event that attackers damaging sufficient equipment in Network 1 to cause a long-term power outage. The horizontal path from the Network 1 event occurs if the attackers do not disable enough equipment to cause a network power outage. The failure path from the Network 1 top event (the vertical path in the event tree) occurs if the attack results in long-term damage to network power supplies.

The SCADA event represents the event that intruders initiating a cyberattack that causes short-term power failures throughout the regional grid. The horizontal path from the SCADA event occurs if the intruders do not disable the regional grid. The failure path from the SCADA event (the vertical path in the event tree) occurs if the intruders cause a regional power outage.

Based on the various scenarios, a damage category is determined, as shown in Fig. 6.6. This event tree provides a basis for analysing uncertainties and probabilities related to the various attack scenarios. As noted by Garrick et al. (2004), in practice, "it is often necessary to increase the level of detail in the supporting analyses to examine the threats, vulnerabilities, and causes that may contribute to each undesired condition. The increased detail facilitates a more systematic

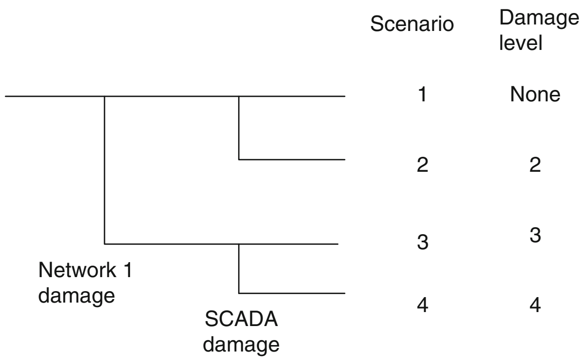


Fig. 6.6 Simple event tree for the initiating event (2)

evaluation of each potential cause of failure and provides a logical framework for assessing the effectiveness of specific mitigation measures". The detailed analyses also often contribute to reduce the inherent uncertainties in the phenomena and processes studied, and identify the most important sources of uncertainty.

An example of a more detailed analysis is a vulnerability analysis of critical systems, such as the SCADA system. A vulnerability analysis studies the possible consequences (specifically addressing the system weaknesses) of possible threats and hazards. The vulnerability study can be conducted in many different ways. An example is the approach by Anton et al. (2003), which is based on an identification of vulnerabilities using a checklist covering a rather comprehensive taxonomy applied to physical, cyber, human/social and infrastructure objects. It covers attributes related to:

- *Design/architecture* (Singularity – uniqueness, centrality, homogeneity; Separability; Logic/implementation errors – fallibility; Design sensitivity – fragility, limits, finiteness; Unrecoverability)
- *Behavioral* (Behavioral sensitivity/fragility; Malevolence; Rigidity; Malleability; Gullibility – deceivability, naivete; Complacency; Corruptibility – controllability) and
- *General* (Accessible – detectable, identifiable, transparent, interceptable; Hard to manage or control; Self-unawareness and unpredictability; Predictability)

By a systematic review of these attributes, the aim is to identify vulnerabilities which are beyond the standard well-known vulnerabilities.

Step 3. Risk description: Up to now we have performed a qualitative analysis with the purpose of gaining insights. The analysis structures the analysts' knowledge on the threats and vulnerabilities and what the consequences of a threat are. Normally there would be a number of scenarios developing from a specific initiating event. There are uncertainties present, and these uncertainties we need to assess and describe. The key questions to address are:

- How likely is it that a physical attack on the electrical grid will occur in a specified period of time?
- Are there large uncertainties in the phenomena that influence the occurrence of this event?
- What are the essential factors creating the uncertainties?
- How likely are the different consequences, using the appropriate categorizations?
- Are there large uncertainties in the phenomena that influence these likelihoods?
- What are the essential factors creating the uncertainties?

Various kinds of risk matrices can be informative to present the likelihoods. The traditional risk matrix show combinations of possible consequences (with some defined categories) and associated probabilities. See Fig. 6.7. In Fig. 6.7 the x-axis is to be interpreted as the assessor's probability that the scenario resulting in damage category 2 will occur. The assignments are based on relevant models and data. These models and data are a part of the background information for the assigned probabilities. The focus in the analysis lies on quantities such as:

- X: the number of future attacks (properly defined)
- Y_i: 1 if attack i is successful and 0 otherwise
- Y: the proportion of the attacks being successful
- Z: the number of successful attacks.

Then we assess uncertainties, using probabilities, and this leads to probability distributions of the above quantities. Given a number of attacks, say 10, we may for example assign a probability of 20% that one of these is successful. From the analysis we may establish a probability distribution for Z, the number of successful attacks.

Probabilities and expected values are used to express uncertainties and degrees of belief. However, we need to see beyond these values. The analyses are based on judgments, made by some experts, a number of assumptions and suppositions are

>50%					
10-50%			x		
1-10%					
<1%					
Probability Damage category	0	1	2	3	4

Fig. 6.7 An example of a risk matrix. Here x corresponds to a scenario in damage category 2 and probability of 10–50%

made, and there could be large uncertainties associated with the phenomena being studied. The outcomes could be surprising relative to the assigned probabilities and expected values. In a risk analysis a number of such probability assignments are performed, and the hidden uncertainties could create surprising outcomes someplace. You do not know where it will come, but it certainly could happen. An assumption could be that the "war of terror" is further escalating, but we could be wrong.

To identify and express such uncertainties different types of procedures are used (Aven 2007a; Sandøy et al. 2005). These relate to the background information (assumptions and suppositions) of the assigned probabilities, as well as factors such as:

- Vulnerabilities
- Complexity in technology
- Complexity in organisations
- Available information
- Time horizon
- The thoroughness etc. of the analysis. What is the experts' competence, seen in relation to the best available knowledge? Do we have available relevant experience data? To what extent would further analysis reduce the uncertainties about the potential consequences? Etc.
- IRGC (2005) consequence features (Sect. 3.7.2 and Table 3.2), such as:
  - Delay effects – which describe the time of latency between an initial event and the actual damage.
  - Reversibility – which describe the possibility to restore the situation to the state before the damage occurred.

For example, the feature "delay effects" could lead to a focus on activities or mechanisms that could initiate deteriorating processes causing future surprises.

Addressing the uncertainties also implies to consider the *manageability*; i.e. to what extent is it possible to control and reduce the uncertainties, and obtain desirable outcomes. Some risks are more manageable than others, meaning that the potential for reducing the risk is larger for some risks compared to others. By proper uncertainty management, we seek to obtain desirable consequences. Risk should be described by addressing such issues along with the probabilities.

The risk assessments systemize the knowledge and uncertainties about the phenomena, processes, activities and systems being analyzed. This knowledge and these uncertainties are described and discussed and this provides a basis for evaluating what is important (tolerable and acceptable) and for comparing options.

Expressing risk also means to perform sensitivity analyses. The purpose of these analyses is to show how sensitive the output risk indices are with respect to changes in basic input quantities, for example assumptions and suppositions.

The above uncertainties are epistemic uncertainties, describing the analysts' knowledge or lack of knowledge related to what the correct values of the quantities X, Y and Z are. In the literature it is also referred to aleatory uncertainties. These uncertainties, which are better called variations, were discussed in Sect. 6.3.2. They reflect average performance of an infinite population of similar units to the one studied. We may think about human beings, mobile telephones etc., and the variations generated in these populations concerning weights, life times, and so on. For the above security application it is difficult to define such a population – the "world repeated in this case" is hard to image. Aleatory variation is therefore not introduced in the above analysis. In other applications however the distinction between aleatory uncertainty (variation) and epistemic uncertainties could be useful as noted in Sect. 6.3.2.

6.4 Concern Assessment

Concern assessments address affects and changes to the socio-economic environment, positive or negative, that wholly or partially results from the risks. In this section we reflect on the way such assessments can be performed, but first we look into ways of categorising the concerns.

6.4.1 Concern Classifications

There exists a number of different classification schemes for socio-economic concerns, see e.g. overview by Vanclay (2002). A comprehensive scheme developed by Vanclay (2002) is presented in the appendix. It is based on the following main categories of impacts:

A. Indicative Health and Social Well-being Impacts
B. Indicative Quality of the Living Environment (Liveability) Impacts
C. Indicative Economic Impacts and Material Well-being Impacts
D. Indicative Cultural Impacts
E. Indicative Family and Community Impacts
F. Indicative Institutional, Legal, Political and Equity Impacts
G. Indicative Gender Relations Impacts.

In a document published by the UK Treasury Department (2005) the authors recommend a risk appraisal procedure that includes the results of risk assessment, the direct input from data on public perception and the assessment of social concerns. The document offers a tool for evaluating public concerns against six factors which are centred around the hazard(s) leading to the risk and its management:

- Perception of familiarity and experience with the hazard;
- Understanding the nature of the hazard and its potential impacts;
- Repercussions of the effect of the hazard and its consequences on equity (intergenerational, intra-generational and social);
- Perception of fear and dread in relation to the effect of the hazard and its consequences;
- Perception of personal or institutional control over the management of the risk;
- Degree of trust in risk management organizations.

A similar list of appraisal indicators was suggested by a group of Dutch researchers and the Dutch Environmental Protection Agency (van der Sluijs et al. 2003, 2004). In the late 1990s, the German Council for Global Environmental Change (WBGU) also addressed the issue of risk appraisal and developed a set of eight criteria to characterise risks beyond the established assessment criteria (WBGU 2000; IRGC 2005), see Sect. 3.7.2, Table 3.2.

When dealing with complex, uncertain and/or ambiguous risk problems it is essential to complement data on physical consequences with data on secondary impacts, including social responses to risk, and insights into risk perception. The suggestions listed above can provide some orientation for the criteria to be considered. Depending on the risk under investigation, additional criteria can be included or proposed criteria neglected. The various lists of concerns point to the importance of risk perceptions as a driver for public concerns. What we know about risk perception is summarized in the next section.

6.4.2 Insights into Risk Perception Research

Perceptions have a reality of their own: Just like the characters in animated films who, suspended in mid-air, do not plunge to the ground until they realize their predicament, people construct their own reality and evaluate risks according to their subjective perceptions. This type of intuitive risk perception is based on how information on the risk source is communicated, the psychological mechanisms for processing uncertainty, and earlier experience of danger. This mental process results in perceived risk – a collection of notions that people form on risk sources relative to the information available to them and their basic common sense (Jaeger et al. 2001). Thus this section focuses on constructed reality, i.e. the world of notions and associations which help people understand their environment and on which they base their actions.

First of all, it is highly important to know that human behavior is primarily driven by perception and not by facts, or by what is understood as facts by risk analysts and scientists. Most cognitive psychologists believe that perceptions are formed by common sense reasoning, personal experience, social communication, and cultural traditions (Brehmer 1987; Drottz-Sjöberg 1991; Pidgeon et al. 1992; Pidgeon 1998). In relation to risk it has been shown that humans link certain expectations, ideas, hopes, fears and emotions with activities or events that have uncertain consequences. People do not, however, use completely irrational strategies to assess information, but – most of the time – follow relatively consistent patterns of creating images of risks and evaluating them. These patterns are related to certain evolutionary bases of coping with dangerous situations. Faced with an imminent threat, humans react with four basic strategies: *flight, fight, play dead* and, if appropriate, *experiment* (on the basis of trial and error) (Marks and Nesse 1994).

In the course of cultural evolution, the basic patterns of perception were increasingly enriched with cultural patterns. These cultural patterns can be described by so-called *qualitative evaluation characteristics* (Slovic 1992). They describe properties of risks, or risky situations going beyond the two classical factors of risk assessment, on which risk is usually judged (i.e. level of probability and degree of possible harm). Here, psychologists differentiate between two classes of qualitative perception patterns: on the one hand, *risk-related patterns*, which are based on the properties of the source of risk; on the other, *situation-related patterns*, based on the idiosyncrasies of the risky situation (Fischhoff et al. 1978; Slovic 1987, 1992; Breakwell 2007:26 ff.).

One example of a risk-related pattern is the perceived "dread" of the consequences of a possibly harmful event. If, for example, people are riding in a car and are thinking about possible accidents, they will always be under the impression that they would, with high probability, get away unscathed in a car accident ("fender-bender mentality"). However, if the same people are sitting in an airplane, they will be under the impression that, if something happens here, there is no getting away. This feeling of apprehension does not subside even if they know the odds and are convinced that statistically many more people die in car accidents than in airplane crashes. Situation-related patterns of perception include aspects such as voluntariness and the ability to exercise self-control (review in Breakwell 2007:29 ff.). If someone is of the opinion that he can control the risk, he will perceive it as less serious. This mode of thinking frequently takes effect where eating habits are concerned. People believe that they can easily do without sweets, alcohol, or other food considered unhealthy, if only they wanted to. However, mostly harmless chemical food additives are perceived as a threat to one's health. With regard to collective risks, people show special concern for risks that they believe are not adequately controlled by public authorities (as in the case of genetically modified organisms, or GMOs).

Considered together, these qualitative evaluation characteristics can be subdivided into a limited number of consistent risk perception classes. In literature they are also called *semantic risk patterns*:

- Risk as a fatal threat
- Risk as fate
- Risk as a test of strength
- Risk as a game of chance
- Risk as an early warning indicator

Risk as a fatal threat: In many areas of technology, particularly industrial technology, major accidents involving safety system failures can have catastrophic effects on humans and the environment. In technical safety philosophy, the main aim is to reduce the likelihood of such failure occurring to ensure that the product of probability and impact is as small as conceivably possible. But the stochastic nature of such an event makes it impossible to foresee when it will actually occur. In consequence, an event could, theoretically, occur at any time although the likelihood of its occurrence is extremely low. A look at perception of rare random events shows that probability plays hardly any role at all: It is the random nature of the event that poses the feeling of threat. Human beings are more comfortable with threats that they can foresee and plan for rather than threats that could materialize themselves at any time regardless how unlikely that might be. Risk sources in this category include major facilities like nuclear power plants, liquid natural gas (LNG) storage facilities, chemical production sites and other man-made sources of potential danger which could have catastrophic effects on man and the environment in the event of a serious accident.

The idea that an event could impact on the population concerned at any time fosters feelings of threat and powerlessness. Instinctively, most people are better able to cope with the idea of risk mentally (whether they can in reality is a different matter) when they are prepared for and expect it. Just as the majority of people are more afraid at night than during the day (although the observed risk figures of coming to harm in daytime is considerably higher than at night, it is easier to be startled by potential danger during the night), most feel more threatened by the potential for danger to happen upon them unexpectedly or when they are unprepared for it than by danger that arises either on a regular basis or where there is enough time for risk control measures to be taken. Thus, the risk impact in this perception model depends on three factors: *the random nature of the event, the expected maximum impact and the time-span for risk control measures*. Conversely, the comparative rarity of an event, i.e. the probability and the statistical expected value, is of little consequence. Rather, regularly occurring events signal more of a continued sequence of harmful events for which one can prepare oneself by a process of trial and error.

While the perception of risk as an impending disaster often governs technical risk assessment, it rarely applies in assessment of natural disasters. Earthquake, flood or tornado activity follows the same determinants as technological innovation, i.e. the occurrence of such events is rare, random and allows little time for risk control measures to be taken. They are, however, assessed using a different risk model, as described below.

Risk as fate: Natural disasters are usually seen as unavoidable events with catastrophic effects, but they are also seen as *quirks of nature* or *acts of God* (and in many cases as the mythological wrath of God for collective sinful behavior) and thus beyond man's control (Watson 1987). In terminology used by Niklas Luhmann, they are risks that humans are simply exposed to. The possibilities for controlling natural disasters and lessening their impacts have not yet anchored themselves sufficiently in people's awareness to allow the risks from natural disasters to be assessed in the same way as those from technological accidents.

Natural burdens and risks are seen as prescribed, almost inevitable fate while technical risks are seen as the consequences of decisions and actions. Such actions are assessed and legitimized according to different standards. Fate only finds justification in mythology or religion. If none other than God can be held accountable, no amount of human activity will improve the situation. The only alternatives are either to flee from the risk situation or to deny its existence. The rarer the event, the more likely people are to deny it or suppress it; the more frequent the event, the more likely people will flee from the danger zone. It is thus understandable, although not altogether rational, that people should settle in earthquake and flood regions and will often return to those regions in the wake of a disaster. As opposed to the circumstances of technical risk, the random nature of the event is not the fear-triggering factor (because randomness involves fate and not the unforeseeable consequences of inappropriate action). Rather, the relative rarity of the event provides psychological reinforcement for risk denial.

With the increasing influence man's actions can have on natural disasters, the *risk as fate* model is more a mixture of risk perception elements than to do with man-made risk. This is evident when, for example, a natural disaster occurs – the question of accountability arises and cause is found in failure to implement possible control or preventive measures (see Douglas 1966; Wiedemann 1993).

Risk as a personal thrill: When, despite the considerable risk, Reinhold Messner climbs the world's highest mountains without the aid of breathing apparatus, when drivers drive far faster than the speed limit allows, when people throw themselves off a mountain or a cliff-top with nothing more than a pair of artificial wings to save them and do so in the name of sport, the meaning of risk takes on a new dimension. As is often claimed, the pursuit of such leisure activities is not about accepting risk as a ticket to the pleasurable benefits (feeling the wind in one's hair or enjoying a magnificent view); instead, the benefit lies in the risk itself: The attraction of such activities is the fact that they involve risk (Machlis and Rosa 1990).

In all these cases, people take risks in order to test their own strength and to experience triumph over natural forces or other risk factors. To pitch oneself against nature or one's competitors and to overcome a self-contrived risk situation is the major incentive in entering into the activity. It may well be that the challenges offered by our safety-conscious society are too few, so that our – often instinct-based – desire for adventure and risk goes unsatisfied. Instead, artificial situations are created to provide a calculable and, through personal effort, surmountable risk that individuals expose themselves to voluntarily. Risk as a thrill involves a range of situation-specific attributes:

- Voluntary involvement
- Personal control of and ability to influence the respective risk
- Limited period of exposure to the risk situation
- The ability to prepare oneself for the risk activity and to practice appropriate skills
- Social recognition for overcoming the risk

Risk as a thrill is such a dominant motivator that many societies have developed symbolic risk situations in the form of sports, games, speculation, investment and the rules of power acquisition as a channel for the "kick" in overcoming danger and to replace any possible negative outcome with symbolic penalties. Symbolic channelling of the "high" in taking risks also includes symbolic anticipation of real danger by way of computer simulation and hypothetical risk assessment (Häfele et al. 1990). Conventional methods of testing or finding new uses for technological innovations by means of trial and error can no longer be morally justified in a society so fixated with protecting the individual. In place of error – which always causes harm – comes symbolic anticipation of danger: Adventure holidays aim only to communicate the idea of risk; spare the thought that someone might get hurt. Technological systems must be so designed that no-one comes to harm as a result of system failure (learning from actual mistakes is replaced by computer simulation of hypothetical disaster scenarios). No social reform bill is passed without scientific analysis of the consequences, complete with compensation strategies for potential victims.

Increased experience of purely symbolic risk naturally increases the demands placed on technological systems. The more the thrill of risk-taking is associated with symbolic consequences for oneself and potential competitors, the more one expects that the consequences of technical sources of risk should also be symbolic. Catastrophic risk outcomes should simply not occur.

The shock of Chernobyl and other technological disasters lies largely in the outrage that the accident did not remain a purely hypothetical game of numbers but rather had very real impacts on the environment. The mix of hypothetical risk assessment and actual harm to health played a large part in causing the general confusion that abounded following Chernobyl (Peters et al. 1987). What had long been deemed impossible both in perceived residual risk and in computerized risk simulation in the "pretend world" of hypothetical risk assessment was suddenly reality, even though the health consequences for Western Europe could only be assessed on a hypothetical basis.

Risk as a game of chance: Risk as a thrill, in which one's own abilities to cope with the risk are instrumental in entering into the activity in the first place, is not the same as what we understand by the risk involved in playing the lottery or games of chance. These involve loss or profit that is usually independent of the player's ability. While simply playing the game can in itself create a high and become the object of the exercise, it is the anticipated or desired payout, the possibility of a big win, that produces that certain "thrill" and not the actual process of playing (in contrast to games in which reward and penalties have only symbolic value).

Psychologists have long conducted in-depth studies on risk behavior in games of chance. Firstly, the circumstances are easily simulated in the laboratory and secondly, it is easy to identify deviations from statistical expected values (Dawes 1988). However, it must be pointed out that the statistical expectations provide no standard on which to base rational gaming behaviour. The stake must be kept to an absolute minimum while the main prize must be particularly attractive. Players tend to underestimate the chance of rare events and are thus more willing to play if their stake remains below their pain threshold.

The fact that there is always a winner incites the belief that we could be next. Games of chance often involve hidden distribution ideologies (like dead-cert betting systems, lucky numbers or fair shares). Some 47% of Americans believe in the existence of lucky numbers and that they increase certain players' chances of winning (Miller 1985). If the random element receives any recognition, then the perceived concept of stochastic payout distribution comes closest to the technical risk model. However, this concept is not used in perception and assessment of technical risk. Quite the opposite: A study conducted in Sweden has shown that those questioned believe it highly immoral to apply a *game of chance mentality* to technical risk sources in cases where human health and life are at stake (Sjöberg 1997).

Risk as an Early Warning Indicator: In recent times, public debate has acquired yet another pattern of risk. Increasing reports on environmental pollution and its long-term impacts on health, life and nature have forced scientific risk assessment to adopt a role as early warning indicators.

In this risk perception model, scientific studies help early detection of lurking danger and the discovery of causal relationships between activities or events and their latent effects. This pattern of risk is used, for example, in cognitive handling of low doses of radiation, food additives, chemical crop protection products and genetic manipulation of plants and animals. Perception of such risk is closely related to the need to find causes for apparently inexplicable consequences (e.g. seal deaths, childhood cancer, or forest dieback). Unlike in the technology-medical risk model, the probability of such an event is not seen as a significant deviation (i.e. it can no longer be explained by chance) from natural variation for the event in question, but rather as the degree of certainty with which a single event can be traced to an external cause. The results of an empirical study on the differences between lay assessment and expert assessment of toxicological knowledge and assumptions confirms the posited theory that laypeople deem causal relationships important if a relationship is seen between individual events (like exposure and illness). Significance is based on causal thinking. See Kraus et al. (1992).

The fact that cancer, for example, can be caused by ionizing radiation at least legitimizes the suspicion that all incidents of cancer that occur in the vicinity of a nuclear power plant can be explained by the fact that the plant emits radiation. Anyone who contracts cancer or is forced to watch a family member or close friend suffer from the illness will search for an explanation. In our secularized world, metaphysically based explanation patterns have lost their importance. At the same time, the best explanation supplied by current scientific knowledge, that cancer occurs at random, does little to satisfy the need for a "meaningful" explanation. There is little consolation in knowing that one has contracted cancer by way of a random distribution mechanism. If one has an actual reason – say, environmental pollution, smoking, or bad eating habits – then the illness's occurrence at least makes some sense. And if, from a subjective standpoint, one's own actions (smoking or alcohol abuse) can be ruled out as the cause of the illness and blame can be placed on external causes it may even fulfil a social purpose: that of heightening awareness in potential victims and stirring them to fight.

The often highly emotional debate on this type of risk must be viewed from this psychological standpoint. Our propensity to empathize helps us identify with the victim. Risk assessment that shows a certain probability of lurking danger due to pollution triggers identification with people affected by it. While risk analysts characterize the relative risk of events by using stochastic theories that do not take in direct cause–effect relationships (thus creating distance between themselves and the object of their study), the layperson sees these theories as proof of the part played by social actors in causing life-threatening diseases.

But then again, the definition of probability is the crux of the discrepancy between intuitive and technical perceptions of risk. It is difficult to give someone a plausible explanation as to why, according to assessments conducted by the US Department of Energy, some 28,000 people in Europe will contract cancer in the next 50 years as a direct result of Chernobyl, but the individual risk of dying of cancer has only risen by 0.002% (Hohenemser and Renn 1988). For the average German, this means an increased probability from around 24% today to 24.002%. So who do these 28,000 cases involve, if each potential victim is only subject to a marginally increased risk of contracting cancer? That this example (the product of low probability and a large population) also sheds light on the limitations of interpretative ability in scientific technical risk assessment goes without saying.

Probability and severity of adverse effects are not the only components that most people use as yardsticks for perceiving and evaluating risks. It is rather the context in which those risks are experienced that determines their fate in risk perception. This dependence on the supporting circumstances is not random, but rather follows certain principles that can be identified by systematic psychological investigation. Research has provided a lengthy list of supporting circumstances or *qualitative factors* (Slovic 1987). Factor analysis usually reduces these lists to a few important compound factors. Studies conducted in Austria, Germany, Great Britain, the Netherlands and the US (see Renn and Rohrmann 2000) have identified the following factors as particularly relevant:

- Familiarity with the risk source
- Voluntary acceptance of the risk
- Ability to personally control the degree of risk
- Whether the risk source is capable of causing a disaster (Catastrophic potential)
- Certainty of fatal impact should the risk event occur (dread)
- Undesired impact on future generations
- Sensory perception of danger
- Impression of fair distribution of benefit and risk
- Impression of reversibility of the risk event impact
- Congruence between benefactors and risk bearers
- Trust in state-operated risk control and risk management
- Experience (collective and individual) with technology and nature
- Reliability of information sources
- Clarity of information on risk

The importance of these qualitative factors in risk assessment offers a plausible explanation for the fact that precisely those risk sources that technical risk assessment classifies as particularly low-risk are the source of greatest concern among the general public. Risk sources that are deemed controversial, like nuclear power, are very often burdened with negative attributes while leisure activities are associated with more positive ones (Jungermann and Slovic 1993).

Psychological research on risk perception brings us a step closer towards an analysis of how society really assesses risk. The observed discrepancy between the results of technical risk assessment conducted by experts and intuitive assessment of the same risk situation by society is not, in the first instance, due to uncertainty about statistically derived expectations or an expression of unverifiable thought processes, but rather an indication of a multidimensional assessment matrix in which anticipated harm is only one of many factors.

Studies conducted on an international scale also show that people everywhere, regardless of their social or cultural background, use practically universal risk assessment criteria in forming their opinions (cf. Renn and Rohrmann 2000). However, the relative effectiveness of these criteria in opinion-forming and risk tolerance varies considerably between different social groups and cultures. While the above-mentioned qualitative characteristics are accepted (often subconsciously) as assessment values for perceived risk, their relative contribution to a person's actual opinion or motivation to take action depends on individual lifestyles, threatening environmental factors and ingrained cultural values (Sjöberg 1994). In assessing risk, people who favor alternative lifestyles tend more than others to consider both "reversibility of the consequences of risk events" and "congruence between risk bearers and benefactors", while those with strong material values assess risk more by way of personal control opportunities and trust in institutional risk control (Buss and Craik 1983). As Otway and Thomas impressively showed in their studies on attitudes to nuclear energy, there is a high correlation between different value models and the relative importance that people attach to either the benefits or the risks of a specific technology (Otway and Thomas 1982).

The conclusion to be drawn from this is that value expectations and cultural background are significant determinants of risk perception that do not add to the semantic and qualitative factors already described but, in effect, presuppose those factors in that they use them as channels to communicate the resulting assessment. Internalized value expectations and external circumstances can control the relative effectiveness of intuitive perception processes, but not their existence. This is not a matter of academic hairsplitting: it has direct relevance to communication and conflict management. If we assume that intuitive mechanisms of risk perception and assessment bear practically universal characteristics that can more or less be reshaped by sociocultural influences, then they can provide a fundamental basis for communication of which one can avail oneself regardless of differences between the various standpoints. In addition to the pool of common symbols and rituals (shared meaning), whose importance to social integration is in constant decline in pluralistic societies, a new pool of common mechanisms of risk perception emerges that along with common sense signals the existence of supra-individual perception models.

6.4.3 Concern Assessment Approaches and Methods

Concern assessment methods include the usual repertoire of the social sciences such as survey methods, focus groups, econometric analysis, macro-economic modelling, and structural hearings with stakeholders (Leinfellner and Köhler 2007).

- A *macro-economic model* is a representation of the real world designed to describe the operation of a national or regional economy, and especially the dynamics of aggregate quantities such as the total amount of goods and services produced, total income earned, the level of employment of productive resources, and the level of prices.
- *Econometric analysis* is statistics applied to economics. The analysis combines economic theory and statistical methods. Hence we can refer to Sect. 6.3.3–6.3.5 for some fundamental concepts and principles. See also textbooks in econometrics, for example Davidson and MacKinnon (2004).
- A *survey* is a method of gathering information from a sample of individuals. This sample is usually just a fraction of the population being studied. For example, a sample of persons is questioned how they perceive the risk associated with different types of exposures, for example radiation. Data are usually collected through the use of questionnaires, although sometimes researchers directly interview subjects. The data analysis is based on statistical sample theory (Kish 1995).
- *Focus group* is a form of qualitative research in which a group of people are asked about their attitude towards a product, service, concept, advertisement idea, or packaging – or risk. Questions are asked in an interactive group setting where participants are free to talk with other group members.
- *Structural hearings with stakeholders* can serve a useful purpose if they are meant to give external stakeholder the opportunity to voice their opinions and arguments. Hearings also provide opportunities for stakeholders to understand the position of the regulatory agencies or other direct players (such as industry). Hearings have proven very ineffective, however, for resolving conflicts or pacifying heated debates. Hearings normally aggravate the tone of the conflict and lead to polarizations. Other than for the purpose of investigating the concerns and objections of organized groups, stakeholder hearings should be avoided.

6.4.4 A Practical Example: Assessing Risks Related to Social Concerns

Risk refers in this book to uncertainty about and severity of the consequences (or outcomes) of an activity with respect to something that humans value. The consequences also cover social concerns, and risk assessment approaches and methods can also be used to describe this type of consequences. Let us use an example to illustrate this.

A study is to be performed to describe the consequences (impacts) of a highway project. A number of aspects are covered, including direct and indirect benefits and costs that the project causes for travelers (users) and nonusers affected by the project. Direct benefits and costs are the first order or immediate impacts of the transportation project on users and nonusers, and consist of elements such as changes in travel time, crashes, vehicle operating costs, agency construction costs, and pollution costs, whereas indirect effects relate to for example changes in employment, wages, business sales, or land use.

Let X denote an attribute generated by such effects, for example a cost, or a change in employment, for a specific period of time. Then the concern assessment seeks to predict X (typical using expected values) and assess uncertainties, analogously to the approaches described in previous sections.

The uncertainties could in many cases, in particular for the indirect effects, be very large, and hence the expected value could produce poor predictions. A way of summarizing the risks is to classify the risk contributors according to expected values (the predictions) using a severity (importance) categorization. There are a number of ways of defining such categories – a simple illustrative example partly based on BP (2002) is shown in Table 6.3 below.

This categorization is used together with a probability ranking, for example using four categories as in Table 6.4.

By multiplying the result for these two dimensions, an expected value type of indicator (E) for each attribute is determined. An example is shown in Table 6.5.

Then we need to address uncertainties U in underlying phenomena and processes that can give large deviations compared to the expected values, and establish a modified risk matrix using the two dimensions expected consequences (E) and uncertainties in underlying phenomena and processes, see Fig. 6.8:

In a practical setting, categories of risk may be defined according to for example the following structure:

- Expected value risk calculations according to the ranking of Table 6.5.
- Uncertainties: High, medium, low (for example based on the factors indicated in Sect. 6.3.8, Step 3).
- Overall risk assessment score: Significant positive, moderate positive, significant negative – established based on the dimensions expected value and uncertainties.

This gives a list of risk attributes (costs, employment change, etc.) as illustrated in Table 6.6.

Starting from the classification based on the expected values, we may modify the risk classification based on the uncertainties. For example, if an attribute is classified to have a moderate negative risk according to the expected consequences criterion, we may reclassify it as having significant negative risk score, if the uncertainties in underlying phenomena and processes are very large. To classify the system according to such a scheme a crude analysis is required. However, often

Table 6.3 Consequence categories

Category	Ranking	Definition
Significant positive	+3	–Major beneficial improvement to human health –Large scale benefits to individual livelihoods (e.g. large scale employment) –Major improvements to community facilities/utilities –Notable impact on the wider economy (e.g. extensive use of local supplies)
Modest positive	+2	–Moderate beneficial improvement to human health –Medium benefits to individual livelihoods (e.g. employment impacts) –Modest improvements to community infrastructure/utilities –Moderate impact on the wider economy (e.g. some local sourcing of supplies)
Limited positive	+1	–Some beneficial improvement to human health –Some benefits to individual livelihoods (e.g. additional employment opportunities) –Limited improvements to community facilities/utilities (e.g. no discernable improvement) –Some impact on the wider economy (e.g. limited local procurement)
None	0	–No impact on human health –No impact on livelihoods –No impact on community facilities/utilities –No impact on the wider economy
Limited negative	−1	–Limited impact on human health and well-being (e.g. occasional dust, odours, traffic noise) –Limited impact on the livelihoods of individuals (e.g. isolated incidents related to ethnic tensions and some restrictions on access to income source) –Limited impact on access to community facilities and utilities (e.g. access to cultural centres restricted to a limited extent, i.e. (days)) –Sparse impact on the wider economy, at a local, regional and national level (e.g. limited procurement)
Moderate negative	−2	–Modest impact on human health and well-being (e.g. noise, light, odour, dust, injuries to individuals) –Moderate impact on individual livelihoods (e.g. restricted access to income source) –Medium impact on access to community facilities and utilities (e.g. access to utilities restricted for long periods (weeks) of time) –Moderate impact on the wider economy, at a local, regional and/or national scale (e.g. only moderate levels of employment and supplies sourced within the area) –Potential breach of company social policy and/or legislation
Significant negative	−3	–Emergency situation with harmful consequences to human health (e.g. fatalities) –Disastrous consequences on the livelihoods of individuals (e.g. curtailment of access to primary Income sources) –Calamitous consequences on those seeking to access community facilities and utilities (e.g. resettlement of large numbers (1000s) of households) –Disastrous consequences on the economy (e.g. all employment and supplier sourcing outwith the area) –Breach of company social policy and/or legislation

Table 6.4 Probability categories

Category	Ranking	Definition (%)
Very likely	4	>50
Likely	3	11–49
Unlikely	2	1–10
Very unlikely	1	<1

Table 6.5 Ranking of attributes based on expected values

Ranking (probability × consequence)	Risk score
≥9	Significant positive
≥4, <9	Moderate positive
>0, <4	Limited positive
0	None
<0, >−4	Limited negative
≤−4, >−9	Moderate negative
≤−9	Significant negative

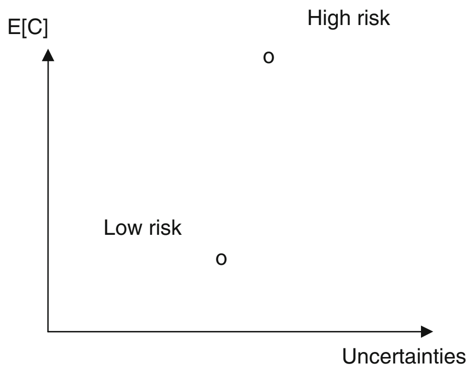


Fig. 6.8 A risk description based on the components expected consequence and uncertainties in underlying phenomena and processes. The o-s represent assessed risks according to this scheme for two different activities

Table 6.6 System for overall risk score

Risk attribute	Risk score based on expected value	Uncertainties	Overall risk score
Pollution costs	Moderate negative	High	Significant negative
Employment change	Limited positive	Moderate	Limited positive

detailed risk analyses have been carried out and these may then provide a basis for the classification. The assessment is based on an integration of different types of consequences, human health, economy etc. It is of course possible to establish procedures as described above for each type of consequence.

Chapter 7
Risk Characterization and Evaluation

7.1 Overview of Characterization and Evaluation

Risk characterization and evaluation aims at making judgement about risk acceptability and/or tolerability. This step follows after the appraisal stage and is undertaken in order to serve two main purposes:

- *First,* to reach a balanced, value-based judgement on the tolerability/acceptability of risk or to perform a trade-off analysis of a set of functional equivalents (of the product, process, or practice under consideration).
- *Second,* to initiate (if deemed necessary) a management process and make preliminary suggestions for the most suitable management approach.

Risk is evaluated in our framework using the analogue of a traffic light (HSE 2001; Bandle 2007). Red signals intolerable, yellow tolerable and green acceptable (see Fig. 7.1). The term "*tolerable*" refers to an activity that is seen as warranted on the grounds of associated benefits, yet which requires additional measures in order to reduce the threat below reasonable limits. The term "*acceptable*" refers to an activity where any residual threat is so low that additional measures for mitigating the threat are not seen as necessary. To draw the line between "intolerable" and "tolerable" as well as "tolerable" and "acceptable" is one of the most difficult tasks in risk governance.

The tolerability or acceptability judgement is informed by the results of the appraisal process (leading to risk characterization) but they do not determine it. Other important considerations on wider social and economic factors may be included in the balancing evaluation process. The main elements of this process are:

- Summarizing the results of the appraisal process in terms of a risk description, which includes the likely consequences for human health, technical systems, ecosystem stability or other relevant endpoints if no management measures were taken, as well as characterizations of uncertainties.
- Deliberation over these results in consideration of wider social and economic factors (e.g. benefits, societal needs, quality of life factors, sustainability,

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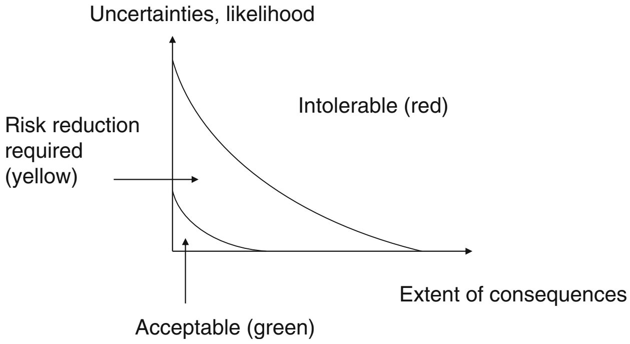

Fig. 7.1 Acceptable, tolerable and intolerable risks (traffic light model)

distribution of risks and benefits, social mobilization and conflict potential, legal requirements and policy imperatives).

- Weighing of pros and cons and trading-off of different (sometimes competing or even conflicting) preferences, interests and values.

While risk characterization compiles scientific evidence based on the results from the risk appraisal phase, risk evaluation assesses broader value-based issues that also influence the judgement. Such issues, which include questions such as the choice of technology, societal needs requiring a given risk agent to be present and the potential for substitution as well as for compensation, reach beyond the risk itself and into the realm of policy-making and societal balancing of risks and benefits.

While appraisal deals with knowledge claims (around what are the causes and what are the effects), evaluation deals with *value claims* (around what is good, acceptable and tolerable). This concept has been criticized as being too simplistic and inadequate for complex risk problems. Indeed, the distinction in non-tolerable (red), tolerable (yellow) and acceptable (green) is quite simple but it reflects the actual need for a judgment at the end of the appraisal and evaluation process. This final closure on the risk allows for only three alternatives: either to do nothing, to ban the risk or to initiate risk-modifying actions. There is no other alternative at this point. This important judgment should be made as transparent as possible to all interested individuals and parties and that the organizations responsible for this judgment have the skills, the assets, the background knowledge and the sensitivity with respect to the corresponding values and socio-cultural preferences to derive at an informed, balanced and fair judgment.

7.2 Risk Characterization

Judgements on acceptability and tolerability rely on two major inputs: values and evidence. What risk level to tolerate or accept can never be derived from looking at the evidence alone. Likewise, evidence is essential if we are to know whether a value has been violated or not (or to what degree).

Hence the traffic light model must be viewed as a way of characterizing risk activities and problems, not as a tool for determining, what is an acceptable/tolerable risk level, and choosing between alternatives. This is an important feature of our risk governance framework. Risk acceptance and tolerability should not be considered a part of the risk assessments. However, in practice it may be attractive to compare the results of the risk quantification with some defined limits, expressing what is considered as typical high or low numbers. Table 7.1 shows some typical limits for individual risk (Trbojevic 2005).

Thus there is an upper probability limit of 1:1,000 for individual yearly risk for workers. This means that the probability that a specific person shall be killed during 1 year should not exceed 1:1,000. Such a limit is recommended by for example HSE (2001).

Also for large scale societal risk, reference values have been established. HSE (2001) refers to an upper probability limit of 1:5,000 (2×10^{-4}) for an accident occurring causing the death of 50 people or more in a single event. For this type of events, risk is often expressed by F–N-curves, showing the expected number (frequency) of accidents with at least N fatalities, see example in Fig. 7.2. From the figure we can read that there is a frequency of about 1×10^{-4} for events causing at least 10 fatalities. For some examples of F–N-curves used in practice, see e.g. Ale (2005) and Floyd and Ball (2000).

Table 7.1 Typical limits for individual risk (Trbojevic 2005)

Probability	Judgment about individual risk
10^{-3}	Intolerable limit of workers
10^{-4}	Intolerable limit for members of the public
10^{-5}	May be considered as tolerable for members of the public
10^{-6}	Broadly acceptable level of risk
10^{-7}	Negligible level of risk

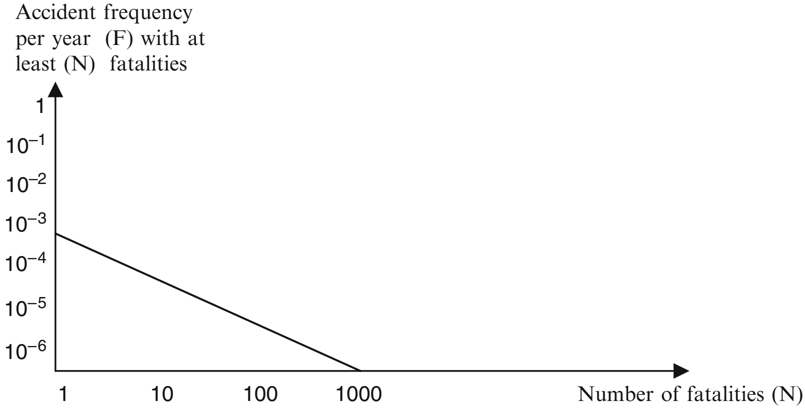

Fig. 7.2 Example of an F–N-curve

Similar type of reference values can be established for other areas, for example environmental risks.

Another type of criterion or reference value is the so-called German MEM (Minimum Endogenous Mortality) principle (Beugin et al. 2007). This principle refers to a basic risk, and makes the point that any new activity must not produce an additional risk that is significant compared to the basic risk. For a member of the public the MEM-principle means that an additional individual risk of 10^{-5} or higher per year is unacceptable. This number is based on a reference to the age group with the lowest technologically caused death rate, the group of 5–15 year olds. For this group, a technologically caused mortality rate of 2×10^{-4} fatalities per person and year is computed (in Germany), and if we consider an increase of more than 5% to be "significant", we obtain the limit 10^{-5}.

We would also like to mention the French GAME (*Globalement Au Moins Équivalent*: globally at least equivalent) principle, which requires that new systems fulfil the same safety requirements as those attained by an equivalent existing system (Beugin et al. 2007).

For safety systems, like a train's emergency braking system, it is also common to specify quantitative probability requirements. A special requirement structure for such systems is established using the so-called Safety Integrity Level (SIL) concept (IEC 2000:61508; Beugin et al. 2007). Four SILs are defined, depending on the criticality of the safety system. For level four, the probability of failure of demand per activation is between 10^{-5} and 10^{-4}, for level three between 10^{-4} and 10^{-3}, for level two between 10^{-3} and 10^{-2} and for level one between 10^{-2} and 10^{-1}.

Limits and criteria as above are useful as a reference for determining what constitutes an acceptable risk level. We will discuss their use in more detail in Sect. 7.5.

All these criteria relate to the safety concern in isolation, but it is also common to use reference values based on cost-effectiveness, where quantities like the expected cost per expected saved number of lives, are calculated. If a measure costs two million euros and the risk assessment shows that the measure will bring about a reduction in the number of expected fatalities by 0.1, then the cost–benefit-ratio would be $2/0.1 = 20$ million euros. This quantity is often referred to as "the implied value of a statistical life" or the implied cost of averting a fatality (ICAF) (Sect. 3.3). By comparing this number with reference values, we can express the effectiveness of the measure. This type of ratio (index) can also be calculated in relation to quantities other than life, e.g. a tonne of spilled oil. Empirical studies show great differences when it comes to the value of an implied statistical life.

This raises the question about what the value of a statistical life should be, i.e. the maximum amount the society (or the decision maker) should be willing to pay for reducing the expected number of fatalities by 1. Typical numbers for the value of statistical life used in cost–benefit analysis are 1–10 million euros, as noted in Sect. 3.3. The Department of Finance in Norway has arrived at a value of approximately two million euros – for official cost–benefit analyses, a value of this order of magnitude is recommended. Similar numbers are used in other western world countries.

An oil company uses the following guideline values of a statistical life (Aven 2008a).

Cost to avert a statistical life (Euros)

0	Highly effective, always implement
100 00	Effective, always implement
0.1 mill	Effective; implement unless individual risk is negligible
1 mill	Consider effective if individual risk levels are high
10 mill	Consider if individual risk levels are very high and/or if there are other highly appreciated benefits
100 mill	Not socially effective – look at other options

Such criteria are often used in ALARP processes. The ALARP principle expresses that the risk should be reduced to a level that is as low as reasonably practicable. The ALARP principle implies what could be referred to as the principle of "reversed onus of proof". This implies that the base case is that all identified risk reduction measures should be implemented, unless it can be demonstrated that there is gross disproportion between costs and benefits. To verify ALARP, procedures mainly based on engineering judgments and codes are used, but also traditional cost–benefit analyses and cost effectiveness analyses. When using such analyses, guidance values as above are often used, to specify what values that define "gross disproportion".

Conclusions are often self-evident when computing indices such as the expected cost per expected life saved. For example, a strategy may be that measures will be implemented if the expected cost per expected life saved is less than 10 million euros.

A measure that has expected net positive present value should be implemented immediately. Crude computations of the expected net present value, where one leaves out difficult assessments related to the value of loss of life and damage to the environment, will often be sufficient for concluding to what extent this criterion can justify the implementation of a measure.

A potential strategy for the assessment of a measure, if the analysis based on expected net present value or expected cost per expected number of lives saved has not produced any clear recommendation, can be that the measure be implemented if several of the following questions give a yes – answer (Aven and Vinnem 2007):

- A relatively high personnel risk or environmental risk?
- Considerable uncertainty (related to phenomena, consequences, conditions) and that the measure will reduce the uncertainties?
- The measure greatly increases manageability? High competence among the personnel can give increased assurance that satisfactory outcomes will be reached, for example, fewer leakages
- Is the solution robust in terms of safety?
- Is the best available technology utilized (BAT)?
- Are the unsolved problem areas personal safety-related and/or work environment-related? Are there possible areas where there is conflict between these two aspects?
- Strategic considerations?

What risk level to tolerate or to accept cannot be derived directly from looking at the computed numbers in isolation. Risk characterization is more than the computed probabilities and expected values. In general risk characterization determines the evidence-based component for making the necessary judgement on the risk tolerability and/or acceptability. It includes (Chap. 6):

- Expressed risk using probabilities and expected values, together with the background knowledge (assumptions and models)
- Descriptions of uncertainties in underlying phenomena and processes
- Potential outcome scenarios including the social and economic implications
- Assurance of compatibility with legal prescriptions
- Risk–risk comparisons and risk–risk trade-offs (how is risk in one area affected by changes in another area)
- Identification of discrepancies between risk assessment and risk perceptions as well as of potential equity violations

The evidence collected and summarized here goes beyond the classic technical reservoir of knowledge and includes economic and social science expertise. This is also the reason why in the process of risk characterization an interdisciplinary team of scientists is needed to draw a complete picture of what is known and what is and may remain unknown. In the course of risk characterization, scientists are asked to produce a multidimensional risk picture, make a judgement about the seriousness of the risk and suggest potential measures to handle the risk.

7.3 Risk Evaluation

The risk evaluation broadens the picture to include aspects such as choice of technology, social need for the specific risk agent (substitution possible?), risk–benefit balances, political priorities, potential for conflict resolution and social mobilization potential. The main objective here is to arrive at a judgement on tolerability and acceptability based on balancing pros and cons, testing potential impacts on quality of life, discussing different development options for the economy and society and weighing the competing arguments and evidence claims in a balanced manner. It should be noted that this elaborate procedure is only necessary if tolerability and/or acceptability is disputed and if society faces major dissents and conflicts among important stakeholders. If so, the direct involvement of stakeholders and the public will be a prerequisite for successful risk governance.

The separation of evidence and values underlying the distinction between characterization and evaluation is, of course, functional and not necessarily organizational. Since risk characterization and evaluation are closely linked and each depends on the other, it may even be wise to perform these two steps simultaneously in a joint effort by both assessors and risk managers. As some analysts have pointed out (Löfstedt and Vogel 2001; Vogel 2003): the US regulatory system tends to favor an organizational combination of characterization and evaluation, while

European risk managers tend to maintain the organizational separation (particularly in the food area). We take no stance in this question: there are good reasons for both systems, yet we do insist on a functional distinction.

The distinction between the three risk problem categories, i.e. complexity, uncertainty and ambiguity, can also assist assessors and managers in assigning, or dividing, the judgement task. If a risk problem is characterized by low uncertainties and hardly any ambiguities, it is wise to let the assessment team dominate the process of making tolerability/acceptability judgements. If, in contrast, the risk is characterized by major unresolved uncertainties and if the results lead to highly

Table 7.2 Summary of steps in risk characterization and evaluation

Risk characterization and evaluation	Definition	Indicators (tools, aspects to consider)
1. Risk characterization	Collecting and summarizing all relevant evidence necessary for making an informed choice on tolerability or acceptability of the risk in question and suggesting potential options and measures for risk handling	
	(a) Risk profile	• Quantified risk – Assigned probabilities and expected values – Prediction intervals, credibility intervals, confidence intervals – Uncertainty distributions • Uncertainty factors, risk influencing factors • Hazard and threat characteristics • Range of "legitimate" interpretations • Risk perceptions • Social and economic implications • Background knowledge (assumptions, models)
	(b) Judging the seriousness of risk	• Compatibility with legal requirements • Risk–risk trade-offs • Effects on equity • Public acceptance
	(c) Conclusions, options and measures	Suggestions for: • Tolerable and acceptable risk levels • Options and measures for risk handling
2. Risk evaluation	Applying societal values and norms to the judgement on tolerability and acceptability and, consequently, determining the need for risk reduction measures	• Choice of technology • Potential for substitution • Risk–benefit comparison • Political priorities • Compensation potential • Conflict management • Potential for social • Mobilization

diverse interpretations of what they mean for society, it is advisable to let risk managers take the lead.

Table 7.2 summarises the risk characterization and the risk evaluation steps which, in conclusion, are closely interrelated and may be merged if the circumstances require it. The list of indicators (tools, aspects to consider) represents only a small selection of potential dimensions and is displayed here for illustrative purposes.

In some industries it is common to use pre-defined criteria and limits for making judgment about acceptability/tolerability of risk. If the calculate risk is exceeding the limit, risk is not tolerable or acceptable, and measures need to be implemented or the activity cannot be carried out. Following such a regime, risk evaluation may be seen as a part of the risk characterization. Care has however to be shown by using this type of formal criteria, as

- Such criteria alone do not capture all the aspects of risk, costs, and benefits.
- No assessment method has a precision that corresponds to a mechanical process based on whether the result is over or below a numerical value.
- It is a managerial responsibility to give weight to risk and uncertainties, and balance different concerns.

We will discuss the use of such criteria and limits in more detail in Sect. 7.5.

7.4 Cases

As already mentioned, judgements on acceptability and tolerability rely on two major inputs: values and evidence. What risk level to tolerate or accept can never be derived from looking at the evidence alone. With respect to values and evidence we can distinguish three cases (1) ambiguity on evidence but not on values (interpretative ambiguity), (2) ambiguity on values but not on evidence (normative ambiguity) and (3) ambiguities on values and evidence.

Case 1: Interpretative ambiguity: This case covers situations where the relevance, meaning and implications of the basis for the decision making are subject to discussion, but where the underlying values are not disputed. An example is electromagnetic radiation; is the radiation to be considered an adverse effect or is the intensified neuronal activities in the human brain when subjects are exposed to electromagnetic radiation just a bodily response without any health implication? In this case a broad risk description and characterization should be produced as a part of the risk appraisal, highlighting the relevant knowledge and lack of knowledge, in line with the principles presented in Chap. 6. Based on this characterization the experts in risk and concern assessments state their recommendations about acceptability and tolerability, and suggest measures for risk reduction. It is, however, not the task of the risk appraisal team to make a selection of measures, let alone decide on which measure should be implemented.

Case 2: Normative ambiguity: This case covers situations where the underlying values of what could be considered as tolerable or acceptable are disputed, while the evidence of what is at stake is clearly given and non-controversial. A good example may be the normative implications of risks related to smoking. Science is very familiar with these risks and there is little uncertainty and interpretative ambiguity about dose–effect relationships. Yet there is considerable debate whether smoking is tolerable or not. Being a voluntary activity some countries leave it to the decision of each consumer while others initiate major activities to reduce and even ban smoking. Another example is wearing helmets on bicycles. The statistical data on this subject is rather strong; there are no major uncertainties or interpretative ambiguities. Yet many countries do want to impinge on the freedom of each cyclist to personally decide whether or not to wear a helmet, while other countries pursue a more paternalistic policy.

As a specific industrial example, consider an oil company that has two undersea pipelines supplying an important customer with natural gas. The gas is recovered at two different processing facilities and fed into the two pipelines. En route, the pressure drops to a level where it is considerably lower at the delivery end. The delivery takes place at two different sites located at a considerable distance from each other. The company is of the opinion that if it installs a plant for gas pressure boosting (pumping station) between the processing facility and the delivery site, it will be able to deliver more gas through the pipeline. The company is evaluating various alternative solutions for pressure boosting:

- Two separate installations – one for each pipeline
- A single installation for compressing the gas. This solution means that the single pipeline must be re-routed over several kilometres

The first alternative is expensive. The second alternative is significantly less expensive. The various alternatives are assessed and compared in a risk assessment. The conclusion of the assessment is that the risks for both personnel and the environment are lowest in the single installation solution.

The management then evaluates the risks, based on the risk characterization. Presently there are no likely events that could simultaneously stop delivery in both pipelines in that all the processing facilities, pipelines, and delivery sites are separate. The company does not wish to increase its vulnerability by setting up a common point for these two independent systems. In the case of an event at the installation proposed in alternative 2, this could have an impact on the entire gas supply to the customer. For this reason, alternative 2 is rejected – it represents an intolerable risk.

Case 3: Interpretative and normative ambiguity: A third case arises where both the evidence and the values are disputed. A good example for this case is the interpretative and normative implications of global climate change. The international expert group Intergovernmental Panel on Climate Change (IPCC) has gone through considerable effort to articulate a common characterization of climatic risks and their uncertainties. Given the remaining uncertainties and the complexities of the causal relationships between greenhouse gases and climate change, it is then a question of values whether governments place their priorities on prevention or on mitigation (Keeney and McDaniels 2001).

From the risk characterization of the IPCC Fourth Assessment Report, Climate Change 2007, we give some examples of typical statements:

- Warming of the climate system is unequivocal, as is now evident from observations of increases in global average air and ocean temperatures, widespread melting of snow and ice, and rising global average sea level.
- Rising sea level is consistent with warming. Global average sea level has risen since 1961 at an average rate of 1.8 (1.3–2.3) mm/year and since 1993 at 3.1 (2.4–3.8) mm/year, with contributions from thermal expansion, melting glaciers and ice caps, and the polar ice sheets. Whether the faster rate for 1993 to 2003 reflects decadal variation or an increase in the longer-term trend is unclear.
- Observational evidence from all continents and most oceans shows that many natural systems are being affected by regional climate changes, particularly temperature increases.
- There is *medium confidence* that other effects of regional climate change on natural and human environments are emerging, although many are difficult to discern due to adaptation and non-climatic drivers.
- Global GHG (greenhouse gases) emissions due to human activities have grown since pre-industrial times, with an increase of 70% between 1970 and 2004.
- Global atmospheric concentrations of CO_2, methane (CH_4) and nitrous oxide (N_2O) have increased markedly as a result of human activities since 1750 and now far exceed pre-industrial values determined from ice cores spanning many thousands of years.
- There is *very high confidence* that the net effect of human activities since 1750 has been one of warming.
- Most of the observed increase in globally-averaged temperatures since the mid-twentieth century is *very likely* due to the observed increase in anthropogenic GHG concentrations. It is *likely* there has been significant anthropogenic warming over the past 50 years averaged over each continent (except Antarctica).
- Human influences have:
  - *Very likely* contributed to sea level rise during the latter half of the twentieth century.
  - *Likely* contributed to changes in wind patterns, affecting extra-tropical storm tracks and temperature patterns.
  - *Likely* increased temperatures of extreme hot nights, cold nights and cold days.
  - *More likely than not* increased risk of heat waves, area affected by drought since the 1970s and frequency of heavy precipitation events.
- Continued GHG emissions at or above current rates would cause further warming and induce many changes in the global climate system during the twenty-first century that would *very likely* be larger than those observed during the twentieth century.
- There is now higher confidence than in the Third Assessment Report (TAR) in projected patterns of warming and other regional-scale features, including changes in wind patterns, precipitation, and some aspects of extremes and sea ice.
- Climate change is *likely* to lead to some irreversible impacts. There is *medium confidence* that approximately 20–30% of species assessed so far are *likely* to be

at increased risk of extinction if increases in global average warming exceed 1.5–2.5°C (relative to 1980–1999). As global average temperature increase exceeds about 3.5°C, model projections suggest significant extinctions (40–70% of species assessed) around the globe.

- A wide array of adaptation options is available, but more extensive adaptation than is currently occurring is required to reduce vulnerability to climate change. There are barriers, limits and costs, which are not fully understood.
- Both bottom-up and top-down studies indicate that there is *high agreement* and *much evidence* of substantial economic potential for the mitigation of global GHG emissions over the coming decades that could offset the projected growth of global emissions or reduce emissions below current levels.
- A wide variety of policies and instruments are available to governments to create incentives for mitigation action. Their applicability depends on national circumstances and sectoral context.

This risk characterization provides a basis for risk evaluations carried out by political parties and governments in different countries, as well as international organizations. Most parties judge the present level of GHG emissions to be intolerable, and formulate targets of x per cent cut from current levels by year y, to obtain a tolerable level.

7.5 Pre-defined Risk Tolerability Limits and ALARP

To manage risk, it is common to use a hierarchy of goals, criteria and requirements, such as:

- Overall goals, for example "our goal is to have no accidents".
- Tolerability limits and risk acceptance criteria (defined as upper limits of tolerable/acceptable risk), controlling the accident risk, for example "the individual probability of being killed in an accident shall not exceed 0.1%".
- Requirements related to the performance of safety systems and barriers, such as a reliability requirement for a safety system.
- Requirements related to the specific design and operation of a component or subsystem, for example the gas detection system.

According to the standard procedures for using such goals, criteria and requirements, they are to be specified before alternatives are generated and subsequently analysed. The point is to look for what to obtain before looking for possible ways of implementation. For example, the Norwegian offshore petroleum regulations state that risk acceptance criteria (expressed as upper limits of acceptable risk) should be developed, and before the risk assessments are carried out (PSA 2001; Aven and Vinnem 2007). These criteria have to be interpreted as tolerability limits using the terminology in this book.

Are such pre-defined limits and criteria appropriate for managing risk? We conclude that for problems with large uncertainties about the phenomena and processes studied it is not meaningful to use such limits and criteria as the precision level is poor. However, it is also questionable to use such criteria in case of large ambiguities, where there is no discussion about the risk picture as such.

Consider the following criterion established for an offshore petroleum activity: *The probability of getting an oil spill during 1 year of operation causing an environmental damage having a restitution period of more than z years, should not exceed* 1×10^{-x}.

At the political level it is obvious that it would not be possible to establish consensus about such a limit. Different parties would have different preferences. But for the Government it should be possible to establish such a number? Say that it would make an attempt to do this. And suppose that it considers two options, a weak limit, say 1×10^{-3} and a strong limit say 1×10^{-4}. What limit should it choose? The answer would be the weak limit, as the strong limit could mean lack of flexibility in choosing the overall best solution. If the benefits are sufficient large, the level 1×10^{-3} could be tolerable. Following this line of arguments, the use of such limits would lead to the formulation of weak limits, which are met in most situations. Risk assessment methods are then used to verify that risks are tolerable in relation to these weak limits. It is to large extent waste of resources and money, the conclusions are obvious.

At the operational level, the same type of arguments will apply. The oil company is to determine a criterion, and it faces the same type of dilemmas as above. Why should it specify strong limits? It would restrict the company from obtaining the overall best solutions. The result is that weak limits are specified and risk assessments play the role of verification, a role that adds not much value.

Similar arguments apply for personnel risk. Consider for example the individual risk limit for workers of 1:1,000. This limit rarely bites (HSE 2001). Hazards that give rise to such levels of individual risks also give rise to societal concerns and the latter often play a far greater role in deciding whether the risk is unacceptable or not. In practice most industries in the western world do much better than that. Specifying such limits and using risk assessment to verify that the risk is tolerable is therefore not contributing much to risk reduction. If a low risk level is sought, other mechanisms need to be implemented than risk tolerability limits. If such limits are established, they give a focus on obtaining minimum standards, instead of continuous improvement and risk reduction.

The ALARP principle represents such a mechanism. According to this principle a risk reducing measure should be implemented provided it cannot be demonstrated that the costs are grossly disproportionate relative to the gains obtained (HSE 2001). One way of determining what is meant by "gross disproportion" is sketched out below (Aven and Vinnem 2005, 2007), see also Sect. 7.2:

(a) Perform a crude assessment of the benefits and burdens of the various alternatives addressing attributes related to feasibility, conformance with good practice, economy, strategy considerations, risk, social responsibility, etc. The assessment would typically be qualitative and its conclusions summarized in a matrix with performance shown by a simple categorization system such as Very positive, Positive, Neutral, Negative, Very negative. From this crude assessment a decision can be made to eliminate some alternatives and include new ones, for further detailing and assessment. Frequently, such crude assessments give the necessary basis for choosing one appropriate alternative.

(b) When considering a set of possible risk reducing measures, a qualitative assessment evaluation in many cases provides a sufficient basis for identifying which measures to implement, as these measures are in accordance with good engineering or with good operational practice. Also many measures can quickly be eliminated as the qualitative analysis reveals that the burdens are much more dominant than the benefits.

(c) From this crude analysis the need for further analyses is determined, to give a better basis for concluding on which alternative(s) to choose. This may include various types of risk assessments.

(d) Other types of assessments may be conducted to analyze for example costs, and indices such as expected cost per expected number of saved lives could be computed to provide information about the effectiveness of a risk reducing measure or compare various alternatives. The expected Net Present Value may also be computed when found appropriate. Sensitivity analyses should be performed to see the effects of varying values for statistical lives and other key parameters.

(e) If conclusion about gross disproportion is not clear, then these measures and alternatives are clear candidates for implementation. Clearly, if a risk reducing measure has a positive expected net present value it should be implemented. Crude calculations of expected net present values, ignoring difficult judgments about valuation of possible loss of lives and damage to the environment, will often be sufficient to conclude whether this criterion could justify the implementation of a measure.

(f) Assessment of uncertainties in the underlying phenomena and processes is carried out. Which factors can yield unexpected outcomes with respect to the probabilities and expected values calculated? Where are the gaps in knowledge? What critical assumptions have been made? Are there areas where there is great disagreement among experts? What are the vulnerabilities in the systems?

(g) An analysis and assessment of manageability takes place. To what extent is it possible to control and reduce the uncertainties and thereby arrive at the desired outcome? Some risks are more manageable than others in the sense that there is a greater potential to reduce risk. An alternative can have a relatively large calculated risk under certain circumstances, but the manageability could be good and could result in a far better outcome than expected.

(h) An assessment of other factors such as risk perception and reputation should be carried out whenever relevant, although it may be difficult to describe how these factors would affect the standard indices used in economy and risk assessments to measure performance.

(i) A total evaluation of the results of the assessments should be performed, to summarize the pros and cons for the various alternatives, where considerations of the constraints and limitations of the assessments are also taken into account.

Note that such assessments are not necessarily limited to the ALARP processes. The above points can be used in other contexts where decisions are to be made under uncertainty.

The application of the ALARP principle is often combined with tolerability limits and acceptability limits. Between the tolerability limit and the acceptability limit the ALARP principle applies. In most cases in practice the risks will be in the ALARP region, but risk assessment often focus on verifying the tolerability limits, as discussed above. This is unfortunate if risk reduction is a main goal of the risk management.

Chapter 8
Risk Management

8.1 Objectives of Risk Management

Risk management starts with a review of all relevant information, particularly from combined risk appraisal, consisting of both risk assessment and concern assessment where the latter is based on risk perception studies, economic impact assessments and the scientific characterization of social responses to the risk source. This information, together with the judgements made in the phase of risk characterization and evaluation, form the input material upon which risk management options are being assessed, evaluated and selected. At the outset, risk management is presented with three potential outcomes:

- *Intolerable situation:* either the risk source (such as a technology or a chemical) needs to be abandoned or replaced, or, in cases where that is not possible (e.g. natural hazards), vulnerabilities need to be reduced and exposure restricted.
- *Tolerable situation:* the risks need to be reduced or handled in some other way within the limits of reasonable resource investments (ALARP, including best practice). This can be done by private actors (such as corporate risk managers) or public actors (such as regulatory agencies) or both (public–private partnerships).
- *Acceptable situation:* the risks are so small – perhaps even regarded as negligible – that any risk reduction effort is unnecessary. However, risk-sharing via insurance and/or further risk reduction on a voluntary basis present options for action that can be worthwhile pursuing even in the case of an acceptable risk.

With regard to these outcomes, risk managers may either face a situation of unanimity (i.e. all relevant actors agree with how a given risk situation should be qualified) or a situation of conflict in which major actors challenge the classification undertaken by others. The degree of controversy is one of the drivers for selecting the appropriate instruments for risk prevention or risk reduction.

For a systematic analysis of the risk management process, it is advisable to focus on tolerable risks and those where tolerability is disputed; the other cases are fairly easy to deal with. In the case of intolerable risks – and often in the case of tolerable

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but highly disputed risks – risk managers should opt for prevention strategies as a means of replacing the hazardous activity with another activity, leading to identical and similar benefits. One should first make sure, however, that the replacement does not introduce more risks or more uncertainties than the agent it replaces (Wiener 1998). In the case of acceptable risks, it should be left to private actors to initiate additional risk reduction or to seek insurance for covering potential but acceptable losses (although this does not eliminate the need for all concerned to have sufficient information and resources to do so). If risks are classified as tolerable, or if there is dispute as to whether they are tolerable or acceptable, risk management needs to design and implement actions that make these risks acceptable over time. Should this not be feasible, then risk management, aided by communication, needs at least to credibly convey the message that major effort is undertaken to bring these risks closer to being acceptable. This task can be described in terms of classic decision theory (Hammond et al. 1999; Morgan 1990; Keeney 1992; Aven and Vinnem 2007:49 ff.). The main steps are described in the following section (See also Table 8.1).

8.2 Steps of Risk Management

8.2.1 Identification and Generation of Risk Management Options

Generic risk management options include risk avoidance, risk reduction, risk transfer and – also an option to take into account – self-retention. While avoiding risk means either selecting a path that does not touch on the risk (e.g. by abandoning the development of a specific technology) or taking action in order to fully eliminate the risk, risk transfer deals with ways of passing the risk on to a third party. Self-retention as a management option essentially means taking an informed decision to do nothing about the risk and to take full responsibility both for the decision and any consequences occurring thereafter. Risk management by means of risk reduction can be accomplished by many different means:

- *Technical standards and limits* that prescribe the permissible threshold of concentrations, emissions, take-up or other measures of exposure
- *Performance standards* for technological and chemical processes, such as minimum temperatures in waste incinerators
- *Technical prescriptions* referring to the blockage of exposure (e.g. via protective clothing) or the improvement of resilience (e.g. via immunization or earthquake-tolerant constructions)
- *Governmental economic incentives*, including taxation, duties, subsidies and certification schemes
- *Third-party incentives* (i.e. private monetary or in-kind incentives)
- *Compensation schemes* (monetary or in kind)

- *Insurance and liability*
- *Co-operative and informative optio*ns, ranging from voluntary agreements to labelling and education programs

All of these options can be used individually or in combination in order to accomplish even more effective risk reduction. Options for risk reduction can be initiated by private and public actors or both together. One way of implementing the risk reduction is to apply the ALARP-principle, expressing that risk should be reduced to a level that is as low as reasonably practicable (See Sects. 7.2 and 7.5). The ALARP principle is based on "reversed burden of proof", which means that an identified measure, should be implemented unless it cannot be documented that there is an unreasonable disparity ("gross disproportion") between costs/disadvantages and benefits. Cost–benefit analyses are often used to support the decision on gross disproportion. An approach of judging what is in "gross disproportion" is presented in Sect. 7.5.

ALARP assessments require that appropriate measures be generated. As a rule, in a risk assessment context, suggestions for measures always arise, but often a systematic approach for the generation of these is lacking, and in many cases, the measures often lack ambitions. They bring about only small changes in the risk picture. A possible way to approach this problem is to apply the following principles:

- On the basis of existing solutions (base case), identify measures that can reduce the risk by, for example, 10, 50, and 90%.
- Specify solutions and measures that can contribute to reaching these levels.

The solutions and measures must then be assessed prior to making a decision on possible implementation. Although expressed by numbers, the assessments need not express risk on a precise scale. The important point here is to generate measures with a certain magnitude of risk reducing effect.

8.2.2 Assessment of Risk Management Options with Respect to Predefined Criteria

Each of the options will have desired and unintended consequences which relate to the risks that they are supposed to reduce. In most instances, an assessment should be conducted according to the following criteria:

- *Effectiveness:* does the option achieve the desired effect?
- *Efficiency:* does the option achieve the desired effect with the least resource consumption?
- *Minimization of external side effects:* does the option infringe upon other valuable goods, benefits or services, such as competitiveness, public health, environmental quality, social cohesion, etc.? Does it impair the efficiency and acceptance of the governance system itself?

- *Sustainability:* does the option contribute to the overall goal of sustainability? Does it assist in sustaining vital ecological functions, economic prosperity and social cohesion?
- *Fairness:* does the option burden the subjects of regulation in a fair and equitable manner?
- *Political and legal implementation:* is the option compatible with legal requirements and political programmes?
- *Ethical acceptability:* is the option morally acceptable?
- *Public acceptance:* will the option be accepted by those individuals who are affected by it? Are there cultural preferences or symbolic connotations that have a strong influence on how the risks are perceived?

Measuring management options against these criteria may create conflicting messages and results. Many measures that prove to be effective may turn out to be inefficient or unfair to those who will be burdened. Other measures may be sustainable, but not accepted, by the public or important stakeholders. These problems are aggravated when dealing with global risks. What appears to be efficient in one country may not work at all in another country. To support the risk trade-offs and the decision process, a number of tools are available for the risk managers (see Table 8.2 and Sect. 8.5).

8.2.3 Evaluation of Risk Management Options

Similar to risk evaluation, this step integrates the available evidence on how the options perform in terms of the evaluation criteria with a value judgement about the relative weight that each criterion should be assigned. Ideally, the evidence should come from experts and the relative weights from politically legitimate decision-makers. In practical risk management, the evaluation of options is conducted in close cooperation between experts and decision-makers. As pointed out later, this is the step where direct stakeholder involvement and public participation are particularly important, and it is therefore best ensured by making use of a variety of methods (Rowe and Frewer 2000; Renn et al. 2002).

8.2.4 Selection of Risk Management Options

Once the different options are evaluated, a decision has to be made as to which options are selected and which rejected. This decision is obvious if one or more options turn out to be dominant (relatively better on all criteria). Otherwise, trade-offs have to be made that require legitimization (Graham and Weiner 1995). A legitimate decision can be made on the basis of formal balancing tools (such as cost–benefit or multi-criteria decision analysis), by the respective decision-makers (given that their decisions are informed by a holistic view of the problem) or in conjunction with participatory procedures.

8.2.5 Implementation of Risk Management Options

It is the task of risk management to oversee and control the implementation process. In many instances, implementation is delegated (e.g. when governments take decisions but leave their implementation to other public or private bodies or to the general public). However, the risk management team has, at any rate, the implicit mandate to supervise the implementation process or at least to monitor its outcome.

8.2.6 Monitoring of Option Performance

The last step refers to the systematic observation of the effects of the options once they are implemented. The monitoring system should be designed to assess intended, as well as unintended, consequences. Often, a formal policy assessment study is issued in order to explore the consequences of a given set of risk management measures on different elements of what people value. In addition to generating feedback on the effectiveness of the options, the monitoring phase should also provide new information on early warning signals for both new risks and old risks viewed from a fresh perspective. It is advisable to have the institutions performing the risk and concern assessments participate in the monitoring and supervision so that their analytic skills and experience can evaluate the performance of the selected management options.

These steps follow a logical sequence but can be arranged in different orders depending upon both situation and circumstance. It might be helpful to visualize the steps not as a linear progression, but as a circle forming an iterative process in which reassessment phases are intertwined with emerging options, arising crises or new demands placed on risk managers. Similarly, occasionally the assessment of different options requires new options to be created in order to achieve desired results. In other cases, the monitoring of existing rules affects the decision to add new criteria to the portfolio. Rarely do issues for risk appraisal and management follow the sequence used for the process described in this chapter. Option generation, information processing and options selection should, indeed, be seen as a dynamic process with many iterative loops.

Table 8.1 summarizes the steps of risk management in accordance with the basic model used by decision theory. The list of indicators represents the most frequently employed heuristic rules for selecting input and for measuring performance.

Table 8.1 Generic components of risk management (adapted from IRGC 2005:44)

Management components	Definition	Indicators
1. Option generation	Identification of potential risk-handling options, particularly risk reduction (i.e. prevention, adaptation and mitigation, as well as risk avoidance, transfer and retention)	• Standards • Performance rules • Restrictions on exposure or vulnerability • Economic incentives • Compensation • Insurance and liability • Voluntary agreements • Labels • Information/education
2. Option assessment	Investigations of the impacts of each option (economic, technical, social, political, and cultural)	• Effectiveness • Efficiency • Minimization of side effects • Sustainability • Fairness • Legal and political implementation • Ethical acceptability • Public acceptance
3. Option evaluation and selection	Evaluation of options (multi-criteria analysis)	• Assignment of trade-offs • Incorporation of stakeholders and the public
4. Option implementation	Realization of the most preferred option	• Accountability • Consistency • Effectiveness
5. Monitoring and feedback	Observation of the effects of implementation (link to early warning) *Ex-post* evaluation	• Intended impacts • Non-intentional impacts • Policy impacts

8.3 Risk-Management Strategies Based on Risk Characteristics

Making again use of the distinction between complexity, uncertainty and ambiguity, it is possible to design generic strategies of risk management to be applied to risk classes, thus simplifying the risk management process outlined above. We distinguish between four such classes:

8.3.1 Linear (Routine) Risk Problems

This class of risk problems requires hardly any deviation from traditional decision-making. Data are provided by statistical analysis, goals are determined by law or statutory requirements, and the role of risk management is to ensure that all risk reduction measures are implemented and enforced. Traditional risk–risk comparisons (or risk–risk trade-offs), cost–benefit analysis and cost-effectiveness studies are the instruments of choice for finding the most appropriate risk reduction measures. Additionally, risk managers can rely upon best practice and, in cases of low impact, upon trial and error. It should be noted, however, that simple risks should not be equated with small or negligible risks. The major issues here are that the potential negative consequences are obvious, the values that are applied are non-controversial and the remaining uncertainties low. Examples are car accidents, known food and health risks, regularly recurring natural disasters or safety devices for high buildings.

8.3.2 Complex Risk Problems

For this risk class, major input for risk management is provided by the scientific characterization of the risk. Complex risk problems are often associated with major scientific dissent about complex dose–effect relationships or the alleged effectiveness of measures to decrease vulnerability (complexity refers to both the risk agent and its causal connections, and the risk-absorbing system and its vulnerabilities). The objective for resolving complexity is to receive a complete and balanced set of risk and concern assessment results that fall within the legitimate range of plural truth claims.

In a situation where there are no complete data, the major challenge is to define the factual base for making risk management or risk regulatory decisions. The main emphasis is on improving the reliability and validity of the results that are produced in the risk appraisal phase. Risk and concern assessors, as well as managers, need to make sure that all relevant knowledge claims are selected, processed and evaluated. They may not get a single answer; but they might be able to get a better overview of the issues of scientific controversy. If these efforts lead to an acknowledgement of wide margins of uncertainty, the management tools of the uncertainty strategy should be applied. If input variables to decision-making can be properly defined and affirmed, risk characterization and evaluation can be done on the basis of risk–benefit balancing and normative standard-setting (*risk-based/risk-informed regulation*). Traditional methods such as risk–risk comparison, cost-effectiveness and cost–benefit analysis are also well suited to facilitate the overall judgement for placing the risk in the traffic-light model (acceptable, tolerable or intolerable). These instruments, if properly used, provide effective, efficient and fair solutions with regard to finding the best trade-off between opportunities and risks. The choice of instruments includes all of the classic options outlined in the previous section (see also Table 8.2).

It is, however, prudent to distinguish between *management strategies for handling the risk agent* (such as a chemical or a technology) and *those needed for the risk absorbing system* (such as a building, an organism, or an ecosystem). Addressing complex structures of risk agents requires methods for improving causal modelling and data-quality control. With respect to risk-absorbing systems, the emphasis is on the improvement of *robustness* in responding to whatever the target is exposed to. Measures to improve robustness include inserting conservatisms or safety factors as an assurance against individual variation (normally a factor of 10–100 for occupational risk exposure and of 100–1,000 for public risk exposure); introducing redundant and diverse safety devices to improve structures against multiple stress situations; reducing the susceptibility of the target organism (e.g. iodine tablets for radiation protection); establishing building codes and zoning laws to protect against natural hazards; and improving the organizational capability to initiate, enforce, monitor and revise management actions (high-reliability learning organizations).

8.3.3 Risk Problems Due to High Unresolved Uncertainty

If a high degree of uncertainty remains, risk management needs to incorporate hazard/threat criteria (which are comparatively easy to determine), including aspects such as reversibility, persistence and ubiquity, and select management options empowering society to deal even with worst-case scenarios (such as containment of hazardous activities, close monitoring of risk-bearing activities, and securing reversibility of decisions in case the consequences turn out to be higher than expected). It seems prudent to take a cautionary/*precautionary approach* when managing risks characterized by multiple and high uncertainties. One should pursue a cautious strategy that enables learning by restricted errors. The main management philosophy for this risk class is to allow small steps in implementation (containment approach) that enable risk managers to stop or even reverse the process as new knowledge is produced or the negative side effects become visible. The primary thrust of precaution is to avoid irreversibility (Klinke and Renn 2002).

Such an approach is based on the cautionary principle, which expresses that in the face of uncertainty, *caution* should be a ruling principle, for example by not starting an activity, or by implementing measures to reduce risks and uncertainties (Aven and Vinnem 2007; HSE 2001, 2006; Stirling 2008). The level of caution adopted has, of course, to be balanced against other concerns such as costs. However, all industries are well advised to introduce some minimum requirements to protect people and the environment, and these requirements can be considered justified by the reference to the cautionary principle. The precautionary principle may be considered a special case of the cautionary principle, as it is a legal basis for cautionary actions in the face of *scientific uncertainties* (Sandin 1999; Löfstedt 2003; Aven 2006). The uncertainty characterizations and the scenarios can provide justified reasons for events that should be covered by a cautionary approach even if the assigned probability of such an event is low. They can also make plausible why it is not prudent to protect oneself against all possible events and help decision makers to set priorities.

With regard to risk-absorbing systems, the main objective is to make these systems resilient so that they can withstand or even tolerate surprises. In contrast to robustness, where potential threats are known in advance and the absorbing system needs to be prepared to face these threats, *resilience* is a protective strategy against unknown or highly uncertain hazards. Instruments for resilience include the strengthening of the immune system; diversification of the means for approaching identical or similar ends; reduction of overall catastrophic potential or vulnerability, even in the absence of a concrete threat; design of systems with flexible response options; and the improvement of conditions for emergency management and system adaptation. Robustness and resilience are closely linked; but they are not identical and require partially different types of actions and instruments.

8.3.4 Risk Problems Due to Interpretative and Normative Ambiguity

If risk information is interpreted differently by different stakeholders in society (i.e. there are different viewpoints about the relevance, meaning and implications of factual explanations and predictions for deciding about the tolerability of the risk, as well as management actions), or if the values and priorities of what should be protected or reduced are subject to intense controversy, risk management needs to address the causes for these conflicting views (von Winterfeldt and Edwards 1984).

Genetically modified organisms for agricultural purposes may serve as an example to illustrate the intricacies related to ambiguity. Surveys on the subject demonstrate that people associate high risks with the application of gene technology for social and moral reasons (Hampel and Renn 2000). Whether the benefits to the economy balance the costs to society in terms of increased health risks was not mentioned as a major concern of the polled public.

Instead, people disagreed about the social need for genetically modified food in Western economies, where abundance of conventional food is prevalent. They were worried about the loss of personal capacity to act when selecting and preparing food, about the long-term impacts of industrialized agriculture and the moral implications of tampering with nature (Sjöberg 2000). These concerns cannot be addressed by either scientific risk assessments or by determining the right balance between overprotection and underprotection. The risk issues in this debate focus on the differences between visions of the future, basic values and convictions, and the degree of confidence in human ability to control and direct its own technological destiny. These wider concerns, and the people who express them, must be included within the risk management process.

Risk managers should thus initiate a broader societal discourse to enable participative decision-making. These discursive measures are aimed at finding appropriate conflict–resolution mechanisms capable of reducing the ambiguity to a manageable number of options that can be further assessed and evaluated. The main effort of risk management is, hence, the organization of a suitable discourse, combined with the assurance that all stakeholders and public groups can question and critique the framing of the issue as well as each element of the entire risk chain.

Table 8.2 provides a summary of these four risk strategies and lists the instruments and tools that are most appropriate for the respective strategy. Again it should be emphasized that the list of strategies and instruments is not exhaustive and can be amended if the case requires it.

8.4 Managing Interdependencies

In an interdependent world, the risks faced by any individual, company, region or country will depend not only on its own choices but also on those of others. Nor do these entities face one risk at a time: they need to find strategies to deal with a series of interrelated risks that are often ill-defined or outside of their control. In the context of terrorism, the risks faced by any given airline, for example, are affected by lax security at other carriers or airports. There are myriad settings that demonstrate similar interdependencies, including many problems in computer and network security, corporate governance, investment in research, and vaccination. Because interdependence does not require proximity, the antecedents to catastrophes can be quite distinct and distant from the actual disaster, as in the case of the 9/11/01 attacks when security failures at Boston's Logan Airport led to crashes at the World Trade Center (WTC), the Pentagon, and in rural Pennsylvania. The same was true in the case of the August 2003 power failures in the Northeastern US and Canada, where the initiating event occurred in Ohio, but the worst consequences were felt hundreds of miles away. Similarly a disease in one region can readily spread to other areas with which it has contact, as was the case with the rapid spread of SARS from China to its trading partners.

For situations in which participants are reluctant to adopt protective measures to reduce the probabilities associated with catastrophic losses due to possible contamination from weak links in the system, a solution might be found in a public–private partnership. This is particularly true if the risks to be dealt with are associated with competing interpretations (ambiguities) as to what type of co-operation is required between different communities as well as risk management agencies in order to deal with various knowledge and competing value claims. Public–private partnerships also provide an interesting alternative in cases in which perceptions differ strongly and external effects are to be expected.

One way to structure such a partnership is to have government standards and regulations coupled with third party inspections and insurance to enforce these measures. Such a management-based regulatory strategy will not only encourage the addressees of the regulation, often the corporate sector, to reduce their risks from e.g. accidents and disasters. Indeed, it equally shifts the focus of decision-making from the government regulatory authority to private companies which are as a result required to do their own planning as to how they will meet a set of standards or regulations (Coglianese and Lazer 2003). This, in turn, can enable companies to choose those means and measures which are most fit for purpose within their specific environment and, eventually, may lead to a superior allocation

Table 8.2 Risk problem categorizations and risk management (adapted from IRGC 2005:47; Aven and Renn 2009b)

Risk problem category	Management strategy	Appropriate instruments	Stakeholder participation (refer Sect. 7.4)
Simple risk problem	Risk informed Routine-based risk treatment (risk reduction)	Statistical analysis Risk assessments, Cost–benefit analyses – Trial and error – Technical standards – Economic incentives – Education, labelling, information – Voluntary agreements	To involve all stakeholders is not necessary. *Instrumental discourse* among agency staff, directly affected groups as well as enforcement personnel is advisable
Complexity induced risk problems	Risk informed (risk agent)	Risk assessments Cost–benefit analyses Characterizing the available evidence • Expert consensus seeking tools (e.g. Delphi) • Results fed into routine operation	Input for handling complexity could be provided by an *epistemic discourse* aimed at obtaining the best predictions of the occurrence of events and associated consequences The goal is to resolve cognitive conflicts
	Risk informed Robustness focused (risk absorbing system)	Risk assessments Cost–benefit analyses Improving buffer capacity of risk target through: • Additional safety factors • Redundancy and diversity in designing safety devices • Improving coping capacity • High reliability organizations	
Uncertainty induced risk problems	Risk informed and Caution/Precaution based (risk agent)	Risk assessments. Broad risk characterizations, highlighting uncertainties and features like persistence, ubiquity etc. Tools include: • Containment • ALARP (as low as reasonably practicable) • BACT (best available control technology), etc.	*Reflective discourse*: Include the main stakeholders in the evaluation process and search for consensus on the extra margin of safety in which they would be willing to invest in exchange for avoiding potentially catastrophic consequences. Deliberation relying on a collective reflection about balancing the possibilities for over- and under-protection

(*continued*)

Table 8.2 (continued)

Risk problem category	Management strategy	Appropriate instruments	Stakeholder participation (refer Sect. 7.4)
	Risk informed. Robustness and Resilience focused (risk absorbing system)	Risk assessments. Broad risk Characterizations and improving capability to cope with surprises • Diversity of means to accomplish desired benefits • Avoiding high vulnerabilities • Allowing for flexible responses • Preparedness for adaptation	
Ambiguity induced risk problems	Risk informed and Discourse based	Political processes. • Application of conflict resolution methods for reaching consensus or tolerance for risk evaluation and option selection • Integration of stakeholder involvement in reaching closure • Emphasis on communication and social discourse	*Participatory discourse*: competing arguments, beliefs and values are openly discussed

of resources compared to more top-down forms of regulation. The combination of third party inspections in conjunction with private insurance is consequently a powerful combination of public oversight and market mechanisms that can convince many companies of the advantages of implementing the necessary measures to make their plants safer and encourage the remaining ones to comply with the regulation to avoid being caught and prosecuted.

Highly interdependent risks that can lead to contamination of third parties pose a specific challenge for global risk management (i.e. the management of transboundary, international and ubiquitous risks). Due to the often particularly decentralized nature of decision-making in this area, a well balanced mix of consensual (e.g. international agreements and standards, gentleman's agreements), coercive (e.g. government regulation) and incentive-based (e.g. emission certificates) strategies is necessary to deal with such risk problems. Again these strategies can be best developed in close – international and trans-national – cooperation between the public and the private sector.

8.5 Risk Management Tools: CBA and Decision Analysis

8.5.1 Different Types of Decision Support Tools and Typical Procedures for Their Use

We consider a set of decision options. Before a decision can be made, some support is needed, as a basis for the decision. Risk assessment provides such decision support. It gives predictions of the performance of the various options with related uncertainty assessments. This information is then linked to costs and benefits associated with the various options. There are many ways of thinking on how to integrate risks, costs and benefits in problems involving multiple attributes. All (rational) approaches involve prediction of future consequences. They differ in the degree to which they include uncertainty, valuation and trade-off of attributes and representation of risk attitude, as well as methods for prescribing choice. The historical and theoretical foundation of the methods varies. In the following we will discuss three common approaches:

(a) Presentation of consequences and risk of selected attributes for the various alternatives, with flexibility in attribute weighting and trade-off
(b) Cost–benefit analysis (CBA)
(c) Formal decision analysis (Expected utility theory)

According to approach a, the idea is to analyze and evaluate factors such as the impact on safety, the investment and operational costs, market impact, and operational and maintenance impact. For costs, safety, maintenance and operational issues, quantitative analyses could be conducted producing predictions and uncertainty assessments and cost–benefit trade-offs. For other important aspects such as political or public opinion pressure, only qualitative analyses and evaluations would normally be performed. The total of these assessments is used as a decision basis. Before a decision is made, the management reviews and evaluates the decision support information, and relates it to values formulated as goals, criteria and preferences. There is no strict procedure on how to do this managerial process. It is an individual process based on the constraints of the structure given by Fig. 8.1. This structure can be interpreted as a prescription, but it is not very detailed and specific.

Basically, we may contrast two different approaches for reaching a good decision:

1. Choose the alternative which maximizes/minimizes some specified criteria, reflecting the performance of the options, uncertainties and values.
2. See decision-making as a process with formal risk and decision analyses providing decision support, followed by an informal managerial judgement and review process (which we refer to as an "evaluation") resulting in a decision.

The first approach is typical for the pioneers of the economic decision-making school (Neumann and Morgenstern 1944), and later the Bayesian decision making theorists, see e.g. Keeney and Raiffa (1993) and Lindley (1985). In this book the second approach is adopted as an overall structure, meaning that we see decision analysis and the use of other tools such as CBA strictly as an aid for decision. This is comparable to the "moderate" view as mentioned by Fischhoff et al. (1981) and supported by a number of decision theorists, see e.g. Watson and Buede (1987) and French and Rios (2000). The decision maker needs to take the results of the decision analysis and make his decision, following a review and judgement process (referred to as the evaluation step in Sect. 7.1). This does not mean that we cannot see examples where approach (1) may be appropriate, but considering varying degrees of the informal evaluation process preceding any decision, we may think of approach (1) as a special case of approach (2).

Regardless of the approach, we will not be able to avoid the fact that some decisions will be followed by negative outcomes. But by following a decision-making

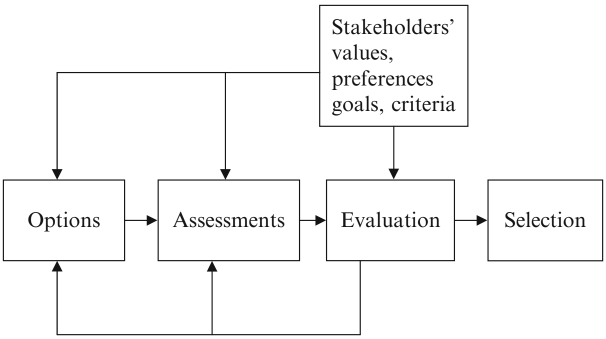

Fig. 8.1 The structure of the decision process (1–4) described in Table 8.1 (Aven 2003)

process in line with the principles in approach (2), we would expect that a collective of decisions will produce positive outcomes in relationship to the objectives. The main features of approach (2) is shown in Fig. 8.1, in line with the steps 1-4 in Table 8.1. The starting point is a decision problem and often this is formulated as a task of choosing among a set of decision options.

Initially a number of possible options may be considered. The problem is then to identify one or two for further detailing and optimization. Clearly, much has already been decided when a set of alternatives to be further assessed has been defined. If, for example for oil exploration, one were to decide at an early stage to adopt a well-proven technology, one would exclude options involving development of new technology. In a practical setting the number of options to be assessed need to be manageable, the consequence being that many options could be excluded at an early stage when uncertainties are large. Further studies could have shown that these options are favorable compared to those being assessed, but this will remain a purely hypothetical problem. The set of options is typically defined through an integrated process involving experts and managers. The experts would often specify an initial list as a basis for discussions. The development of options would to a large extent be driven by the boundary conditions of the decision problem, as judged by the experts and the management. The boundary conditions include stakeholders' values, for example formulated as organizational goals, criteria, standards and preferences, as well as views expressed by politicians, environmentalists and others. Both experts and managers have a background, i.e. knowledge, experience, values, preferences, etc. that could significantly influence the selection process of options. We have to appreciate the subjective element in this creative part of decision-making, establishing an appropriate set of options. People may have personal agendas, but by ensuring that the process involves a sufficient broad group of personnel, the generated options should provide the necessary basis for identifying a good alternative.

Sensitivity Analysis plays an important role in the use of decision support tools. Most comparisons of the consequences of alternative management alternatives involve projection of what will happen to system over time under each of the alternatives or options. Sometimes these projections are simply estimates or predictions based on expert judgment, but increasingly, mathematical models are used to make the projections. Projections either from models or from the judgment of experts depend on the assumptions and the data being used to make the projections. So a very useful means for gaining insights into which factors are most important in making the decision is to carry out a systematic sensitivity analysis to data inputs and model assumptions. Sensitivity analysis is done by asking about how the projections would change if alternative assumptions and input data are used. Make up a list, and for each input or model assumption on the list, ask how the evaluation of the alternatives would change if this factor were different, within a range judged to be reasonable.

Sensitivity analysis is therefore equivalent to a list of "what–if" questions. What if there is a drought? Or a flood? In a study of a river basin, a series of wet years or dry years might be examined as alternatives to an assumption of average precipitation and resulting stream flows. Does the evaluation of the management alternatives change as the precipitation levels vary from wetter to drier? If so, further study may be warranted for this factor now identified as sensitive for the decision being studied. Often models have a great many assumptions and input parameters. Outside review of the model by experts in the relevant technical disciplines may be useful in identifying assumptions and inputs that might be sensitive. When the input is uncertain and important, then it may be useful to proceed to the next tool we shall discuss – assessment of uncertainty in the form of a probability distribution for an uncertain factor. But often an important aspect of sensitivity analysis is to determine that many inputs to the model (or in the absence of a model, factors affecting the system) are *not* critical in the sense of having a strong impact on the evaluation of which decision is best. Afterwards a discussion and debate can move away from the factors that are not critical, and concentrate on the factors that appear to be more important to the decision. Patil and Frey (2004) in a publication on sensitivity analysis methods in food safety conclude that food safety models should be designed to facilitate sensitivity analysis, and that sensitivity analysis methods are a valuable tool in supporting food safety regulation. Such conclusions seem also appropriate for other areas of environmental assessment and decision making.

8.5.1.1 Application Example: Health Monitoring Systems (First part)

To illustrate the approaches we will consider an example from investment in risk reducing equipment on offshore helicopters (Aven and Kørte 2003). Based on the frequency of accidents of helicopters supporting North Sea oil exploration between the 1960s and the 1980s, the risk associated with helicopter transportation was considered high. Independent risk assessments were performed, and investigations into contributing factors carried out. Health monitoring systems (HUMS) were identified as a measure which would reduce risk significantly. This conclusion was largely derived through expert judgement by groups of experts from several fields of expertise (technical, operational, legislative and users). A risk picture was established which expresses for example the probability distribution of helicopter accident fatalities for the next years, as shown in Fig. 8.2.

The figures are based on a prediction of 40,000 flight hours per year, and an average of 17 passengers and crew per flight. The expected number of fatalities for 1 year equals 2.7. The FAR is equal to 400 (FAR is defined as the expected number of fatalities per 10^8 exposure hours). With the installation of HUMS on the whole fleet, a reduction in fatality risk, expressed as the expected number of fatalities, equal to 15–50% was calculated, depending on the assumptions made. Based on the figures of Fig. 8.2, a reduction in the number of expected fatalities equal to 1.9 was derived. The distribution provides additional decision support, as it informs the decision maker that the expected reduction is to be highest for accidents with high numbers of fatalities.

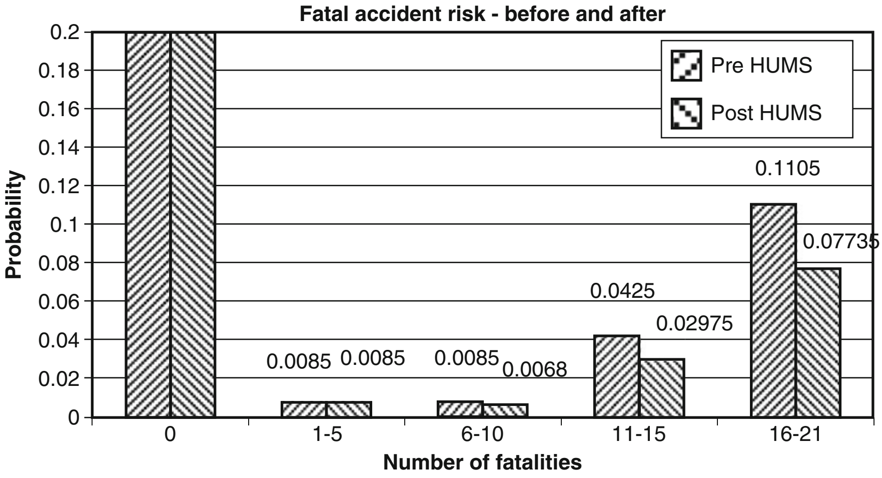

Fig. 8.2 Fatal accident risk, expressed as the probability distribution for the number of fatalities in 1 year; before and after hums, for operations on the Norwegian continental shelf

The presentation of consequence distributions in such a manner can be regarded as the most fundamental basis for decision makers. It is the basis for any associated formal decision analysis and should be part of the decision support information. In some cases it may be the only information required. But, comparing options in this way can be challenging, as a number of factors of different dimensions need to be considered.

In the following we will consider the alternative decision analysis tools, CBA and decision analysis, for supporting decision-making, concerning the most promising option, the HUMS.

8.5.2 Cost–Benefit Analysis

Cost–benefit analysis (CBA) means to balance explicitly the costs and benefits of a variety of options for action by comparing and quantifying opportunities and risks. This comparison is made on the basis of a full monetarization of all benefit and cost categories (Fischhoff et al. 1985). A variety of methods (shadow prices, willingness to pay, price standard) are used to convert into monetary units the benefits and expenditures (costs, organizational effort, costs of conflict, costs for decision-making etc.) of the different options for action.

A cost–benefit analysis attempts to measure the change in economic welfare associated with all costs and all benefits generated by a project. In general, these will fit into one of three categories (1) marketed (direct) benefits and costs, (2) A direct benefits and costs, and (3) non-marketed indirect benefits and costs. For benefits, we attempt to measure the willingness to pay by all affected consumers for the relevant project benefits. The rationale for doing so derives from applied economic welfare analysis. This approach argues that economic welfare derives from preference satisfaction and that preference satisfaction is reflected by the consumer's willingness to pay (Nas 1996).

Market goods are easy to transform to monetary values since the prices on the market goods reflect the willingness to pay. The willingness to pay for non-market goods is on the other hand more difficult to determine, and special methods are required (Hanley and Spash 1993). Basically there are two categories of methods, the revealed approach and the expressed approach. In the former category, values are derived from actual choices made. As was noted in Section 3.3, a number of studies have been conducted to measure for example the implicit cost of averting a fatality. The costs differ dramatically, from net savings to costs of nearly $100,000 million. Common reference values are in the area $1–20 million. The latter category, the expressed approach, is used to investigate individual tendency towards risk taking and willingness to pay under different hypothetical situations, see Nas (1996).

After transformation of all attributes to monetary values, the total performance is commonly summarized by computing the expected net present value, the E[NPV]. The formula used to calculate NPV is:

$$NPV = \sum_{t-0}^{T} \frac{X_t}{(1 + r_{\mathrm{t}})^t},$$

where X_t is equal to the cash flow at year t, T is the time period considered (in years) and r is the required rate of return, or the discount rate, at year t. The terms capital cost and alternative cost are also used for r. As these terms express, r represents the investor's cost related to not employing the capital in alternative investments. When the cash flows are uncertain, which is usually the case, they are represented by their expected values, and the E[NPV] results. The discount rate used to calculate the E[NPV] is adjusted to compensate for the uncertainties (risk). However, not all types of uncertainties are considered relevant when determining the magnitude of the risk-adjusted discount rate, as shown by the portfolio theory (Levy and Sarnat 1990). This theory justifies the ignorance of unsystematic risk and states that the only relevant risk is the systematic risk associated with a project. The systematic risk relates to general market movements, for example caused by political events, and the unsystematic risk relates to specific project uncertainties, for example accident risks.

What makes cost–benefit analysis so attractive is that it offers a tool by which to orient risk evaluation to market prices that can directly reflect societal benefits. Thus costs for risks can be integrated in insurance premiums, while expected gains from opportunities can be integrated in share prices or in the provision of venture capital. However, the integration of external effects and the valuation of public goods present difficulties. Here shadow prices that simulate market value must be ascertained indirectly. While scientific approaches have been developed by which to perform this, these approaches vary substantially, so that in many cases their results remain ambiguous (Fischhoff et al. 1985). A further difficulty is presented by the question of how to discount such prices over time (Hartwick and Olewiler 1998; Smith 1986). While for market prices the usual interest rate on the market is adopted, it is difficult to justify the choice of discount rate for the monetarization of nature. While it makes sense to discount with a negative interest rate such gains that are only expected in the distant future, it is scarcely plausible to appraise the victim of a future damaging event as being less "valuable" than the victim of a present exposure. The above problems are particularly striking when dealing with risks to human health and ecosystems. Which money value corresponds to an x% rise in the risk of dying from cancer? How does this money value change if the damaging event only occurs in 20 years from now? (Baram 1980; Kelman 1981).

CBA is based on the use of expected values, and hence care has to be shown using this tool for supporting investments in safety and security as was discussed in Sect. 3.3. Modifications of the traditional cost–benefit analysis have been suggested to solve this problem, see e.g. EAI (2006) and Aven and Flage (2009). In these methods, adjustments are made to either the discount rate or the contribution from cash flows. This latter case could be based on the use of certainty equivalents for uncertain cash flows. Although arguments are provided to support these methods, their rationale can be questioned. There seems to a significant element of arbitrariness associated with the methods.

As another example we look into the application of the ALARP principle (refer to Sects. 7.2 and 7.5). To verify ALARP, procedures mainly based on engineering judgments and codes are used, but also traditional cost–benefit analyses and cost effectiveness indices. When using such analyses, guidance values are often used, to specify what values that define "gross disproportion". A typical number for a value of statistical life used in cost–benefit analysis is £1–2 million (HSE 2006; Aven and Vinnem 2005). For certain areas the numbers are much higher, for example in the offshore UK industry it is common to use £6 million (HSE 2006). This increased number is said to account for the potential for multiple fatalities and uncertainty, and may be viewed as an extra weight justified by the ALARP principle and the principle of "reversed onus of proof".

This practice can however be challenged, as the expected net present value calculations performed in a cost–benefit analysis does not take into account the risks and uncertainties, as discussed above. Moreover, one may also question why more resources should be used on safety measures for one group than another. Does that mean that society has a stronger preference for avoiding fatalities in one specific group of people?

Despite these problems, cost–benefit analysis has an important function in industry, public policy and the courts. This is particularly so where it is necessary to compare, in a manner independent of the subjective preferences of the individual members of a society, the costs incurred by and the benefits accruing to a national economy. Indirect indicators such as prices for buying additional insurance cover or costs for restoring health can provide useful approximations to the monetary expenditures and gains that are to be expected in the real world. For instance, the damage caused by acid rain can be operationalized in terms of the losses incurred by the timber trade and the tourism sector (Wicke 1982). However, such an analysis captures neither esthetic nor ecological damage.

8.5.2.1 Application Example: Health Monitoring Systems (second part)

Let us look at a simplified case of the HUMS investment, with the two options considered; option A: reject the investment in HUMS and, option B: invest in HUMS and receive the effect on risk. The decision makers in this case were the Norwegian oil companies, who had to make a decision, based on the risk assessment and a cost prediction from the helicopter operators. Both profit and cost are assumed to be fixed, i.e. no uncertainty is associated with these quantities. The cost of HUMS used here, is a yearly cost of \$3 million, reflecting both annualized capital cost and operational cost.

Balancing the cost and accident risk is a management task, which is based on goals, criteria and preferences, but in most cases there is no obvious line to a specific decision. In our example, alternative A means a reduced cost compared to B, but a higher probability of a fatality. How should one value the difference in probability distributions or the expected number of fatalities? The statistical expected fatalities for the two alternatives are 2.7 and 1.9, respectively. For the sake of simplicity we assume that there are no other factors to consider. What option should be chosen? Of course, no general answer exists to this, but we can compute a cost effectiveness index expressing cost per expected life saved, which gives a reference and a link between the two dimensions costs and safety. We see that the cost index, which makes the two alternatives equal, in this case is 3/(2.7–1.9), which is approximately equal to 3.7 ($\$ \times 10^6$). The reasoning is as follows: To go from alternative A to B, it would cost 3, and the expected number of saved lives would be 2.7–1.9.

In many situations, this type of information, combined with the results of the risk assessment is what is needed for decision makers in comparing the effects of alternative actions and choosing among alternative mitigating actions, when resources are limited. In addition to the cost-effectiveness index, risk assessment provides the basis for a decision, as the decision makers might have a special interest to reduce the probability for accidents with high numbers of fatalities.

A cost–benefit analysis is closely linked to this cost effectiveness index. According to this approach, a measure should be implemented if the expected net present value is positive, i.e. E[NPV] >0. Although cost–benefit analysis was originally developed for the evaluation of public policy issues, the analysis is also used in other contexts, in particular for evaluating projects in firms. The same principles apply, but using values reflecting the decision maker's benefits and costs, and the decision maker's willingness to pay.

Following our example, we will limit the analysis to the criteria profit, i.e. monetary gain, and safety. With option A, we associate a gain of 1,000 (i.e. a cost of $-1{,}000$), the profit of the industry and with option B, a reduced gain of $1{,}000 - 3 = 997$ (i.e. a cost of -997). We may think of one cost unit as one million dollars.

For the cost–benefit analysis to be complete, we are required to state a value for a statistical life, i.e. the maximum value the decision maker is willing to pay for reducing the expected number of fatalities by one. This value should not be confused with the cost-effectiveness index calculated above. Let the value we specify for a statistical life be $7 million. Then the total statistical expected gain associated with option A would be $1{,}000 - 7 \times 2.7 = 981$, for option B, the corresponding value would be $997 - 7 \times 1.9 = 984$.

The conclusion would thus be that option B is preferable as the gain is 984 compared to a gain of 981 for option A. In practice one might need to take into account time and the discounting of cash flow, but the above calculations show the main principles of this way of balancing cost and benefit.

Note that in the analysis we have not specified the value of a life, but the willingness to pay for reducing the expected number of fatalities by one. This might appear to be solely semantic, but we would like to see it as an important ethical discrimination. The number used for a statistical life does not imply that anyone in reality would trade a specific life for a higher value. In our example, if a company knew that a specific person would die with certainty, but his/her life could be saved for a $7 million that could be made available, could there be doubt? The value of a life is infinite. Using cost–benefit numbers in such a way would be a cynicism not warranted by the idea behind the cost–benefit approach. It merely reflects recognition (resignation?) that in any situation, resources are limited and potential actions to reduce uncertainty and risk are indefinite. Cost–benefit values of expected fatalities, in this situation, provide an instrument to relate to uncertainty and risk in decision making. The chosen values, in our example $7 million, would always refer to specific methods or standards of comparing risks and benefits. It is a value that can only be related to a population exposed to risk, not to decide on life or death of specific individuals.

Sensitivity analysis should be used to see the effect on the result of varying input quantities, such as the value of a statistical life. An example is shown in Fig. 8.3.

The results of the decision support assessments need to be evaluated in light of the premises, assumptions and limitations of these assessments. The assessments are based on background information that must be reviewed, together with the results of the assessments. Considerations need to be given to factors such as:

- The decision options being analyzed
- The performance indices focused
- The fact that the results of the analyses to large extent represent expert judgements
- The difficulty of assessing values for costs and benefits, and uncertainties
- The fact that the analysis results apply to models, i.e. simplification of the world, and not the world itself

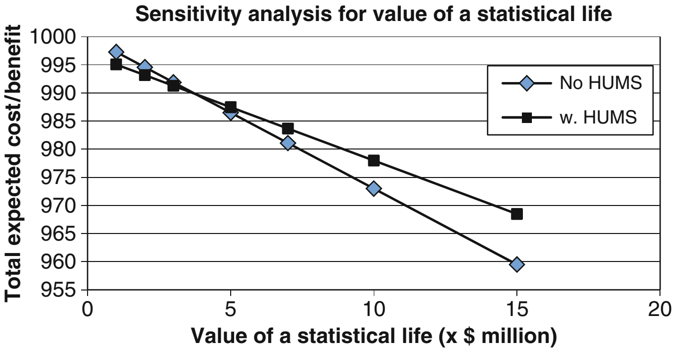

Fig. 8.3 Sensitivity of expected cost–benefit depending on the value of a statistical life

Such considerations are an essential element of the managerial evaluation (review and judgment) process. For example, in the assessment we may have defined just a few possible consequences of an event – for the HUMS example only two – even though in the real world there could be many aspects and facets that need consideration. In real life cases there will always be factors of relevance that go beyond the results of the formal analyses.

In cost–benefit analysis, expectations of all consequences are integrated into one unit, typically the expected net present value (NPV). This requires a transformation function for all consequences into monetary units. For NPV calculations, time discounting factors are required as well.

Cost–benefit analyses provide decision support, not hard recommendations. Thus we may for example consider different values of a statistical life, to provide insights for the decision. In the expected net present value formula, expected values are mixed with value judgments (how much are you willing to pay). In a multi-stakeholder decision process, we would expect to encounter difficulties in obtaining consensus about the recommendations provided by the cost–benefit analysis, as there are always different opinions about how to look at risk in society. Do we expect a group of stakeholders with different agendas, e.g. management, union and public authority representatives to agree on a decision based on the cost–benefit values of 984 and 981 alone, for the two options considered in our HUMS example? –Hardly. For example, in the cost–benefit analysis, an option with a high expected cost–benefit is preferred to an option with a lower cost–benefit value, even if the latter alternative would mean a negligible probability of a serious hazard, whereas this could not be disregarded in the former case. As discussed above and in Sect. 2.2 cost–benefit analysis to large extent ignore the risks and uncertainties, and hence, it is of paramount importance that the cost–benefit analyses are being reviewed and evaluated. We cannot replace difficult ethical and political deliberations with a mathematical one-dimensional formula, integrating complex value judgements.

8.5.3 Decision Analysis

8.5.3.1 Philosophy of Decision Analysis: Three Types of Approaches

Decision analysis (DA) provides insights into three areas (Slovic et al. 1977; Skinner 1999):

(a) How human beings or organizations identify, evaluate and select choices when making decisions (*descriptive* DA)
(b) How decision making can be structured in logical steps that need to be addressed in some way when humans make decisions, including ignoring them (*typological or systematic* DA) and
(c) How, inspired by the goal of instrumental rationality, humans should proceed when making decisions (*normative* or *prescriptive* DA)

In addition to DA, social scientists investigate the factors that influence decision making processes or determine different routes and strategies for decision making with respect to individuals as well as organizations (behavioral decision *theory*). Decision theory (DT) provides valuable insights for testing normative models of DA with respect to the appropriateness, effectiveness, efficiency and other criteria of good governance in different domains. What may turn out to be appropriate for one domain (for example, consumer choices in purchasing products), may be totally inappropriate for another domain (for example, decisions about environmental policies).

What do these three forms of DA entail? Normative DA is focused on analytical procedures and tools for supporting decision making and for assuring logical consistency in how results are obtained from inputs into the analysis (Howard 1966, 1968; Fishburn 1981; Behn and Vaupel 1982; von Winterfeldt and Edwards 1986:15 ff.). Logical consistency in dealing with complex problems can be achieved through using mathematical modeling such as probability theory as a formal logic for dealing with uncertainty. The difficult part is the interface with the real world – the inputs and modeling assumptions. Assessment of these inputs must be based on both observational data and on human judgments. These include judgments about uncertainties, which may be subdivided into aleatory (in the sense of statistical randomness and variation) and epistemic as a result of lack of knowledge. There may be uncertainties about the parameters of models and the assumptions underpinning the models. Judgments are also needed about valuing consequences including risk preference, time preference, and trade-offs, and judgments about what options are possible (the set of available options often reflect legal and political structures as well and technical possibilities).

How to understand and capture human judgment is the realm of descriptive DA and behavioral decision theory, as applied to individuals and to groups up to and including national governments and international institutions (overview in: Einhorn and Hogarth 1981; Yates 1990; Dawes 2001b). This line of research illuminates the actual decision making processes by individuals, organizations and groups and highlights the mechanisms, biases, and intuitions that lead to judgments about options. Psychological research has focused on the inherent reasoning processes when facing behavioral choices. This includes the processing of information such as probabilities (Kahneman et al. 1982), the intuitive mechanisms of making inferences, the process of dealing with cognitive stress and dissonance and the coping mechanisms when experiencing conflicting evidence claims or value assertions. Sociological and other social science studies have been investigating social and cultural constraints for identifying and generating options, the framing process of identifying and defining problems and procedures for their solution, norms and rules of evaluating expected outcomes within different social and cultural contexts, the perceived legitimacy of selection and evaluation schemes and the institutional and organizational interpretations of decision making in different cultures and political domains (Heap et al. 1992:62 ff.; Hofstede 2003). The contribution of many disciplines within the humanities is to provide evidence for the variety of decision making processes in history, literature or other representations of human activities.

All these descriptions feed into the building of analytical theory construction. The main objective, as with any other scientific endeavor, is to understand causal connections between independent variables such as personality, social bondage and cultural affiliation to decision making structures and preferences. In addition, these insights enlighten the construction of normative advice, as its effectiveness relies on behavioral insights into decision making in order to improve decision making processes, especially those involving decisions on behalf of a group. Social and behavioral sciences research has much to teach normative analysts about how to assess uncertainty in the form of probabilities and how to deal with value assessment of consequences, including the difficult tradeoffs between economic and environmental objectives. Such research can substantially improve normative decision analysis in support of environmental decision making.

The third DA approach, the typological, can be generically captured in a sequence of steps, as given in Table 7.3. In the typological model, the analytic parts comprise estimations of negative or positive consequences associated with each option (magnitudes) and the assignment of probabilities to each outcome (Phillips 1979:4). The deliberative component refers to the desirability of outcomes. Once the desirability has been established, it is then specified as a cardinally measured utility providing a hierarchical order from beneficial to adverse effects.

8.5.3.2 Prospects and Limitations of Decision Analysis

In many policy arenas in which problems of structuring human decisions are relevant, the tools of normative decision analysis have been applied. Especially in economics, sociology, philosophical ethics, and also many branches of engineering and science, these methods have been extended and refined during the past several decades (Edwards 1954; Howard 1966, 1968; North 1968; Howard et al. 1972;

North and Merkhofer 1976; Behn and Vaupel 1982; Pinkau and Renn 1998; van Asselt 2000; Jaeger et al. 2001).

The procedures and analytical tools of normative DA provide a number of *possibilities* to improve the precision and transparency of the decision procedure. However, they are subject to a number of limitations. The opportunities refer to:

- Different action alternatives can be quantitatively evaluated to allow selection of a best choice. Such evaluation relies both on a description of uncertain consequences for each action alternative, with uncertainty in the consequences described using probabilities, and a description of the values and preferences assigned to consequences (*explicit characterization of uncertainty and values of consequences*).
- The opportunity to assure transparency, in that (1) models and data summarizing *complexity* (e.g. applicable and available scientific evidence) (2) probabilities characterizing judgment about *uncertainty,* and (3) values (utilities) on the consequences are made explicit and available. So the evaluation of risk management alternatives can be viewed and checked for accuracy by outside observers (*outside audit enabled of basis for decision*).
- A complex decision situation can be decomposed into smaller pieces in a formal analytical framework. The level of such composition can range from a decision tree of action alternatives and ensuing consequences that fits on a single piece of paper, to extremely large and complex computer-implemented models used in calculating environmental consequences and ascribing probabilities and values of the consequences. More complex analysis is more expensive and is less transparent to observers. In principle, with sufficient effort any formal analytical framework can be checked to assure that calculations are made in the way that is intended (*decomposition possible to include extensive detail*).

On the other hand, there are important limitations:

- Placing value judgments (utilities) on consequences may be difficult, especially in a political context where losses of life, impairment of health, ecological damage, or similar social consequences are involved. The basic tradeoff judgments balancing different concerns are difficult and controversial, and inherently subjective (*difficulties in valuing consequences*).
- Assessing uncertainty in the form of a numerical probability also poses difficulties, especially in situations there is not a statistical data base on an agreed-on model as the basis for the assessment (*difficulty in quantifying uncertainty, assigning probabilities*).
- The analytical framework may not be complete. Holistic or overarching considerations or important details may have been omitted (*analytical framework incomplete*).
- Decision analysis is built upon an axiomatic structure, both for dealing with uncertainty (i.e. the axiomatic foundation of probability theory), and for valuing consequences (i.e. the axiomatic basis for the utility theory) (Von Neumann and Morgenstern 1944 and Lindley 1985). Especially when the decision is to be

made by a group rather than an individual decision maker, rational preferences for the group consistent with the axioms may not exist (the "Impossibility" Theorem of Arrow 1951). So in cases of strong disagreements on objectives, decision analysis methods may not be helpful (*limits on applicability*).

Decision analytic methods should not be regarded as inherently "mechanical" or "algorithmic", in which analysts obtain a set of "inputs" about uncertainty and valuing consequences, then feed these into a mathematical procedure (possibly implemented in a computer) that produces an "output" of the "best" decision. Normative DA can only offer coherent conclusions from the information which the decision maker provides by his/her preferences among consequences and his/her state of information on the occurrence of these consequences. Where there is disagreement about the preferences or about the information, DA may be used to implore the implications of such disagreement. So in application, there is often a great deal of iteration (sensitivity analysis) to explore how differences in judgment should affect the selection of the best action alternative.

Normative DA thus merely offers a *formal framework* that can be effective in helping participants in a decision process to better understand the implications of differing information and judgment about complex and uncertain consequences from the choice among the available action alternatives. Insight about which factors are most important in selecting among the alternatives is often the most important output of the process, and it is obtained through extensive and iterative exchange between analysts and the decision makers and stakeholders. The main advantage of the framework is that it is based on logic that is both explicit and checkable – usually facilitated by the use of mathematical models and probability calculations. Research on human judgment supports the superiority of such procedures for decomposing complex decision problems and using logic to integrate the pieces, rather than relying on holistic judgment on which of the alternatives is best (this is not only true for individual decisions, see Heap et al. 1992:36 ff.; Jungermann 1986; but also for collective decisions, see Heap et al. 1992:197 ff.). One should keep in mind, however, that "superior" is measured in accordance with indicator of instrumental rationality, i.e. measuring means-ends effectiveness. If this rationality is appropriate, the sequence suggested by DA is intrinsically plausible and obvious. Even at the level of qualitative discussion and debate, groups often explore the rationale for different action alternatives. Decision analysis simply uses formal quantitative methods for this traditional and common-sense process of exploring the rationale – using models to describe complexity, probability to describe uncertainty, and to deal with ambiguity, explicit valuation of consequences via utilities. By decomposing the problem in logical steps, the analysis permits better understanding of differences in the participants' perspective on evidence and values. DA offers methods to overcome these differences, such as resolving questions about underlying science through data collection and research, and encouraging tradeoffs, compromise, and rethinking of values.

Based on this review of opportunities and shortcomings we conclude that decision analysis provides a suitable structure for guiding discussion and problem formulation, and offers a set of quantitative analytical tools that can be useful for decision making under uncertainty, especially in conjunction with deliberative processes. Yet it does not replace the need for additional methods and processes for including other objectives such as finding common goals, defining preferences, revisiting assumptions, sharing visions and exploring common grounds for values and normative positions.

8.5.3.3 Integration of Decision Analytic Tools in Risk Management

Decision theory provides a logical framework distinguishing action alternatives or options, consequences, likelihood of consequences, and value of consequences. This makes it an ideal tool for risk management. Decision analysis can be used in risk management following the steps outlined in Table 8.3. The structuring potential of decision analysis has been used in many risk management processes and deliberations on risk including the major stakeholders. It helps the facilitator of such processes to focus on one element during the deliberation, to sort out the central from the peripheral elements, provide a consistent reference structure for ordering arguments and observations and to synthesize multiple impressions, observations and arguments into a coherent framework. The structuring power of decision analysis has often been used without expanding the analysis into quantitative modeling.

Table 8.3 Generic steps in a decision analytic approach (Jaeger et al. 2001:51)

Generic steps of the decision analysis approach	Example: municipal solid waste disposal
Structure the problem and specify goals for the choice situation ahead	Priorities: reduce waste generation, encourage voluntary re-use and recycling, mandate recycling, incineration and landfills
Extract appropriate value-dimensions from stated goals	Equity of risk exposure, compensation, cost effectiveness, minimize impacts
Define criteria and indicators for each value dimension (or attribute)	Meta-criteria: health risks, environmental risks, social and cultural risks
Assign relative weights to each value dimension	Health risk = 40%; environmental risk = 35%; cost = 25%
Describe alternatives or options that seem to meet the criteria	Option A: Regional recycling centers and an expanded landfill. Option B: a new landfill in community W
Measure how well each decision option performs on the criteria	Geological borings, probabilistic risk assessments, collect statistical data, elicit citizen's responses
Assess probabilities for each possible outcome	Option A: health risk = 0.11; eco risk = 0.21; cost = 0.82. (arbitrary numbers here) Option B: health risk = 0.34; eco risk = 0.75; cost = 0.20
Sum each decision option's utility on each criterion multiplied with the weight of each value dimension	Option A = 32; Option B = 45
Do a sensitivity analysis to incorporate changes in the criteria composition, outcome generation, assignment of weights and probability assessments	Option A (28, *32*, 56); Option B (16, *45*, 47)

The second potential, agenda setting and sequencing, is also frequently applied in risk management. It often makes sense to start with problem definition, then develop the criteria for evaluation, generate options, assess consequences of options, and so on. The third potential, quantifying consequences, probabilities and relative weights and calculating expected utilities, is more controversial than the other two. Whether the risk management process should include a numerical analysis of utilities or engage the participants in a quantitative elicitation process is contested among decision analysts (Gregory et al. 2001). One side claims that quantifying helps risk managers to be more precise about their judgments and to be aware of the often painful trade-offs they are forced to make. In addition, quantification can make judgments more transparent to outside observers. The other side claims that quantification restricts the managers to the logic of numbers and reduces the complexity of argumentation into a mere trade-off game. Many philosophers argue that quantification supports the illusion that all values can be traded off against other values and that complex problems can be reduced to simple linear combinations of utilities. One possible compromise between the two camps may be to have risk managers to go through the quantification exercise as a means to help them clarify their thoughts and preferences, but make the final decisions on the basis of holistic judgments (Renn 1986). In this application of decision analytic procedures, the numerical results (i.e. for each option the sum over the utilities of each dimension multiplied by the weight of each dimension) of the decision process are not used as expression of the final judgment of the participant, but as a structuring aid to improve the mangers' professional judgment. By pointing out potential discrepancies between the numerical model and the professional judgments, the managers are forced to reflect upon their opinions and search for potential hidden motives or values that might explain the discrepancy.

Assisting risk managers in eliciting and structuring values: Most decision analysts agree that applying the concepts from decision analysis requires specific tools that help risk managers to use the decision analytic framework most productively. This is true both for eliciting values on the consequences and for organizing information – issues of complexity and uncertainty in the prediction of the consequences for the various options under consideration. The main criteria for choosing such tools for value elicitation are (Keeney 1988, 1992):

- Adequacy of tools to represent the managers' values and preferences
- Adequacy of tools to distinguish between inviolate values (principles) and relative values (for which trade-offs can be made)
- Incorporation of cognitive, affective, normative, and expressive arguments into the elicitation process
- Assistance to participants to clarify their value and preferences structure and to find strategies to balance perceived pros and cons
- Compatibility of structuring and evaluating tools with the reasoning process of all managers
- Intelligibility of all operations for all participants

Obviously some of these criteria are in conflict with each other. The better a tool represents non-linear patterns of thinking and evaluating, the less intelligible are the respective mathematical operations for a non-skilled manager. The more a tool reflects the whole horizon of statements (cognitive, affective, normative, and expressive) the less straightforward is the process of amalgamation and integration of concerns. It therefore depends on the case, the qualification of the risk managers and the situation to decide which of the many tools that decision analysis provides for risk management processes should be selected for which purpose.

Assisting participants in generating, structuring and evaluating evidence: The tools needed on the informational aspects involve another set of criteria, including:

- Have all evidence claims been fairly and accurately tested against commonly agreed standards of validation (methodological rigor)?
- Has all the relevant evidence in accordance with the actual state of the art in knowledge been collected and processed (comprehensiveness and representativeness)?
- Was systematic, experiential and practical knowledge and expertise adequately included and processed (incorporation of all relevant knowledge claims)?
- Have all conflicts about evidence been resolved using accepted means of validation, testing and methodology that have been approved by the respective scientific or knowledge communities?
- Were all normative judgments inherent in evidence claims made explicit and thoroughly explained? Were normative statements deduced from accepted ethical principles, legally prescribed norms or accepted conventions within the knowledge community?

Of specific interest are the claims about cause-and-effect relationship between the options under consideration and the consequences – what will happen, given the choice made in the decision. The use of models and statistical analysis is well known among scientists, but some risk managers may not agree with the assumptions, choice of parameters, algorithms and model structure chosen for the scientific models, and scientists may not agree among themselves (Funtowicz and Ravetz 1993; Koenig and Jasanoff 2001). Uncertainty compounds the difficulty – adverse consequences may be agreed to be possible, but scientific understanding is not normally sufficient to make predictions that are accepted as valid by all experts in the relevant scientific disciplines (Merkhofer 1987; van Asselt 2005).

It is essential to acknowledge in the context of decision making under uncertainty that human knowledge is always incomplete and selective and thus contingent on a number of assumptions, assertions and predictions (Funtowicz and Ravetz 1992). It is obvious that the modelled chance distributions within a numerical relational system can only represent an approximation of the empirical relational system with which to understand and predict uncertain events. It therefore seems prudent to include other, additional, aspects of uncertainty (Morgan and Henrion 1990; van Asselt 2000:93ff.). In decision analysis the standard approach is to use knowledge-based probabilities reflecting epistemic uncertainties. Various types of uncertainty intervals may be computed based on these probabilities. Additional information may be needed for making explicit the evidentiary basis underlying the probability calculations.

In this situation risk management may involve soliciting a diverse set of viewpoints, and judgments need to be made on what sources of information are viewed as responsible and reliable. Publication in scientific journals and peer review from scientists outside the government agency are the two most popular methods by which managers try to limit what will be considered as acceptable evidence. Other methods are to reach a consensus among the management board up front which expertise should be included or to appoint representatives of opposing science camps to explain their differences in public. In many cases, different constituencies have strong reasons for questioning scientific orthodoxy and would like to have different science camps represented. Many stakeholders in risk decisions have access to expert scientists, and often such scientists will take leading roles in criticizing agency science. Such discussions need to be managed so that disagreements among the scientific experts can be evaluated in terms of the validity of the evidence presented and the importance to the decision. It is essential in these situations to have a process in place that distinguishes between those evidence claims that all parties agree on, those where the factual base is shared but not its meaning for some quality criterion (such as "healthy" environment), and those where even the factual base is contested (Foster 2002).

Another point of consideration is the issue of presenting scientific results. Managers without scientific training may feel disadvantaged by presentation of information in scientific terminology, and by extensive use of models, mathematics, and statistics. The point here is not that one should simplify to be comprehensible to a lay audience (which may be important for communication with stakeholders, but not for an environmental decision making process that uses mathematical logic as an appropriate means for dealing with great scientific complexity). The point is rather that the assumptions and conditions that may constrain the validity and applicability of the models should not remain hidden behind the image of exact figures and algorithms (Klein 1997). These assumptions and conditions should be made explicit and be subject to questioning and challenge by the participants. It may be advisable for those responsible for the risk management process to work closely with scientists and analysts so that information is made available in a format that guarantees that all assumptions, underlying values and norms and scientific conventions (such as using the 95th percentile for significance testing) become transparent and are open for criticism.

8.5.3.4 Two Tools Used in Decision Analysis

Value-tree-analysis: A value-tree identifies and organizes the values of an individual or group with respect to possible decision options (Keeney et al. 1984, 1987). In the process of structuring a value-tree, representatives of different stakeholder groups are asked to identify their criteria and objectives for evaluating different options. Values in this context are abstractions that help organize and guide preferences (von Winterfeldt 1987).

A value-tree structures the elicited values, criteria, and corresponding attributes in a hierarchy, with general values and concerns at the top, and specific criteria and attributes at the bottom. Depending on the political context and the nature of the decision to be made, the values of the various stakeholder groups may vary considerably. By giving each group the right to assign a weight of zero to each criterion that they regard irrelevant, it is possible to construct a joint or combined value-tree that accounts for all viewpoints and can be verified by all participants (Keeney et al. 1984).

Many users of the value-tree techniques (e.g. von Winterfeldt 1987) take value trees as a first step in the sequence of decision making. In this line, they elicit performance measurements for each option on each criterion or ask for the assignments of trade-offs between the various independent criteria. Other argue that both tasks are extremely prone to strategic game playing and would likely end in a process by which each group would be able to rationalize its latent preference for one of the decision options available. They would use the qualitative value-trees as input for further discussions based on other less strategically sensitive techniques.

Value-of-information analysis: A highly useful but not frequently used aspect of using quantitative probability methods is that of value-of-information methods. If uncertainty can be resolved before the commitment to a decision alternative, rather than afterward, the value of the decision situation may be much greater, because what would be by hindsight a mistake may be avoided. The concept is explained in early decision analysis text such as Raiffa (1968), Bell et al. (1995).

An example of the use of value-of-information calculations: We shall give an example of value of information calculations from application to environmental policy at the Presidential level on weather modification, carried out in the early 1970s (Howard et al. 1972). The main (epistemic) uncertainty was whether cloud seeding would reduce the maximum winds and therefore the damage caused by a hurricane. There were good data on the aleatory uncertainty, how the maximum wind speed (and therefore damage potential) of a hurricane grows or diminishes over time. There were three scientific hypotheses, only one of which could be true (1) seeding makes a hurricane less damaging (on the average over many hurricanes), (2) seeding has no effect on the damage caused by the hurricane, and (3) seeding would (on the average over many hurricanes) make a hurricane more damaging. Experimental data and expert judgment were combined to give probabilities of 49% to (1) and (2) and 2% to (3).

In the absence of further information, the alternative of seeding a hurricane approaching a coastal area was calculated to give an expected reduction of about 20% less property damage. However, reducing property damage was not the only criterion – hurricanes are highly variable in intensity, and a seeded hurricane might intensify. (The probability was calculated to be about 1/6.) Intensification after seeding might create adverse political, legal and social consequences for those in the government who ordered the seeding: An aroused public might perceive that this action by the government made a "natural disaster" worse! A "government responsibility" cost was therefore assessed, with a high negative value (judged equal to an addition of up to 50% of property damage value, depending on the degree of intensification after seeding). With this government responsibility negative value added to property damage, the alternative of seeding is calculated to be only slightly better (5%) than not seeding the hurricane. This matched the intuition of some government officials, who felt that hurricanes about to hit a coastal area should only be seeded after the experimental evidence that seeding reduced hurricane intensity was overwhelming. So the analysis recognized and incorporated a difficult value judgment – a seeded hurricane is no longer a natural disaster, but altered by human action, with people held responsible for this action if something unexpected and bad happens. The analysis focused not just on "should the US government seed a hurricane approaching the US coast", but also on what it would be worth to resolve the uncertainty on which of the hypotheses is correct: Would seeding reduce hurricane wind speed and therefore the damage caused by hurricanes? Or would cloud seeding do nothing, or even make the hurricane more destructive?

Consider the decision to seed or not to seed, with present information and with much better information. Suppose the uncertainty can be completely resolved on which of the three scientific hypotheses is correct. If seeding on the average reduces hurricane damage, then the best decision will be to seed. If seeding has no effect or makes hurricanes more damaging, then the best decision is not to seed. The value of better information is calculated by comparing the expected value (more precisely, expected utility) of the decision with current information with the expected value (utility) of the decision situation with better information – but before the better information is known, so we must use probabilities for what the information will turn out to be. The expected value calculation is as follows for making the decision after the uncertainty on which hypothesis is true has been resolved. First, this epistemic uncertainty is resolved we can learn which of the three hypotheses is true. And we have the probabilities on the three possibilities: seeding reduces damage: 49%, seeding has no effect: 49%, seeding increases damage: 2%. For each of these possibilities, calculate the expected value of property damage (and government responsibility cost and a small cost to carry out the seeding if the decision is to seed, which is the best decision for the first hypothesis). We multiply each of these results taking the best decision with the new information, times the probability of getting that information, to calculate the expected value of the decision situation with full resolution of the epistemic uncertainty. Then we compare this result to the best decision without the new information – with current uncertainty, described by the probabilities on which hypothesis is correct. The expected improvement in the decision from learning which hypothesis is true before deciding, rather than after, is about 12% of property damage – and this result is an average over aleatory uncertainty on how individual hurricanes vary in intensity over time.

The 12% reduction is a very large number, given that some hurricanes have caused up to about $10 billion in property damage. If government responsibility cost is not included, the value of the information drops by about an order of magnitude. This is because the probabilities used in the analysis implied it was very unlikely (2%) that seeding would on average increase property damage, but a lot more likely (17%) that the first seeded hurricane may intensify between the time it was seeded and the time it impacted a populated coastal area. So the bulk of the value of the information about which scientific hypothesis is correct comes from avoiding the government responsibility of seeding a hurricane if the hypothesis that seeding reduces damage is NOT true – which had a probability slightly over 50%. The main insight from this analysis was the importance of the government responsibility issue, which then became the subject of further legal investigation, as reported in Howard et al. (1972). The analysis also highlighted that value of information was very high compared to the research budget for hurricane research.

It is also possible to calculate the value of experiments that revise the probabilities for the scientific hypotheses. Two experimental hurricane seedings had previously been carried out – a wind reduction of 31% was observed after one seeding, and 15% after another seeding. Were these reductions due to the seedings, or just natural fluctions in hurricane intensity? This pair of experiments provided strong, but not conclusive, evidence in favor of the hypothesis that seeding reduced the wind and hence, property damage (This previous evidence was factored in to the probabilities discussed above). The analysis calculated the value of future experimental seedings by looking at how the resulting data (i.e. observed wind change after future seedings) would further change the probabilities on the three scientific hypotheses (via Bayes' Rule, a basic relationship among probabilities). The approach to valuing experiments is similar, but more complex computationally than for full resolution of uncertainty – one calculates probabilities for the set of possible experimental data that could be obtained, then examines what is the best decision (i.e. that which minimizes expected property damage plus government responsibility cost and the small cost of carrying out the seeding), given each of the possible experimental results. Then one calculates an overall expected value for the decision situation after the seeding experiment, by multiplying the expected value with the best decision alternative for each experimental result, times the probability of that experimental result will be obtained, and summing over all the possibilities. Then compare the value of the decision situation after the seeding experiment to the expected value of the best decision without the additional information; the difference is the expected value of the information from the experiment. Details and decision tree diagrams are found in Howard et al. (1972).

8.5.3.5 Application Example: Health Monitoring Systems (third part)

We return to HUMS example. Now we will study the problem using the expected utility theory. The expected utility is in mathematical terms written like Eu(Y), where u is the utility function and Y is the outcome expressing a vector of different attributes, for example costs and the number of fatalities.

Using the same data as before, the possible consequences for the two alternatives are (1,000, X) and (997, X), where the first component of (·,·) represents the benefit and X represents the number of fatalities which for our example is taken as either the number of fatalities, given an accident, 15, or 0.

Now, what is the utility value of each of these consequences? Well, the best alternative would obviously be (1,000, 0), so let us give this consequence the utility value 1. The worst consequence would be (997, 15), so let us give this consequence the utility value 0. It remains to assign utility values to the consequences (1,000, 15) and (997, 0).

Consider the standard of balls in an urn with u being the portion of balls that are white. Let a ball be drawn at random; if the ball is white the consequence (1,000, 0) results, otherwise, the consequence is (997, 15). We refer to this lottery as "(1,000, 0) with a chance of u". Now, how does "(1,000, 0) with a chance of u" compare to achieving the consequence (997, 0) with certainty? If $u = 1$, the gamble is clearly better than (997, 0), if $u = 0$ it is worse. If u increases, the gamble gets better. Hence there must be a value of u such that you are indifferent between "(1,000, 0) with a chance of u" and a certain outcome (997, 0), call this number u_0. Were $u > u_0$, the urn gamble would improve and be better than (997, 0); with $u < u_0$ it would be worse. This value u_0 is the utility value of the consequence (997, 0). Similarly, we assign a value to (1,000, 1), say u_1. As a numerical example, we may think of $u_0 =$ 99/100, and $u_1 = 1/10$, reflecting that we consider a life to have a high value relative to the gain difference. Now, according to the utility-based approach, that decision should be chosen which maximizes the expected utility.

For this simple example, we see that the expected utility for option A (do not invest in HUMS) is equal to

$$1.0 \cdot P(X = 0) + u_1 \cdot P(X = 15) = 1.0 \cdot 0.83 + 0.1 \cdot 0.17 = 0.839$$

whereas for option B (invest in HUMS),

$$u_0 \cdot P(X = 0) + 0 \cdot P(X = 1) = 0.9 \cdot 0.88 + 0 \cdot 0.12 = 0.836.$$

The conclusion from this analysis is that option A is to be preferred. Observe that the computed expected values are in fact equal to the probability of obtaining the best consequence, namely a gain of 1,000 and no fatalities. To see this, note that for option A, the consequence (1,000, 0) can be obtained in two ways, either if X = 0, or if X = 15 and we draw a white ball in the lottery. Thus by the law of total probability, the desired results follow for option A. Analogously we establish the result for option B.

We conclude that maximizing the expected gain would produce the highest probability of the consequence (1,000, 0) and, as the alternative is the worst outcome, (997, 15). We have established that maximizing the expected utility value gives the best decision. This is an important result. Based on requirements of consistent (coherent) comparisons for events and for consequences, we are led to the inevitability of using the expected utility as a criterion for choosing decisions among a set of alternatives.

8.5.4 Discussion

By adopting the expected utility procedure, we can ask what have we gained compared to the cost–benefit approach? We have not assumed monetary values for all consequences (except those that are expressed as money, i.e. the profit). We have specified our preferences by comparing the outcomes (all consequences) and have expressed the uncertainties by probabilities. The result is a utility calculation on a normalised scale, representing a total performance index. Along the same argument as for cost–benefit, we do not expect a group to reach agreement on a decision based on the utility values of 0.839 and 0.836 alone. The assessment process of objectives and value trade-offs in the expected utility approach combined with the use of sensitivity analyses could provide knowledge and insight into aspects of the decision, but the utility approach is not easy to implement. The analysis needs to be evaluated, in light of its premises, assumptions and limitations, as discussed above for the cost–benefit analyses. In practice, decisions are often taken by a group of people with their own array of probabilities and utilities, but the expected utility approach is only valid for a single decision-maker. No coherent approach exists for the multiple decision makers' problem. Of course, if the group can reach consensus on the judgments, probabilities and utilities, we are back to the single decision-maker situation. Unfortunately, life is not that simple in most cases; people have different views and preferences. Reaching a decision then is more about discourse and negotiations than mathematical optimization.

We have considered two different approaches for aiding decision-making involving costs, benefits and risk, cost–benefit analyses and maximization of expected utility. Now, should any single approach be taken as prescriptive for all decision-analysis processes?

Decision analytic tools can be of great value for risk management. They can provide assistance in problem structuring, in dealing with complex scientific issues and uncertainty, and in helping a diverse group to understand disagreements and ambiguity with respect to values and preferences. Decision analysis tools should be used with care. They do not provide an algorithm to reach an answer as to what is the best decision. Rather, decision analysis is a formal framework that can be used for risk assessment and environmental decision making to explore difficult issues, to focus debate and further analysis on the factors most important to the decision, and to provide for increased transparency and more effective exchange of information and opinions among the process participants. The basic concepts are relatively simple and can be implemented with a minimum of mathematics (Hammond et al. 1999).

The expected utility approach is attractive as it provides recommendations based on a logical, mathematically coherent basis. Given the framework in which such maximization is conducted, this approach has a strong appeal to our sense of rationality. The question remains whether it provides information to decision makers which is perceived as relevant and a legitimate basis for the decision. Some of the problems with this approach have been discussed already. An important point when comparing it with the cost–benefit analyses as decision aid, is that preferences have to be specified for *all* consequences, which is a difficult task in practice, and more important, not necessarily something that a management would like to do. The use of reference gambling to produce the utilities is hard to carry out in practice, in particular when there are many relevant factors, or attributes, measuring the quality of an option. Various approaches of multi-attribute utility theory (Keeney and Raiffa 1993; Bedford and Cooke 1999) offer simplification in the assumptions and advice on practical methodology. A simplification procedure is obtained by defining a parametric function for the utility function, which is determined up to a certain parameter, and the value specification is reduced to assigning a number to this parameter. Examples of such procedures are found in for example Aven (2003). This approach simplifies the specification process significantly, but it can be questioned whether the process imposes a too strong requirement on the specification of the utilities. Is the parametric function actually reflecting the decision maker's preferences? The decision maker should be sceptical to let his preferences be specified more or less automatically without a careful reflection of what his preferences are. Complicated value judgments are not easily transformed to a mathematical formula.

Hence, methods exist that makes the specification process more feasible in practice. Nonetheless, we still see the expected utility theory as difficult to use in many situations, in particular for the situations of main interest in this book, high complexity, uncertainty and ambiguity induced risk problems. It is also acknowledged that even if it were possible to establish practical procedures for specifying utilities for all possible outcomes, decision makers would be sceptical to reveal these as it would mean reduced flexibility to adapt to new situations and circumstances. In situations with many parties, as in political decision making, this aspect is of great importance.

In theory, the meaning of the total expected utility is clear from the assumptions, definitions and the derivations as originally developed (refer Neumann and Morgenstern 1944; Savage 1972) and later operationalised by e.g. the above mentioned authors. In practice, we doubt, however, that practitioners of significant decisions will be able to relate to the resulting utility numbers as a basis for decisions. The utility must always be seen in relation to the defined worst and best outcomes. The implications are not easy to grasp for the relatively trivial example used here. For a truly multi-objective problem it will be even more difficult to comprehend the meaning. Decision makers are not omnipotent actors – they are accountable to others, often with even less capacity than themselves to study underlying assumptions. Communication of the basis for a decision is important. Theoretical soundness of the analysis approach may not be the ultimate requirement for applied decision analysis.

Are there decision situations where this type of approach does have a role? We can see the expected utility approach to be of relevance in repeated, standardized decision situations, where the consequences/attributes of the decision are the same, the stakeholders are few and the values and trade-offs do not vary from situation to situation. An example could be e.g. a bank's decisions to grant mortgages based on risk assessment of the loaner and the project. A number of factors could be relevant to consider. Standardization of the appreciation of the individual factors is desirable and a certain non-linearity of the utility of some factors might be considered. The stakeholders will normally be the bank and the loaner. In such settings, the expected utility approach should be a strong candidate.

The expected utility theory is just a tool, a normative theory saying how to make decisions strictly within a mathematical framework – it does not replace a management review and judgement (evaluation) process of results produced by a formal analysis. There are factors and issues that go beyond strict mathematics that management needs to consider. In practice, there will always be constraints and limitations restricting the direct application of the expected utility thinking. Expected utility theory provides guidance on how people ought to make decisions, not how they are made today. Descriptive theory – theory on how people actually behave – can give insights into decision makers' behavior and limitations, but such theory does not replace normative theory. Descriptive theory provides no guidance for attacking new, specific decision problems of some complexity. Here, a method, a prescriptive tool is required, which provides a consistent procedure to process the elements of the decision problem and aids in making a decision. Such tools are often identified with normative theory. Expected utility theory is such a tool and is by many recognized as a good framework for making decisions, as its assumptions and coherency are hard to disagree with on principle.

The cost–benefit approach is often considered closely linked to expected utility optimisation. However, there are important differences in these two approaches:

- Cost–benefit analysis is risk-neutral in the sense that it is based on expected values. This is in contrast to the utility theory, which may take into account risk aversion. In cost–benefit analysis valuing uncertainty is not an inherent element as it is for expected utility. Modifications of the traditional cost–benefit analysis have been suggested to reflect risk aversion, see e.g. Aven and Flage (2009) (Sect. 3.3). Although arguments are provided to support these methods, their rationale can be questioned. There seem to a significant element of arbitrariness associated with these methods.
- Traditional cost–benefit analysis is based on a notion of objective market prices. For most attributes this requires application of some method of contingent valuation (willingness-to-pay/accept), which invariably generates fundamental disagreement about validity. Utility theory, on the other hand, is by definition subjective with respect to the assessments and values included.
- Discounting of benefits and burdens over time in cost–benefit analysis results in unreasonably low and even negligible regard of burdens for distant future generations. Expected utility theory in its original version addresses single

time periods, but in theory also the time dimension could be reflected using the lottery approach (French et al. 2005).

The results from a cost–benefit analysis and an expected utility analysis have to be interpreted considering the method used. The results must be subjected to evaluation before decisions are taken. The evaluation (review and judgement) process involves taking into account factors outside the boundaries of the model and formal analysis. The decision scenario discussed above involves accident risk. A company may be under scrutiny from the public, authorities or unions for their safety policy and management. In this case, the perception of risk by the public and associated negative attention could influence the decision maker – regardless of the results of the formal analysis. If we take the case of an oil company, conservatism on safety issues might be seen as an advantage for future exploration licenses. Such political considerations could be difficult to capture in the formal analysis, but would still be an important element of the decision making process.

As discussed in the section on cost–benefit analyses above, the primary basis for decisions is the risk assessment. The various attributes: costs, safety, political aspects, etc. are analyzed separately. One alternative, and not an uncommon one, is to leave it a management task to make a decision balancing the costs and benefits. The decision basis could be improved by supplying cost-effectiveness indices for the risk reducing measures, as exemplified. Would that mean lack of coherence in decision-making. Yes, it could in some cases. The ideal is not always attainable. If mathematical coherence means that we loose important aspects for the decision, then the result of a "coherent" decision analysis would become meaningless to the decision maker. The rationality of the result could certainly be questioned, and a more flexible approach should be chosen.

Rationality has a lot to do with consistency. If we adopt and declare the rules to which our statements or actions should conform, we act in a way that is consistent with them. In this sense, rationality appears to be close to the ideas of Watson and Buede (1987). Rules are defined by the people involved in the decision (including stake-holders). This means that whether a behavior is rational will depend on the rules adopted. We find Bayesian decision theory a sensible and (more than anything else) consistent framework for decision analysis. But it follows from our definition of rationality that people who do not abide by the precepts of Bayesian decision theory may be perfectly rational if they abide by their rules for decision making, which could involve informal review and judgement of the results of the risk and decision analysis. Consequently, if one adopts the structure for decision-making presented here, one would behave rationally, according to the rules set by this structure.

Chapter 9
Risk Communication

9.1 Introduction

What is risk communication? The 1989 report on *Improving Risk Communication*, prepared by the Committee on Risk Perception and Communications of the US National Research Council, defined risk communication as:

> An interactive process of exchange of information and opinion among individuals, groups and institutions. It involves multiple messages about the nature of risk and other messages, not strictly about risk, that express concerns, opinions or reactions to risk messages or to legal and institutional arrangements for risk management (US National Research Council 1989:21).

The ultimate goal of risk communication is to assist stakeholders and the public at large in understanding the rationale of a risk-based (risk-informed) decision, and to arrive at a balanced judgment that reflects the factual evidence about the matter at hand in relation to their own interests and values. In other words, good practices in risk communication are meant to help all affected parties to make informed choices about matters of concern to them. At the same time, the purpose of risk communication should not be seen as an attempt to convince people, such as the consumers of a risk-bearing product, that the communicator (e.g. a government agency that has issued advice concerning the product) has done the right thing. It is rather the purpose of risk communication to provide people with all the insights they need in order to make decisions or judgments that reflect the best available knowledge and their own preferences.

Most people show a distinct sensitivity to risks with respect to health and environment. Comparative cross-cultural studies (Rohrmann and Renn 2000) confirm that people all over the world are concerned about the health risks and the environmental quality. Risks pertaining to complex health threats and environmental changes are difficult to communicate because they are usually effective only over a longer time period, may induce negative impacts only in combination with other risk factors and can hardly be detected by human senses (Peltu 1985, 1989;

T. Aven and O. Renn, *Risk Management and Governance*,
Risk, Governance and Society 16, DOI 10.1007/978-3-642-13926-0_9,

Morgan et al. 2001). Risk communication in the field of health and environment therefore needs to address the following major challenges:

- Explain the concept of probability and stochastic effects.
- Cope with different time scales, such as long-term effects.
- Provide an understanding of synergistic effects with other lifestyle factors.
- Improve the credibility of the agencies and institutions that provide risk information (which is crucial in situations where personal experience is lacking and people depend upon neutral and disinterested information).
- Cope with the diversity of stakeholders and parties in the risk management phase.
- Cope with intercultural differences within pluralist societies and between different nations and cultures.

Given these challenges, risk communication is a necessary and demanded activity which is partly prescribed by laws and regulations (also pertaining to the European Community), partly required by public pressure and stakeholder demand. In the light of new activism by consumer and environmental groups, people expect governmental regulatory agencies and the industry to provide more information and guidelines for consumers, workers and bystanders. These challenges are embedded in a new industrial and political paradigm of openness and "right to know" policy framework (Baram 1984). In addition, globalization and international trade make it mandatory that potentially dangerous products are identified, properly labeled and regulated. All people exposed to risks should have sufficient information to cope with risk situations.

This chapter summarizes the main results of risk communication research. First, it addresses the main context variables which have an impact on the success or failure of any risk communication program. Those refer to (1) levels of the risk debate, (2) different types of audiences, and (3) sub-cultural prototypes. Secondly, the chapter will deal with the major functions of risk communication (1) dealing with public perception, (2) changing individual behavior and (3) gaining trust and credibility. The last function of involving stakeholders in the communication process will be covered in a chapter of its own. At the end the chapter will draw some conclusions for improving risk communication practice.

9.2 Context Matters: Risk Communication in Perspective

9.2.1 The Three Levels of Risk Debates

One of the major goals of all risk communication programs is to reconcile the legitimate intention of the communicator to get a message across with the equally legitimate set of concerns and perceptions that each person associates with the risk agent. It is obvious that technical experts try to communicate the extent of their expertise while most observers are less interested in the technical details but want to communicate about the likely impacts of the exposure to the risk for their health and well-being. Regardless of the intension of the communicator, the first step in any communication effort is to find a common denominator, a common language, on which the communication can proceed and develop.

Finding a common denominator or a common wavelength requires a good understanding of the needs of the audience. Having investigated many different types of audiences and issues, our own research has lead us to a classification of typical communication levels that are normally addressed during a risk debate (based on: Funtowicz and Ravetz 1985; Rayner and Cantor 1987; first published in Renn and Levine 1991; refinement in Renn 2002; Renn et al. 2002). These levels refer to:

- Factual evidence and probabilities
- Institutional performance, expertise, and experience
- Conflicts about worldviews and value systems

Figure 9.1 is a graphical representation of this model using a modified version of the original categories. An overview of the three levels of risk debate and their requirements (including elements for evaluation) is illustrated in Table 9.1. The first level involves factual arguments about probabilities, exposure levels, dose–response-relationships and the extent of potential damage. The function of communication on the first level is to provide the most accurate picture of factual knowledge, including the treatment of uncertainties. Even if the objective here is to transfer knowledge or to create a common understanding of the problem, an attempt at two-way communication is needed to ensure that the message has been understood and that the technical concerns of the audience have all been addressed.

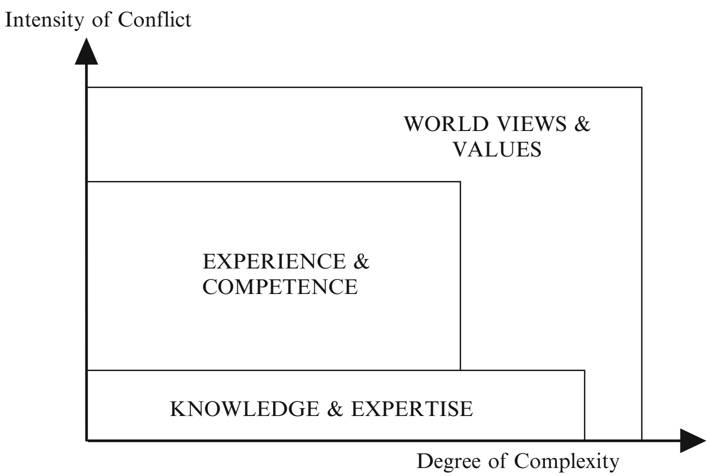

Fig. 9.1 Levels of concern in risk debates

Table 9.1 The three levels of risk debate and their communication needs and evaluation criteria

Criteria levels	Issue of conflict	Communication needs	Evaluation
1	Technical expertise	Information transfer	Access to audience Comprehensibility Attention to public concerns Acknowledgement of framing problems
2	Experience, trustworthiness and performance	Dialogue with stakeholders and the public	Match between public expectations Openness to public demands Regular consultations Commonly agreed procedures for crisis situations
3	Values and world views	Dialogue and mediation	Fair representation of all affected parties Voluntary agreement to obey rules of rational discourse Inclusion of best available expertise Clear mandate and legitimization

The second, more intense, level of debate concerns institutional competence to deal with the risks. At this level, the focus of the debate is on the distribution of risks and benefits, and the trustworthiness of the risk management institutions. This type of debate does not rely on technical expertise, although reducing scientific uncertainty may help. Risk communication on the second level requires evidence that the risk managers of private institutions, as well as public agencies, have met their official mandate and that their performance comes up to public expectations. In a complex and multifaceted society, such evidence is difficult to provide.

Gaining institutional trust requires a continuous dialogue between risk managers, stakeholders and representatives of the public. The chemical industry's program, as it was originally designed, on "responsible care" may serve as an example for such a dialogue (King and Lenox 2000). The participants express their positions on aspects such as emergency planning or accident management; they exchange interpretations about the current situation or future threats and work on mutually acceptable means of improving existing risk management practices. In such dialogues, trust can be gained by showing that the risk management institution is competent, effective and open to public demands, even though the citizen advisory groups within the responsible care programs have been established and organized by industry itself.

At the third level, the conflict is defined along different social values and cultural lifestyles, and their impact upon risk management. In this case, neither technical expertise nor institutional competence and openness are adequate conditions for risk communication. Dealing with values and lifestyles requires a fundamental consensus on the issues that underlie the risk debate. This implies that the communication requirements of the first and second level (i.e. risk information or involvement in a two-way dialogue) are insufficient to find a solution that is acceptable to all or most parties. Often, risk communication by private actors or industry may come across as a convenient strategy to diffuse responsibility and legitimate self-interests or sell products. Public authorities may face major problems if they insist that residual risks are tolerable and can be imposed even upon those who do not share the benefits of the respective activity. In particular, the label "unavoidable" for some residual risk may trigger off major controversies. Are pesticide residues unavoidable? Greenpeace and other more radical environmental groups would probably oppose this statement. The main point here is that the use of the word "unavoidable" may trigger a debate on the third level and fuel (and reinvigorate) the old controversy between the right and the left, between industrialists and environmentalists and other value-driven groups (Mazur 1981; Schwarz and Thompson 1990; Stern 1991).

Third-level debates require new unconventional forms of stakeholder involvement, such as mediation, citizen panels, open forums with special groups and others (see Chap. 10 on stakeholder involvement and participation). The main task of such exercises is to reflect on the relevant values that apply to the situation; to search for solutions that all participants find acceptable or at least tolerable; and to build an atmosphere of mutual trust and respect.

There is a strong tendency for risk management agencies to reframe higher-level conflicts into lower-level ones: third-level conflicts are presented as first- or second-level conflicts, and second-level conflicts as first level. This is an attempt to focus the discussion on technical evidence, in which the risk management agency is fluent. Stakeholders who participate in the discourse are thus forced to use first-level (factual) arguments to rationalize their value concerns. Unfortunately, risk managers often misunderstand this as "irrationality" on the part of the stakeholders. Frustrated, many stakeholders then turn to direct action and protest. In the end, there is only disillusion and distrust.

The three levels of risk debate correspond to the nature of the risk problem under question. It makes sense to distinguish four types of risk problems for which different communication strategies are appropriate (IRGC 2005; Renn 2007), in line with the categorization introduced in Chaps. 1 and 4. The first two categories (simplicity and complexity) relate mostly to level 1 of risk debates, uncertainty to level 2 and ambiguity to level 3. Yet, there are, as usual, interactive effects between and among these categories.

9.2.2 The Characteristics of the Audience: Addressing Different Subcultures in Society

Another major problem of risk communication is to tailor the content of the communication process to the interests and concerns of the different social and cultural groups within a society. Of major assistance to risk communicators is a crude characterization of the audience according to cultural beliefs.

A group of anthropologists and cultural sociologists, such as Aaron Wildavsky, Mary Douglas and Michael Thompson, have investigated the social response to risk and have identified four or five patterns of value clusters that separate different groups in society from each other (Douglas and Wildavsky 1982; Schwarz and Thompson 1990; Thompson et al. 1990; Rayner 1992). These different groups have formed specific positions on risk topics and have developed corresponding attitudes and strategies.

They differ in the degree of *group* cohesiveness (the extent to which someone finds identity in a social group) and the degree of *grid* (the extent to which someone accepts and respects a formal system of hierarchy and procedural rules).

These groups comprise entrepreneurs, egalitarians, bureaucrats, stratified individuals and (in some publications) hermits who can be localized within the group grid space (see Fig. 9.2) (cf. also Section 3.6). Organizations or social groups belonging to the *entrepreneurial* prototype perceive risk-taking as an opportunity to succeed in a competitive market and to pursue their personal goals. They are characterized by a low degree of hierarchy and a low degree of cohesion. They are

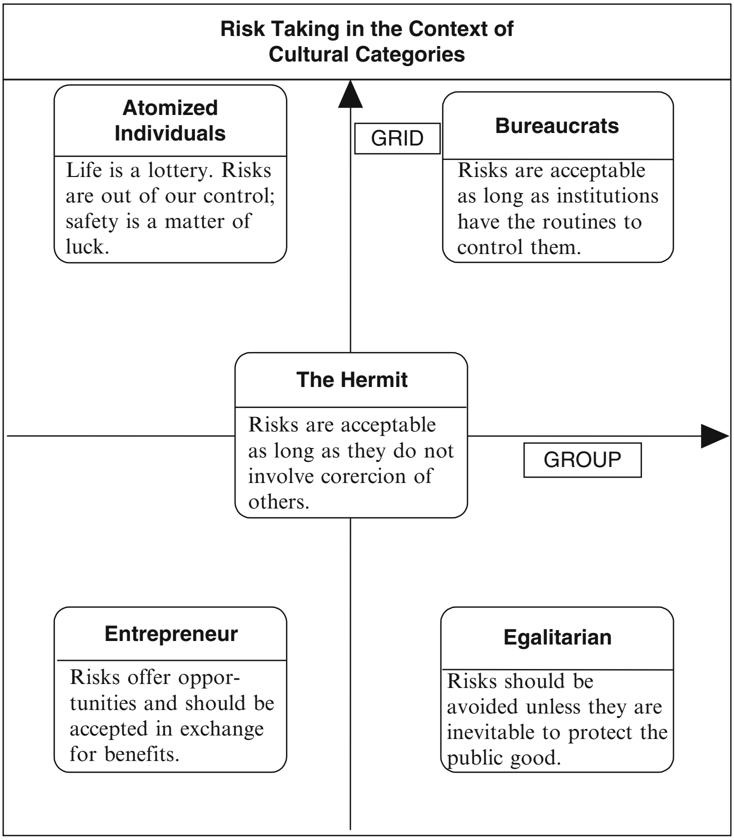

Fig. 9.2 The cultural prototypes of risk experiences (adapted from Thompson et al. 1990 and Renn et al. 2007:57)

less concerned about equity issues and would like the government to refrain from extensive regulation or risk management efforts. This group contrasts most with organizations or groups belonging to the *egalitarian* prototype, which emphasizes cooperation and equality rather than competition and freedom. Egalitarians are also characterized by low hierarchy, but have developed a strong sense of group cohesiveness and solidarity. When facing risks, they tend to focus on the long-term effects of human activities and are more likely to abandon an activity (even if they perceive it as beneficial to themselves) rather than take chances. They are particularly concerned about equity.

The third prototype – the *bureaucrats* – relies on rules and procedures to cope with uncertainty. Bureaucrats are both hierarchical and cohesive in their group relations. As long as risks are managed by a capable institution and coping strategies have been provided for all eventualities, there is no need to worry about risks.

Bureaucrats believe in the effectiveness of organizational skills and practices, and regard a problem as solved when a procedure to deal with its institutional management is in place. The fourth prototype, the group of *atomized or stratified individuals,* in principle, believes in hierarchy, but it does not identify with the hierarchy to which they belong. These people trust only themselves, are often confused about risk issues and are likely to take on high risks for themselves, but oppose any risk they feel is imposed upon them. At the same time, however, they see life as a lottery and are often unable to link harm to a concrete cause. In addition to the four prototypes, there may be a hybrid group called the *autonomous individuals, or the hermits*, who can be grouped at the centre of the group grid coordinates. Thompson (1980) describes autonomous individuals as self-centred hermits and short-term risk evaluators. They may also be referred to as potential mediators in risk conflicts since they establish multiple alliances with the four other groups and believe in hierarchy only if they can relate the authority to superior performance or knowledge.

This theory has been criticized on several grounds (Nelkin 1982; Sjöberg 1996; Breakwell 2007:72 ff.). The debate is still proceeding without a clear consensus in sight. Many risk communicators have expressed that this classification has helped them tremendously in preparing communication programs for different audiences. There is sufficient anecdotal evidence that people with an entrepreneurial attitude react very differently to specific arguments compared to people with an egalitarian or bureaucratic attitude. For example, a reference to cost–benefit ratios makes perfect sense when presented to an audience of entrepreneurs, but would trigger off outrage when referred to in a group of egalitarians.

9.2.3 Different Types of Audiences

The last context variable that is important to mention here is the interest of the target audience in the issue. As pointed out before, the group of the atomized individuals will have little if any interest in the debate on risk assessment methods.

For practical purposes of preparing risk communication programs, it is helpful to have a classification of potential audiences at hand, even if each audience is certainly unique. The classification that is offered here refers to two dimensions: the interest of the audience in the subject and the type of arguments that different audiences may find appealing or, at the other end of the spectrum, appalling. For both purposes, our preferred choice is the “elaboration-likelihood model of persuasion”, developed by Petty and Cacioppo (1986). The major component of the model is the distinction between the *central or peripheral route of persuasion*. The central route refers to a communication process in which the receiver examines each argument carefully and balances the pros and cons in order to form a well-structured attitude. The peripheral route refers to a faster and less laborious strategy to form an attitude by using specific cues or simple heuristics.

When is a receiver likely to take the central route and when the peripheral route? According to Petty and Cacioppo, route selection depends on two factors: *ability and motivation. Ability* refers to the physical availability of the receiver to follow the message without distraction, *motivation* to the readiness and interest of the receiver to process the message. The central route is taken when the receiver is able and highly motivated to listen to the information. The *peripheral route* is taken when the issue is less relevant for the receiver and/or the communication context is inadequate to get the message across. In this case, the receiver is less inclined to deal with each argument, but forms an opinion or even an attitude on the basis of simple cues and heuristics. One can order the cues into four categories: *source-related, message-related, transmitter-related, and context-related cues*. These are illustrated in Table 9.2 (adopted from Renn and Levine 1991).

Within each route, the mental process of forming an attitude follows a different procedure. The central route is characterized by a systematic procedure of selecting arguments, evaluating their content, balancing the pros and cons, and forming an attitude. The peripheral route, however, bypasses the systematic approach and assigns credibility to a message by referring to the presence of cues.

Unfortunately, the communication process is more complex than the model implies. First, the audience of a communicator may be mixed and may consist of persons with central and peripheral interests in the subject. Many cues that are deliberately used to stir peripheral interest (e.g. using advertising methods for risk communication) can be offensive for people with a central interest in the subject.

Table 9.2 Clues relevant for peripheral communication

Type	Examples
Source-related	Credibility, reputation, social attractiveness, perceived impartiality
Message-related	Length, number of arguments, package quality (such as color, paper, graphical appeal, illustrations, layout), presence of highly appreciated symbolic signals
Transmitter-related	Perceived neutrality, past performance of transmitter, perceived credibility, reputation
Context-related	Crisis situation, conflict situation, social and cultural setting, circumstances of transmission

Second, most people are not predisposed to exercise a central or peripheral interest in a subject. It may rather depend on the message itself whether it can trigger central interest or not. Third, and most important, the two routes are prototypes of attitude formation and change, and therefore only analytically separable. In reality, the two routes are interlinked. Persons may tend to respond primarily to the cues or primarily to the arguments presented, but they will not exclusively pursue one route or the other.

An effective risk communication program must therefore contain a sufficient number of peripheral cues to initiate interest in the message, but also enough "rational" argumentation to satisfy the audience with central interest in the subject. The problem is how to avoid anger and rejection by centrally interested persons if they are confronted with "superficial" cues, e.g. the simple assertion that food will remain safe and healthy, and how to sustain the interest of the peripherally interested persons if they are confronted with lengthy arguments. The problem can be resolved if the message eschews "obvious" cues, but includes cues that are acceptable to both types of audiences.

9.3 Responding to Risk Communication Needs

9.3.1 Functions of Risk Communication

In a thorough review of risk communication, William Leiss identified three phases in the evolution of risk communication practices (Leiss 1996:85 ff.). The first phase of risk communication emphasized the necessity of conveying probabilistic thinking to the general public and to educate the laypersons to acknowledge and accept the risk management practices of the respective institutions. The most prominent instrument of risk communication in phase 1 was the application of risk comparisons. If anyone was willing to accept x fatalities as a result of voluntary activities, they should be obliged to accept another voluntary activity with less than x fatalities. However, this logic failed to convince audiences: people were unwilling to abstract from the context of risk-taking and the corresponding social conditions, and they also rejected the reliance on expected values as the only benchmarks for evaluating risks. When this attempt at communication failed, phase 2 was initiated. This emphasized persuasion and focused on public relations efforts to convince people that some of their behavior was unacceptable (such as smoking and drinking) since it exposed them to high risk levels, whereas public worries and concerns about many technological and environmental risks (such as nuclear installations, liquid gas tanks or food additives) were regarded as overcautious due to the absence of any significant risk level. This communication process resulted in some behavioral changes at the personal level: many people started to abandon unhealthy habits. However, it did not convince a majority of these people that the current risk management practices for most of the technological facilities and environmental risks were, indeed, the politically appropriate response to risk.

The one-way communication process of conveying a message to the public in carefully crafted, persuasive language produced little effect. Most respondents were appalled by this approach or simply did not believe the message, regardless of how well it was packaged; as a result, phase 3 evolved. This current phase of risk communication stresses a two-way communication process in which it is not only the members of the public who are expected to engage in a social learning process, but the risk managers as well. The objective of this communication effort is to build up mutual trust by responding to the concerns of the public and relevant stakeholders. Good practices in risk communication help stakeholders to make informed choices about matters of concern to them and to create mutual trust (Hance et al. 1988; Lundgren 1994; Breakwell 2007:130 ff.).

Risk communication is needed throughout the whole risk-governance chain, from the framing of the issue to the monitoring of risk management impacts. The precise form of communication needs to reflect the nature of the risks under consideration, their context and whether they arouse, or could arouse, societal concern. Communication has to be a means of ensuring that:

- Those who are central to risk framing, risk appraisal or risk management understand what is happening, how they are to be involved, and, where appropriate, what their responsibilities are (internal risk communication) and
- Others outside the immediate risk appraisal or risk management process are informed and engaged (external risk communication)

The variety of objectives that one can associate with both internal and external risk communication can be summarized in four general categories (cf. Covello et al. 1986; US National Research Council 1989; Renn 2002; Renn et al. 2002):

- To foster understanding of risks among different constituencies (customers, workers, consumers, interest groups, environmental groups, and the general public), including risks pertaining to human health and the environment, taking into account the dominant risk perception patterns of the target audiences (*enlightenment function*).
- To assist people in changing their daily behavior or habits with the purpose to reduce their risks to life and personal health (*behavioral change function*).
- To promote trust and credibility towards those institutions that handle or regulate risks (*trust-building function*).
- To provide procedures for dialogue and alternative methods of conflict resolution as well as effective and democratic planning for the management and regulation of risks (*participatory function*).

The first objective relies on a better understanding of peoples' concerns and perceptions of risk. Section 9.3.2 will deal with this issue. Section 9.3.3 will deal with the persuasion literature and its impact on behavioral change. Section 9.3.4 will cover the communicational means to promote trust and credibility. The last function on stakeholder and public participation will be addressed in Chap. 10.

9.3.2 Function 1: Coping with Risk Perception

Today's society provides an abundance of information, much more than any individual can digest. Most information to which the average person is exposed will be ignored. This is not a malicious act but a sheer necessity in order to reduce the amount of information a person can process in a given time. Once information has been received, common sense mechanisms process the information and help the receiver to draw inferences. These processes are called intuitive heuristics (Kahneman and Tversky 1979; Slovic 1987). They are particularly important for risk perception, since they relate to the mechanisms of processing probabilistic information. One example of an intuitive strategy to evaluate risks is to use the mini–max rule for making decisions, a rule that many consumers and people exposed to chemical hazards prefer to apply (Lopes 1983). This rule implies that people try to minimize post-decisional regret by choosing the option that has the least potential for a disaster regardless of its probability. The use of this rule is not irrational. It has been developed over a long evolution of human behavior as a fairly successful strategy to cope with uncertainty, i.e. better safe than sorry.

This heuristic rule of thumb is probably the most powerful factor for rejecting or downplaying information on risks. If any exposure above zero or above a defined threshold (minus safety factor) is regarded as negative, the simple and intuitively reasonable rule to minimize exposure makes perfect sense. Most regulatory regimes are based on this simple rule (Morgan 1990) ranging from the ALARA principle (risk should be reduced to a level this is As Low As Reasonably Achievable) to the application of the best available control technology (BACT). Such principles imply that any exposure might be negative so that avoidance is the most prudent reaction.

Psychological research has revealed different meanings of risk depending on the context in which the term is used (review in Slovic 1992; Boholm 1998; Rohrmann and Renn 2000; Jaeger et al. 2001). With respect to human-induced risks Table 9.3 illustrates the main semantic images (Renn 1990). They were described in Sect. 6.4.2.

Risks associated with substances that can be linked to toxic, carcinogenic or genotoxic effects are mostly to be found in the category of insidious dangers. In this risk perception category, scientific studies facilitate early detection of lurking danger and the discovery of causal relationships between activities or events and their latent effects. This categorization applies for example, to low doses of radiation, food additives, chemical crop protection products, and genetic manipulation of plants and animals. Perception of such risk is closely related to the need to find causes for apparently inexplicable consequences (e.g. seal deaths, childhood cancer, or forest dieback). The probability of such an event is not seen as natural variation for the event in question, but rather as the degree of certainty with which a single event can be traced to an external cause (Kraus et al. 1992; Renn 2004a).

This has far-reaching implications. When people are confronted with risks belonging to the category of insidious dangers, they depend upon information provided by third parties because, as a rule, these risks cannot be perceived with the human senses.

Table 9.3 The five semantic images of risk perception (adapted from Renn 1990)

1 Emerging danger (*fatal threat*)
– Artificial risk source
– Large catastrophic potential
– Inequitable risk–benefit distribution
– Perception of randomness as a threat
2 Stroke of Fate
– Natural risk source
– Belief in cycles (not perceived as a random event)
– Belief in personal control (can be mastered by oneself)
– Accessible through human senses
3 Personal thrill (*desired risks*)
– Personal control over degree of risk
– Personal skills necessary to master danger
– Voluntary activity
– Non-catastrophic consequences
4 Gamble
– Confined to monetary gains and losses
– Orientation towards variance of distribution rather than expected value
– Asymmetry between losses and gains
– Dominance of probabilistic thinking
5 Indicator of insidious danger (*slow killer*)
– (Artificial) ingredient in food, water or air
– Delayed effects; non-catastrophic
– Contingent upon information rather than experience
– Quest for deterministic risk management
– Strong incentive for blame

Moreover, these risks are highly complex (i.e. there are usually many years of latency between emission and effect). When we drink water containing pesticide residues, health symptoms may be visible only many years later, if at all.

If laypeople assess these risks, they sooner or later come across a key question: do I trust the institutions providing the necessary information or do I not? Trust is a key variable in the perception of risks in this category (Siegrist 2000; Siegrist et al. 2000). If the answer is yes, people are willing to use a balancing approach between risks and benefits and to assign trade-offs between the two. If the answer is no, they demand zero risk. For example, if one depends upon information provided by third parties for the assessment of such risks, and these third parties are not considered trustworthy, then one does not accept any cost–benefit calculation. If the answer is yes, such a balancing act between perceived benefits and risks is performed. If the answer is maybe, often peripheral factors become decisive for deriving a final judgement (Renn and Levine 1991). These include hints or cues related to conflicts of interest (is the communicator paid by industry or an NGO?); similarity of values (does the communicator share the same lifestyle or cultural background?); or affiliation to a highly esteemed reference group (does the communicator belong to a social group whom I deeply respect – for example, Nobel Prize winners?).

This perception pattern is, for example, a central problem of genetically modified organisms (GMOs) in agriculture and food. Many surveys indicate that those

Table 9.4 Overview of qualitative characteristics (adapted from Renn 1990)

Qualitative characteristics	Direction of influence
Personal control	Increases risk tolerance
Institutional control	Depends upon confidence in institutional performance
Voluntariness	Increases risk tolerance
Familiarity	Increases risk tolerance
Dread	Decreases risk tolerance
Inequitable distribution of risks and benefits	Depends upon individual utility; strong social incentive for rejecting risks
Artificiality of risk source	Amplifies attention to risk; often decreases risk tolerance
Blame	Increases quest for social and political responses

institutions which want to advance green genetic engineering meet with a lack of faith on the part of consumers (Frewer et al. 1995; Zwick and Renn 1998; Hampel 2004; Siegrist 2000). Under these circumstances, consumers who are unable to assess the hazard of GMOs on their own, demand zero risk. This example also proves that it is not helpful to improve the acceptance rate of GMOs by providing risk–risk comparisons. The same people, who demand zero risk in genetic engineering, will ride a bicycle, drive a car or get on an airplane. They do not perceive this as inconsistent since these means of transportation are part of a different risk pattern, where the trade-off between benefit and risk are considered legitimate.

In addition to the images that are linked to different risk contexts, the type of risk involved and its situational characteristics shape individual risk estimations and evaluations (Slovic et al. 1981). Psychometric methods have been employed to explore these qualitative characteristics of risks (Slovic 1992). Table 9.4 lists the major qualitative characteristics and their influence on risk perception.

Furthermore, the perception of risk is often part of an attitude that a person holds about the cause of the risk, i.e. consumption, production or use of hazardous materials. Attitudes encompass a series of beliefs about the nature, consequences, history, and justifiability of a risk cause. Due to the tendency to avoid cognitive dissonance, i.e. emotional stress caused by conflicting beliefs, most people are inclined to perceive risks as more serious and threatening if other beliefs contain negative connotations and vice versa. Often risk perception is a product of these underlying beliefs rather than the cause for these beliefs (Renn 1990). This has an effect on for instance chemical additives as they are associated with strong negative connotations in contrast to natural ingredients such as acrylamide where people are more willing to assign risk–risk or risk–benefit trade-offs.

9.3.3 Function 2: Persuasion and Behavioral Change

Psychological research about attitude and attitude change has shed some light on the conditions under which receivers of information assign credibility to a communicator and change their own attitudes or even behaviour. These research results are usually discussed in the framework of persuasion (Petty and Wegener 1998; Perloff 2003). What elements of a message or a communication context are likely to enhance or diminish the persuasive effect of a message? What elements of the message are remembered and which trigger changes in opinions or attitudes?

Before reporting on some of these studies, we should mention their restrictions and limitations to avoid misinterpretation (Anderson 1983; McGuire 1985; Breakwell 2007:133). Most of the research on attitude change has been performed in laboratory settings with student populations. Most experiments were conducted with a limited set of issues or topics so that it is not clear whether the revealed relationships can be extended to other topics or audiences. Many experiments were conducted during the 1960s and 1970s, both time periods in which the social climate for trust and credibility differed considerably from today. For example, experiments involving experts as communicators usually resulted in considerable "persuasion" effects during the early 1960s, whereas recent experiments demonstrate more ambiguous results depending upon the existence of social controversy and the expert's own perceptions (Eagly et al. 1981; Heesacker et al. 1983; Ajzen 1992; Petty and Wegener 1998; Cialdini and Sagarin 2005). But at the same time, many of the research findings have been consistent over time and have been tested with a variety of subjects and topics (Eagly and Chaiken 1984; Chaiken and Stangor 1987; Ajzen 1992; Cialdini 1995; Stiff and Mongeau 2003). They can at least be regarded as well-founded hypotheses for application in risk communication until more specific research studies are conducted (similar conclusion in Drottz-Sjöberg 2003).

The following review of research results is based on psychological experiments of persuasion. For the purpose of this chapter, we will only present their conclusions and omit their methodologies or designs (Readers interested in a more detailed review should consult the following: Eagly and Chaiken (1984); McGuire (1985); Chaiken and Stangor (1987); Ajzen (1992); Cialdini (1995); Stiff and Mongeau (2003), and, specifically for risk communication, Lee (1986); Drottz-Sjöberg (2003); Breakwell 2007:132 ff.). Factors that have been found to enhance the persuasiveness of communication include the following:

- *Attractiveness of information source:* attractiveness is composed of similarity of positions between source and receiver, likeability of the source and physical attraction (McGuire 1985; Lee 1986; Chaiken and Stangor 1987; Ajzen 1992).
- *Sympathy or empathy of the receiver for the source:* this refers to the possibility of a receiver identifying with the source or its motivations (Eagly and Chaiken 1984; McGuire 1985; Peters et al. 1997).
- *Credibility of source:* among the components tested are perceived competence, expertise, objectivity, impartiality and interest in the source (Tyler 1984; Rempel and Holmes 1986; Lee 1986; Jungermann et al. 1996; Breakwell 2007:133).
- *Suspicion of honest motives:* receivers do not detect any hidden agendas or motives behind the communication effort (Rosnow and Robinson 1967; Eagly et al. 1981).
- *High social status or power of communication source:* the effect of these two variables depends heavily upon the issue and the composition of the audience

(McGuire 1985; Chaiken and Stangor 1987; Cialdini and Goldstein 2004; Breakwell 2007:133).

These factors seem almost intuitively plausible. A communicator is likely to make a longer lasting impression on the audience if the message appears honest, accurate and fair, and if the communicator is a likable person with whom the audience can easily identify. The more difficult question, however, is how a communicator can impart these impressions on the audience under real-life conditions. What do we know about the effectiveness of message composition and personal appeal that would allow us to tailor information programmes in order to seek more persuasive power?

Unfortunately (or fortunately, depending upon one's perspective), we do not have any recipes to enhance credibility or to increase the persuasiveness of a message. But psychological research during the past two decades has yielded some interesting, sometimes even counterintuitive, findings that link specific aspects of message composition or personal style of communication with persuasive effect. Some of the more counterintuitive factors deserve special mention:

- *High credibility sources, such as scientists or opinion leaders, produce more opinion change, but no difference in message learning*. The learning of a message is more closely related to the similarity of the message than to existing attitudes and beliefs (Hovland and Weiss 1967; McGuire 1985; Ajzen 1992).
- *Perceived expertise depends upon many factors*. Among them are status, education, perception of technical authority, age and social class. If the expertise of a communicator is challenged in public, people tend to focus on replacements for expertise, such as suspected interests or reliance on reference group judgements (Heesacker et al. 1983; Stiff and Mongeau 2003).
- *Stating explicitly the persuasive intent is usually more convincing than hiding such an intention and leaving it to the audience to make their own inferences*. People like to know what the communicator wants them to believe. If it is not openly stated, they will suspect a hidden agenda (McGuire 1985; Lee 1986; Cialdini and Sagarin 2005).
- *Perceived fairness and social status are both variables that can compensate for a lack of objectivity*. Even if people are aware that the communicator has a vested interest in the issue and that he or she argues from a specific viewpoint, they may believe the message or develop confidence in the communicator, provided that the information presented appears to be fair to potential counterarguments and that it is presented with technical authority (Lee 1986).
- *Being explicit when drawing conclusions and presenting counterarguments have proven more effective than operating with implicit conclusions or presenting only one side of the story*. The two often conflicting goals of the fairness of the communicator's view to the opponents and the honesty of one's own motives have to be reconciled in each communication effort in order to be most persuasive (McGuire 1985; Aizen 1992; Breakwell 2007:132).
- *The perception that the goals and motives of the source serve a common interest or refer to highly esteemed social values, such as protection of the environment*

or public health, enhances public confidence in the communicator but reinforces distrust if the task performance of the communicator is perceived as weak. People invest more trust in these institutions in the beginning, but tend to be more disappointed if the outcome does not match their expectations (Tetlock 1986).

- *The agreement to listen to disliked sources increases the probability of attitude change*. Although the likeableness of a source usually enhances the persuasive effect, the mere acceptance of listening to a non-likeable source may motivate the audience to focus on the message instead of the source of communication. The psychological mechanism involved here is called avoidance of cognitive dissonance (Festinger 1957). One can only justify spending time with a disliked source if the message at least is worth the effort. However, the motivation to engage in communication with an unpopular person may also serve to reassure how bad the source and the message are. Which of the two reactions is likely to emerge as a result of a communication with a disliked source? This depends upon the degree of commitment to one's previous attitude, the strength and salience of the attitude with respect to other beliefs and values, and the perception of the source's vested interests (Fazio et al. 1977; Chaiken and Stangor 1987; Cooper et al. 2005).
- *Credibility reversal*. When people generate primarily positive thoughts in response to a message (e.g. because the message contains strong arguments) and then learn of the source, high source credibility leads to more favourable attitudes than does low source credibility. When people have primarily negative thoughts in response to a message (e.g. because it contains weak arguments), however, this effect is reversed – that is, high source credibility leads to less favorable attitudes than does low source credibility (Tormala et al. 2006).

All of these insights are helpful to design communication programs and to train communicators for their task. But it should be kept in mind that most of these results were accomplished in rather artificial laboratory environments and may not be valid for the specific risk communication arena. Furthermore, most of these insights refer to changes in attitude not behavior. Most analysts agree that once attitudes towards a risk or a risk source (activity) are formed, they generate a propensity to take action. As known from many attitude studies, the willingness to take action, however, is only partly related to overt behavior (Allport 1935; Rokeach 1969; Wicker 1969; Fishbein and Ajzen 1975; Feldman and Lynch 1988; Ajzen 1992; Wall 1995; Sutton 1998). A positive or negative attitude is a necessary but not sufficient step for corresponding behaviour. A person's decision to take action depends upon many other variables, such as behavioral norms, values and situational circumstances. Hence, the communication process will influence the receiver's behavior; but the multitude of sources, the plurality of transmitters and the presence of situational forces on personal behavior render it almost impossible to measure, not to mention to predict, the effect of a single communication activity.

The weak correlation between attitudes and behavior is one of the major problems in risk communication that aims to change behavior (e.g. for emergency responses). Most analysts agree that it is difficult enough to change or modify attitudes through information; but that it is even more difficult to modify behavior. Some success stories (Salcedo et al. 1974; Fessenden-Raden et al. 1987; Pinsdorf 1987) in the area of health risks (e.g. reducing cholesterol and pesticide use), as well as some failures (Mazur 1987; Sandman et al. 1987; Powell and Leiss 1997) to promote actions (e.g. protection against indoor radon) suggest that three factors are crucial for increasing the probability of behavioral changes:

- *Continuous transmission of the same information* even after a positive attitude has been formed towards taking action (need for constant reinforcement).
- *Unequivocal support of most relevant information sources* for the behavioral change advocated in the communication process (need for consistent and consensual information).
- *Adoption of the behavioral changes by highly esteemed reference groups or role models* (social incentive for imitation).

Behavioral changes, particularly if they involve painful changes of habits, are rarely triggered by information alone. Rather, information may be effective only in conjunction with other social factors, such as social norms, roles and prestige.

9.3.4 Function 3: Enhancing Trust and Credibility

With the advent of ever-more complex technologies and the progression of scientific methods to detect even the smallest quantities of harmful substances, personal experience of risk has been increasingly replaced by information about risks and individual control over risk by institutional risk management. As a consequence, people rely more than ever on the credibility and sincerity of those from whom they receive information about risk (Barber 1983; Blair 1987; Zimmerman 1987; Johnson 1999; Löfstedt 2003, 2005; Breakwell 2007:140 ff.). Thus, trust in institutional performance has been a major key for risk responses. Trust in control institutions is able to compensate for even a negative risk perception and distrust may lead people to oppose risks even when they are perceived as small.

Since trust is one major objective in risk communication and also a prerequisite for many other objectives, risk communicators need a better understanding of the meaning and implications of the term trust (Luhmann 1980; Rempel and Holmes 1986; Covello 1992; Earle and Cvetkovich 1996; Peters et al. 1997; Siegrist and Cvetkovich 2000; Löfsedt 2005). For our purpose of defining trust in the context of the communication within social organizations, we suggest the following definition (Renn and Levine 1991):

> Institutional trust refers to the generalized judgement whether and to what degree the perceived performance of an organization matches the subjective and/or socially shared expectations of a variety of social actors and the public with respect to its assigned institutional function, including its perceived competence in meeting its tasks and its communication style in dealing with professionals, stakeholders, media and the public at large.

Although trust and confidence are often used interchangeably, confidence in a source can be distinguished from trust as a more enduring experience of trustworthiness over time. Accordingly, *confidence denotes the generalized impression of an enduring and continuous experience of the trustworthiness of an organization based on its perceived performance record*. This distinction between confidence and trust is sometimes reversed in the literature (Cvetkovich 2000). In our view, however, the intuitive connotation is that confidence builds upon the experience of trust and not vice versa. People have confidence in an organization if their prior investment of trust in that source has not resulted disappointing over a longer period of time. The last term in this context refers to credibility. This term is related only to communication. As a result, we can define *credibility as the degree of shared and generalized expectancy that the communication efforts of an organization match to the subjective and/or socially shared expectations in terms of honesty, openness, responsiveness and professionalism*.

To make these terms more operational, it makes sense to identify the major features that constitute trust, confidence and credibility. The literature includes several approaches (Barber 1983; McGuire 1985; Sheridan 1985; Lee 1986; Earle and Cvetkovich 1996; Cvetkovich 2000; Löfstedt 2003). Renn and Levine (1991) tried to amalgamate some of the proposed suggestions from the literature and developed a classification scheme consisting of six components. Empathy was later added to this list (Covello 1992; Peters et al. 1997). Table 9.5 lists the seven components:

Trust relies on all seven components; but a lack of compliance in one attribute can be compensated for by a surplus of goal attainment in another feature. If objectivity or disinterestedness is impossible to accomplish, a fair message and faith in the good intention of the source may serve as substitutes. Competence may also be compensated for by faith and vice versa. Consistency is not always essential in gaining trust; but persistent inconsistencies destroy the common expectations and role models for behavioural responses. Trust cannot evolve if social actors experience inconsistent responses from others in similar or even identical situations. Finally, empathy signals the public that the institution cares about the effects of its performance. If people assign high competence to an organization, empathy helps but is not essential. If performance is in doubt, empathy can make all the difference in the world between trust and distrust.

Table 9.5 Components of trust (adopted from Renn and Levine 1991)

Components	Description
Perceived competence	Degree of technical expertise in meeting institutional mandate
Objectivity	Lack of biases in information and performance as perceived by others
Fairness	Acknowledgement and adequate representation of all relevant viewpoints
Consistency	Predictability of arguments and behavior based on past experience and previous communication efforts
Sincerity	Honesty and openness
Empathy	Degree of understanding and solidarity with potential risk victims
Faith	Perception of goodwill in performance and communication

In risk debates, issues of trust evolve around institutions and their representatives. People's responses to risk depend, among others, on the confidence they have in risk initiating and controlling institutions (Slovic et al. 1991). Since the notion of risk implies that random events may trigger accidents or losses, risk management institutions are always forced to legitimate their action or inaction when faced with a negative health effect such as cancer or infertility. On the one hand, they can cover up mismanagement by referring to the alleged randomness of the event (labeling it as unpredictable or an act of God). On the other hand, they may be blamed for events against which they could not possibly provide protective actions in advance (Luhmann 1989, 1990). The stochastic nature of risk demands trustful relationships between risk assessors, risk managers and risk bearers since single events do not prove nor disprove assessment mistakes or management failures.

The handling of risk by private corporations and governmental agencies has been crucial for explaining the mobilization rate of individuals for taking actions. The more individuals believe that risks are not properly handled, in addition to being perceived as serious threats, the higher is the likelihood of them becoming politically active. It has been shown that in the case of nuclear power generation, the disillusionment of the US population with the nuclear option as well as the number of people becoming political advocates of antinuclear policies grew simultaneously with the growing distrust in the nuclear regulatory agency (Baum et al. 1983). Negative attitudes are a necessary but by far not a sufficient reason for behavioral responses. Public confidence in institutional performance is another and even more important element in triggering behavioral responses.

Establishing and gaining trust is a complex task that cannot be accomplished simply by applying certain operational guidelines (such as declaring empathy) in a mechanical fashion. There is no simple formula for producing trust. *Trust grows with the experience of trustworthiness*. Nobody will read a brochure, attend a lecture, or participate in a dialogue if the purpose is solely to enhance trust in the communicator. Trust is the invisible product of a successful and effective communication of issues and concerns. The less trust is being alluded to in a communication process, the more likely it is either sustained or generated. *There is only one general rule for building trust: listening to public concerns and, if demanded, getting involved in responsive communication*. Information alone will never suffice to build or sustain trust. Without systematic feedback and dialogue there will be no atmosphere in which trust can grow (Morgan et al. 2001).

9.4 Lessons Learned for Risk Communication

The objective of this chapter has been twofold: *First,* it has been aimed at providing the necessary background knowledge in order to understand the needs and concerns of the target audiences when it comes to risk communication. *Second,* it is designed to provide specific information on the potential problems and barriers for successful risk communication.

The main message of the chapter is that *risk communication goes beyond public information and public relation*. It needs to be seen as a necessary complement to risk assessment and management. Advertisement and packaging of messages can help to improve risk communication, but they will be insufficient to overcome the problems of public distrust in risk assessment and management institutions and to cope with the concerns, worries, or complacency of consumers (Bohnenblust and Slovic 1998). The potential remedies to these two problems lie in a *better performance* of all institutions dealing with or regulating risks and in structuring the risk communication program mainly as a *two-way communication process*. With respect to performance, it is well understood that many risk management institutions complain that their specific task is not well understood and that public expectations do not match the mandate or the scope of management options available to these institutions. This is specifically prevalent for any communication program on possible non-threshold toxic effects. First, the issue at stake, health and environment, tops the concerns of the public of all industrialized countries. So people are very concerned when confronted with a challenge to their fundamental belief that all exposure to potentially toxic or even carcinogenic material is bad and should be avoided. Second, the probabilistic nature of risk impedes an unambiguous evaluation of management success or failure. If there is a small chance that somebody might experience adverse effects from a low dose that is deemed acceptable by the risk regulators, it will be difficult to justify the decision to set this limit. In spite of these difficulties, careful management, openness to public demands, and continuous effort to communicate are important conditions for gaining trustworthiness and competence. These conditions cannot guarantee success, but they make it more probable.

The second most important message is that risk management and risk communication should be seen as parallel activities that complement each other. Risk communication supports ongoing management efforts as a means to gain credibility and trustworthiness. By carefully reviewing in-house performance, by tailoring the content of the communication to the needs of the final receivers, and by adjusting the messages to the changes in values and preferences, risk communication can convey a basic understanding of the choices and constraints of risk assessment and risk management and thus create the foundations for a trustworthy relationship between the communicator and the audience. Specifically a sequential organization of different discourse models is required to develop a continuous link between public dialogue and further management decisions.

The third main message is to take risk perception seriously. Any successful risk communication program needs to address the problems faced by risk perception. Risk perception studies can help to anticipate public reaction to new risk sources. Regardless whether individuals belong to the cultural category of the risk-taking entrepreneur or the rather risk-averse egalitarian, timely information and dialogue are favored by any individual.

Such a sophisticated risk communication program requires an approach based on multi-channel and multi-actor information tailoring. A communication program needs to be designed to meet the needs of different audiences. In addition, we recommend a dialogue program with the potential stakeholders if the issue becomes a hot topic in the public debate. In the case of a heated debate leading to an intense controversy it is not sufficient to establish round tables of participants and let them voice their opinions and concerns. Since all three levels of a risk debate are then affected at the same time, one needs a more structured approach. First, it is necessary to continue to organize epistemological discourses on the questions of the scientific benefits of this approach, the best benchmarking procedure and the suggested safety factors employed. Once credible answers are provided to these questions, a more reflective discourse is necessary in which stakeholders from industry, NGOs, consumer groups and other influential groups convene and discuss the issue of risk tolerability thresholds and the determination of acceptable regulatory frameworks. As soon as the consumers would be affected by any regulatory changes, a participative discourse is required. The goal here would be for risk analysts and managers to consult with opinion leaders and get their informed consent or informed rejection.

Risk communication will not perform any miracles. It can help to overcome some of the perception biases that have been outlined above and make people more susceptible to the risks and benefits of the products or activities in question. Information and dialogue are valuable instruments to generate and sustain public trust in regulating agencies and the industry.

Chapter 10
Stakeholder and Public Involvement

10.1 Introduction

The risk governance process, as it has been described in Chap. 4 implies decision-making processes which affect various groups of actors. On a general level, there is the distinction between the risk producers on the one hand, and those who are exposed to the risks on the other hand. It is obvious, that between these two groups, conflicting interests are to be expected. The two groups can be further divided into subgroups with distinct interests of their own, the so called stakeholder. They are defined here "as socially organised groups that are or will be affected by the outcome of the event or the activity from which the risk originates and/or by the risk management options taken to counter the risk" (IRGC 2005:49). In general risk issues affect the four main stakeholders in society. These are *political*, *business*, *scientific* and *civil society* representatives (as far as they are socially organized). Additionally, other groups that play a role in the risk governance process can be defined: the *media*, *cultural elites* and *opinion leaders*, and the *general public*, either in their role as non-organized *affected* public, or as the non-organized *observing* public (cf. IRGC 2005:50).

As governance aims at reaching acceptance of the outcomes of the decision-making process, the interests of all these different actors have to be met. At the same time, however, the number of options and the procedures how they are selected have to be restricted, as time and effort of the participants of the governance process have to be regarded as spare resources and therefore treated with care. Consequently, an inclusive risk governance process, as it is required when facing risks, can be characterized by inclusion of all affected parties on one hand, and closure concerning the selection of possible options and the procedures that generate them, on the other hand:

Inclusion describes the question of what and whom to include into the governance process, not only into the decision-making, but into the whole process from framing the problem, generating options and evaluating them to coming to a joint conclusion. This goal presupposes that, at least, major attempts have been made to

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meet the following conditions (cf. IRGC 2005:49 f.; Trustnet 1999; Webler 1999; Wynne 2002):

- Representatives of all four major actor groups have been involved (if appropriate).
- All actors have been empowered to participate actively and constructively in the discourse.
- The framing of the risk problem (or the issue) has been co-designed in a dialogue with the different groups.
- A common understanding of the magnitude of the risk and the potential risk management options has been generated and a plurality of options that represent the different interests and values of all involved parties have been included.
- Major efforts have been made to conduct a forum for decision-making that provides equal and fair opportunities for all parties to voice their opinion and to express their preferences.
- There exists a clear connection between the participatory bodies of decision-making and the political implementation level.

Two goals can be reached with the compliance of these requirements: the included actors have the chance to develop faith in their own competences and they start to trust each other and to have confidence in the process of risk management.

Anyway, while these aims can be reached in most cases where risks are able to be governed on a local level, where the different parties are familiar with each other and with the risk issue in question, it is much more difficult to reach these objectives for risks that concern actors on a national or global level, and where the risk is characterized by high complexity or where the effects are, for example, not directly visible or not easily referred to the corresponding risk agent. Sometimes, one party may have an advantage from performing acts of sabotage to the process, because their interests profit from leaving the existing risk management strategies into place. Consequently, inclusive governance processes need to be thoroughly monitored and evaluated, to prevent such strategic deconstructions of the process.

Closure, on the other hand, is needed to restrict the selection of management options, to guarantee an efficient use of resources, be it financial or the use of time and effort of the participants in the governance process. Closure concerns the part of generating and selecting risk management options, more specifically: Which options are selected for further consideration, and which options are rejected. Closure therefore concerns the product of the deliberation process. It describes the rules of when and how to close a debate, and what level of agreement is to be reached. The quality of the closure process has to meet the following requirements (cf. IRGC 2005:50; Webler et al. 1995; Wisdon and Willis 2004):

- Have all arguments been properly treated? Have all truth claims been fairly and accurately tested against commonly agreed standards of validation?
- Has all the relevant evidence, in accordance with the actual state-of-the-art knowledge, been collected and processed?

- Was systematic, experimental and practical knowledge and expertise adequately included and processed?
- Were all interests and values considered, and was there a major effort to come up with fair and balanced solutions?
- Were all normative judgements made explicit and thoroughly explained? Were normative statements derived from accepted ethical principles or legally prescribed norms?
- Were all efforts undertaken to preserve plurality of lifestyle and individual freedom and to restrict the realm of binding decisions to those areas in which binding rules and norms are essential and necessary to produce the wanted outcome?

If these requirements are met, there is at least a chance of being able to achieve consensus and a better acceptance of the outcomes of the needed risk assessment options, when facing risk problems with high complexity, uncertainty and ambiguity. The success of the stakeholder involvement strongly depends on the quality of the process. Consequently, this process has to be specifically designed for the context and characteristics of the corresponding risk. The balance of inclusion and closure is one of the crucial tasks of risk governance.

10.2 Coping with the Plurality of Knowledge and Values

The different social groups enter the governance process with very different preconditions regarding their knowledge about the risk characteristics. The perception of risks varies greatly among different actor groups. Even among different scientific disciplines, the concepts of risk are highly variable. All the varying types of knowledge and the existing plurality of values have to be taken into consideration, if acceptable outcomes of the risk governance process are aspired. The only possibility to include all these plural knowledge bases and values, are to embed procedures for participation into the risk governance process.

Depending on the type of risk problem, different levels of public and stakeholder participation seem appropriate to guarantee the quality of the process, if time and effort of the participating groups are regarded as spare resources. Four types of "*discourses*", describing the extent of participation, have been suggested, refer Table 8.2.

In the case of simple *risk problems* with obvious consequences, low remaining uncertainties and no controversial values implied, like many voluntary risks, e.g. smoking, it seems not necessary and even inefficient to involve all potentially affected parties to the process of decision-making. An "*instrumental discourse*" is proposed to be the adequate strategy to deal with these situations. In this first type of discourse, agency staff, directly affected groups (like product or activity providers and immediately exposed individuals) and enforcement personnel are the relevant actors. It can be expected that the interest of the public into the regulation of these types of risk is very low. However, regular monitoring of the outcomes is important, as the type of risk problem might turn out to be more complex, uncertain or ambiguous than characterized by the original assessment.

In case of *complex risk problems* another discourse is needed. An example for complexity based risk problems are the so-called 'cocktail-effects' of combined pesticide residues in food. While the effects of single pesticides are more or less scientifically proven, the cause and effect chains of multiple exposures with respect to different pesticides via multiple exposure routes are highly complex. As complexity is a problem of insufficient knowledge about the coherences of the risk characteristics, which is in itself not solvable, it is the more important to produce transparency over the subjective judgements and about the inclusion of knowledge elements, in order to find the best predictions of the occurrences of events and their consequences. This "*epistemic discourse*" aims at bringing together the knowledge from the agency staff of different scientific disciplines and other experts from academia, government, industry or civil society. The principle of inclusion is bringing new or additional knowledge into the process and aims at resolving cognitive conflicts. Appropriate instruments of this discourse are described later in this chapter.

In the case of risk problems due to large *uncertainties*, the challenges are even higher. The problem here is: How can one judge the severity of a situation when it is extremely difficult to predict the occurrence of events and/or their consequences? This dilemma concerns the characterization of the risk as well as the evaluation and the design of options for the reduction of the risk. Natural disasters like tsunamis, floods or earthquakes are for example characterized by high uncertainty. In this case, it is no longer sufficient to include experts into the discourse, but policy makers and the main stakeholders should additionally be included, to find consensus on the extra margin of safety in which they would be willing to invest in order to avoid potentially catastrophic consequences. This type is called "*reflective discourse*", because it is based on a collective reflection about balancing the possibilities for over- and under-protection. For this type of discourse, other forms of participation are required, which will be introduced later in this chapter (cf. Amy 1983; Perritt 1986; Rowe and Frewer 2000).

If the risk problems are due to *high ambiguity*, the most inclusive strategy is required, as not only the directly affected groups have something to contribute to the debate, but also the indirectly affected groups. If, for example, decisions have to be taken concerning the use or the ban of genetically modified foods and their production, the problem if going far beyond the mere risk problem, but touches also principal values and ethical questions, and questions of lifestyle or future visions. A "*participatory discourse*" has to be organized, where competing arguments, beliefs and values can be openly discussed. This discourse affects the very early step of risk framing and of risk evaluation. The aim of this type of discourse is to resolve conflicting expectations through identifying common values, defining options to allow people to live their own visions of a "good life", to find equitable and just distributions rules for common resources, and to activate institutional means for reaching common welfare so that all can profit from the collective benefits. Means for leading this normative discourse are described in the following sections.

In this typology of discourses, it is presupposed, that the categorization of risk problems into simple, complex, uncertain and ambiguous is uncontested. But, very often, this turns out to be complicated. Who decides whether a risk issue can be categorized as simple, complex, uncertain or ambiguous? To resolve this question, a *meta-discourse* is needed, where the decision is taken, where a specific risk is located and in consequence, to which route it is allocated. This discourse is called "*design discourse*", and is meant to provide stakeholder involvement at this more general level. Allocating the risks to one of the four routes has to be done before assessment starts, but as knowledge and information may change during the governance process, it may be necessary to re-order the risk. A means to carry out this task can be a screening board that should consist of members of the risk and concern assessment team, risk managers and key stakeholders.

Figure 10.1 provides an overview of the described discourses depending on the risk characteristics and the actors included into these discourses. Additionally it sets

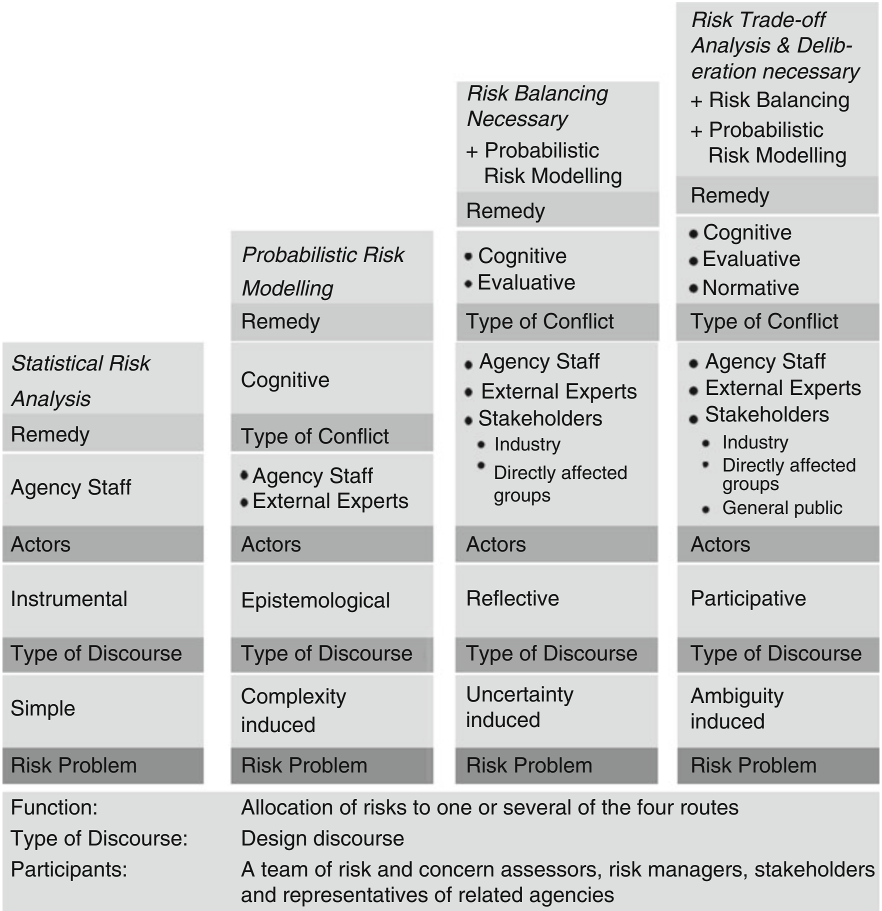

Fig. 10.1 The risk management escalator and stakeholder involvement (cf. IRGC 2005:53)

out the type of conflict produced through the plurality of knowledge and values and the required remedy to deal with the corresponding risk.

Of course, this scheme is a simplification of real risk problems, and is meant to provide an idealized overview for the different requirements related to different risk problems. Under real conditions, risks and their conditions often turn out to be more interdependent among each other and the required measures more contingend on the context in which the risk is embedded.

10.3 Review of Participatory Instruments

10.3.1 Classification

The distinction in complexity, uncertainty and ambiguity that has guided the risk governance approach in this book can serve as a guide for classifying different instruments for expert, stakeholder and public participation. Risks characterized by a high degree of complexity but little uncertainty and ambiguity demand deliberative processes that are focused on knowledge and expertise. High uncertainty in predictions calls for deliberative processes that emphasize reflection about fairness and equity in benefit- and burden-sharing. Risk which triggers off major ambiguities and controversies necessitates deliberations about future visions, basic values and aspirations. For each of these three risk formations there is a pool of deliberative instruments to choose from. If a risk is associated with two or all three characteristics (high complexity, uncertainty and ambiguity), one is well advised to combine the respective instruments from each pool. Table 10.1 provides an overview of the three pools of instruments and their functions for risk management. The following section briefly introduces the diversity of procedures and instruments using the distinction between the three pools of instruments.

10.3.2 Instruments for the Epistemic Discourse (pool 1)

Resolving conflicts during assessment requires deliberation among knowledge carriers. The instruments listed in this category provide opportunities for experts (not necessarily scientists) to argue over the factual assessment with respect to the main characteristics of the risk under investigation. The objective of a discourse in each of these instruments is the most adequate description or explanation of a phenomenon (e.g. the question: which physical impacts are to be expected by the emission of specific substances?). Instruments that promise to meet these requirements are expert hearings, expert workshops, science workshops, expert panels or advisory committees, or consensus conferences as practised in the medical field (Coppock 1985; McGlynn et al. 1990; Jones and Hunter 1995; Renn et al. 1995;

Table 10.1 Pool of instruments for risk management challenges

	Challenge	Objective	Function	Instruments
Pool 1	Complexity	Inclusion of best available knowledge	Agreement on causal relations and effective measures (best suited for assessment stage)	Expert panels, expert hearings, meta-analysis, Delphi method, etc.
Pool 2	Uncertainty	Fair and acceptable arrangement for benefit- and burden-sharing	Balancing costs of under-protection with costs of overprotection facing uncertain outcomes (best suited for assessment and evaluation stages)	Negotiated rule-making, mediation, roundtables, stakeholder meetings, etc.
Pool 3	Ambiguity	Congruency with social and cultural values	Resolving value conflicts and ensuring fair treatment of concerns and visions (best suited for framing problems, evaluation and the choice of risk management options)	Citizen advisory committees, citizen panels, citizen jury, consensus conferences, public meetings, etc.
	Combination	Meeting more than one challenge	Meaningful and effective integration of functions	Selection from each of the three pools

Roqueplo 1995; Koenig and Jasanoff 2001). If anecdotal knowledge is needed, one can refer to focus groups, panels of volunteers and simple surveys (Milbrath 1981; Dürrenberger et al. 1999). More sophisticated methods of reducing complexity for difficult risk issues include Delphi methods, group Delphi, meta-analytical workshops and scoping exercises (Pill 1971; Webler et al. 1991; Sutton et al. 2000). The most frequently used instruments for resolving espistemic conflicts are described below (Renn et al. 2002):

Expert hearing: This is the most popular form of resolving differences among experts (Renn et al. 1995; Boehmer-Christiansen 1997; Renn et al. 2002, 2003b). Experts with different positions are asked to testify before the representatives of the organizing institution (most often a regulatory agency) or the deliberative panel. The organizers ask each expert a specific question and let them develop their line of arguments. Occasionally, hearings allow for open discussions among the experts; but the final judgement is left to the organizing committee or the deliberative panel. Hearings are excellent and fairly inexpensive settings, if the objective is to get a clearer picture of the variability of expert judgements and to become aware of the arguments supporting each position. Hearings do not provide consensus and may not resolve any conflict. However, they may clarify the basis of the conflict or the different points of view in a contested risk issue.

Expert committees: Expert committees, advisory boards, think tanks and scientific commissions are also very popular forms of involving external knowledge carriers within the risk management process (Primack and von Hippel 1974; Renn 1995; Rich 2004; Rakel 2004). They have the advantage that experts interact freely with each other, have more time to learn from each other and are able to consult other experts if deemed necessary. They work independently of the agency or deliberative body to which they report. The main disadvantage is that expert committees may not arrive at a consensus, may take too much time to reach a conclusion, may not respond to the urgent needs of the deliberative body and may “live a life of their own”. In addition, many expert committees can only come to an agreement if the members have similar backgrounds and positions.

Expert consensus conference: Particularly in the medical field, experts are gathered in a workshop to discuss treatment options and to decide on a general standard to be applied in comparable cases throughout the world (McGlynn et al. 1990; Jones and Hunter 1995). The workshop is organized in group sessions in order to prepare common standards and in plenary sessions to reach a common agreement. One could envision consensus conferences in the risk area for the purpose of setting and articulating common conventions for risk assessment and evaluation.

Delphi exercises: A Delphi process is aimed at obtaining a wide range of opinions among a group of experts (Turoff 1970; Pill 1971; Linstone and Turoff 2002). The process is organized in four steps. In step 1, a questionnaire asks a group of distinguished scientists to assess the severity or the scope of the risk. The scientists provide their best assignments, possibly including some type of uncertainty interval to their answers. In step 2, the organizing team feeds back to each participant the scores of the whole group, including medians, standard deviation and aggregated uncertainty intervals. Each individual is then asked to perform the same task again, but now with the knowledge of the responses of all other participants. In step 3, this procedure is repeated until individuals do not change their assessment any more. In step 4, the organizer summarizes the results and articulates the conclusions. A variation of the classic Delphi method is the group Delphi (Webler et al. 1991). During a group Delphi all participants meet face to face and make the assessments in randomly assigned small groups of three and four. The groups whose average scores deviate most from the median of all other groups are requested to defend their position in a plenary session. Then the small groups are reshuffled and perform the same task again. This process can be iterated three or four times until no further significant changes are made. The advantage of Delphi is that a serious effort has been invested in finding the common ground among the experts and in finding the reasons and arguments that cause differences in assessments. The disadvantage is that the quality of Delphi outcomes depends upon the accuracy and completeness of the expertise and information brought into the process.

In general, we have had mostly positive experiences with Delphi processes, particularly group Delphi.

10.3.3 Instruments for the Reflective Discourse (pool 2)

The next set of instruments refers to risk with high uncertainty focussing on the impacts when balancing the pros and cons of different risk reduction methods. Scientific input is also needed in order to compile the relevant data and the various arguments for the positions of the different science camps. Procedures such as the "pedigree scheme" by Funtowicz and Ravetz (1990) might be helpful in organizing the existing knowledge. Furthermore, information about the different types of uncertainties has to be collected and brought into a deliberative arena. The central objective is, however, to deliberate about the post-prudent handling of unresolved uncertainty. For this purpose, representatives of affected stakeholders and public interest groups must be identified, invited, and informed about the issue in question (Yosie and Herbst 1998a:644 ff.). The objective of the deliberation is to find the right balance between too little and too much precaution. There is no scientific answer to this question, and even economic balancing procedures are of limited value since the stakes are uncertain. Major instruments for reflective discourses are roundtables, negotiated rule-making, mediation, arbitration and stakeholder dialogues. The most popular instruments for conducting a reflective discourse within a deliberative setting are the following (Renn et al. 2002; OECD 2003b):

Stakeholder hearings: Most regulatory regimes of the world require hearings with stakeholders or directly affected citizens under specific circumstances (Checkoway 1981; Kemp 1985; Renn et al. 1995). Such hearings can serve a useful purpose if they are meant to give external stakeholders the opportunity to voice their opinion and arguments. Hearings also provide opportunities for stakeholders to understand the position of the regulatory agencies or other direct players (such as industry). But hearings have proven very ineffective for resolving conflicts or pacifying heated debates. On the contrary, hearings normally aggravate the tone of the conflict and lead to polarizations. Other than for the purpose of investigating the concerns and objections of organized groups, stakeholder hearings should be avoided.

Roundtables (*advisory committees, stakeholder dialogues and negotiated rule-making*): Roundtables are very popular settings for stakeholder involvement (Brooks 1984; English et al. 1993; Rose-Ackerman 1994; Hadden 1995; Renn et al. 1995; Wondelleck et al. 1996; Yosie and Herbst 1998b; US EPA/SAB 2001; Stoll-Kleemann and Welp 2006). Normally, the participants represent the major social groups, such as employers, unions, professional associations and others. The advantage is that the ritual window-dressing activities (typical for classic hearings) can be overcome through the continuity of the process and a strict working atmosphere. The major disadvantage is that groups outside the roundtable and representatives of the general public are left out. They can only trust the process to be effective and fair. If the debate is heated and adversarial elements govern the political climate, roundtables will face severe difficulties to legitimize their agreements. For many regulatory issues and risk management decisions, however, such roundtables have been very effective and also cost efficient in incorporating the perspective of organized groups and in suggesting adequate management options. There are also good techniques available (such as value-tree analysis, multi-attribute decision-structuring and meta-planning exercises) to make these heterogeneous group meetings more productive (Rauschmayer and Wittmer 2006). Essential for organizing a successful roundtable is the involvement of a professional moderator. Moderation should be performed by a neutral institution rather than the organizer.

Mediation (arbitration and alternate dispute resolution methods): If conflicts are already clearly visible and unavoidable, the procedures of alternate dispute resolution are effective and less costly instruments compared to legal litigation (Cormick 1980; Mernitz 1980; Amy 1983; Bingham 1984; Folberg and Taylor 1984; Edwards 1986; Moore 1986; Baughman 1995; Fiorino 1995; Hadden 1995; US EPA 1995; Moore 1996; Susskind and Fields 1996; Wondelleck et al. 1996). Mediation and similar procedures rest on the assumption that stakeholders can find a common solution if they do not insist on positions, but try to meet their crucial interests and underlying values. Under these circumstances, win–win solutions may be available that will please all parties. Mediation requires the involvement of a skilled and professional mediator. Similar to roundtables, such mediators should be recruited from neutral professional services. It is advisable that mediators have sufficient knowledge about the issue, that they can understand and evaluate all participants' statements, but that they do not have a clear commitment to one or the other side. The advantage of mediation is that conflicts among participants can be reconciled before they reach the legal arena. The disadvantage is that, depending upon the composition of the group, interests which are not emphasized at the roundtable will not be considered. Most alternate dispute-resolution methods work well under the condition of adversarial and corporatist styles; they may be seen as unnecessary in more trustful environments where conflicts are rare and stakeholders less agitated.

10.3.4 Instruments for the Participatory Discourse (pool 3)

The last group of instruments addressed in this subsection deals with ambiguity. Most often, ambiguities arise over the issue of social or moral justification of a risky activity in the evaluation phase, and over the selection of the right management options, including the decision of who is to be responsible and accountable. Before investing in resolving ambiguity, it is essential to investigate the cause of the ambiguity and to find the right spot where the involvement procedure would best fit in the decision-making process. Preferred instruments here are citizen panels or juries (randomly selected), citizen advisory committees or councils, public consensus conferences, citizen action groups and other participatory techniques. The main instruments belonging to this category are as follows (Renn et al. 2002):

Public hearings: Public hearings are required in many regulatory regimes all over the world (Kemp 1985; Renn et al. 1995). The idea is that people who feel affected by a decision should be given an opportunity to make their concerns known to the authorities and, vice versa, to give the authorities the opportunity to explain their viewpoint to the public (Hartmann et al. 1983). Although public hearings are fairly inexpensive and easy to organize, their effectiveness is rated as poor in most of the scientific investigations on the subject. Hearings tend to stereotype the issue and the actors involved, to aggravate emotions, to emphasize dissent rather than consensus and to amplify distrust rather than generate trust. Unless the issue is only slightly controversial and the climate is characterized by an overall consensual mood, we do not recommend public hearings as a setting for resolving ambiguity.

Surveys and focus group: Surveys of the general public or special groups are excellent settings in which to explore the concerns and worries of the addressed audience (Milbrath 1981; Dürrenberger et al. 1999). If they are performed professionally, the results are usually valid and reliable. The results of surveys provide, however, only a temporary snap shot of public opinion; they do not produce solutions for conflict resolution or predict the fate of positions once they have entered the public arena. Surveys describe the starting position before a conflict may unfold. Focus groups go one step further by exposing arguments to counter-arguments in a small group discussion setting (Krueger and Casey 2000). The moderator introduces a stimulus (e.g. statements about the risk) and lets members of the group react to the stimulus and to each other's statements. Focus groups provide more than data about people's positions and concerns; they also measure the strength and social resonance of each argument vis-à-vis counter-arguments. The major disadvantage of surveys and focus groups is the lack of real interaction among participants. Therefore, both instruments are advisable as preliminary steps in understanding the context and the expectations; but they do not assist risk managers in resolving a pressing issue. In addition, both instruments are fairly expensive.

Citizen advisory committees (ombudsman, neighborhood associations, citizen boards): The instrument of citizen advisory committees is particularly popular in local and regional contexts, but there are also examples for advisory committees on a national level (Laksmanan 1990; Lynn and Kartez 1995; Vari 1995; Applegate 1998). The chemical industry has been experimenting with citizen advisory committees for a long time in the framework of its responsible care programme (Prakash 2000). This programme is directed towards people in the vicinity of chemical installations. Such an approach is also feasible with consumers if companies or agencies would like to involve their ultimate clients in the risk management process. The problem here is selection: either one invites representatives of stakeholder groups (such as the consumer associations) or one tries to find a sample of "representative" consumers of the specific products or chemicals under review. Both approaches have their merits and drawbacks. Stakeholder groups are often quite distanced from the members they are supposed to represent. This is particularly true for consumer associations since consumers form a very heterogeneous group, and the majority of them do not belong to consumers associations. At the same time, a representative sample of consumers is difficult to obtain and it is questionable whether such a sample can speak in the interest of all consumers. In spite of these difficulties, such advisory committees can be very effective in detecting potential conflicts (early warning function) and getting the concerns of the consumers heard and reflected in the respective organizing institutions. In addition, the organization of citizen advisory committees is fairly inexpensive and easy to do.

Citizen consensus conferences: The Danish Board of Technology introduced a new form of citizen involvement, which it called "consensus conferencing". This instrument is strongly based on the belief that a group of non-committed and independent citizens is best to judge the acceptability or tolerability of technological risks (Joss 1995, 1997, 1998; Sclove 1995; Andersen and Jaeger 1999). Six to ten citizens are invited to study a risk issue in detail and to provide the legal decision-maker, or an agency, with a recommendation at the end of the process. The citizens are usually recruited by self-selection. The organizers put an advertisement in the newspaper asking for volunteers. If too many people volunteer for the consensus conference, the organizers follow specific rules for ensuring equal representation. An equal amount of women and men are required, as well as a cross-section of the population in terms of age, social class and political preferences. The participants receive a substantial amount of material before they convene for the first time. They study this material during two consecutive weekends. The consensus conference itself lasts 3 days. During the first day, the participants share their reflections with a body of regulators or decision-makers (often members of parliament). They also raise their questions and listen to the answers given by politicians and experts. On the second day in the morning the hearing continues; but this time it is open to the wider public. In the afternoon, the participants meet behind closed doors and articulate their recommendations. These are then presented to the decision-makers on the following day. The decision-makers have the opportunity to give further comments. Finally, the participants write the final draft of the recommendations and present them to the media at the end of the third day. The advantage of consensus conferencing is the transposition of a major conflict to a small group of laypeople who are being educated about the subject and are asked to make recommendations based on their knowledge and personal values. The main disadvantage is the small number of people who are assigned such an important task. The restricted number of six to ten participants has been the thrust of criticism in the literature (Einsiedel and Eastlick 2000). Consensus conferences seem to yield a compelling legitimacy effect within countries that are small and emphasize consensus over conflict. Most successful trials are reported in Denmark, Norway and Switzerland. The experiences in more adversarial countries such as the UK, France and Germany are less encouraging (Joss 1997). The results of the deliberations were not widely published in the media; decision-makers were not willing to submit sufficient time to small groups of laypeople; and administrators paid only lip-service to the conference statements.

Citizen panels, planning cells or citizen juries: Planning cells or citizen panels (juries) are groups of randomly selected citizens who are asked to compose a set of policy recommendations on a specific issue (Crosby et al. 1986; Dienel 1989; Stewart et al. 1994; Armour 1995; Crosby 1995). The objective is to provide citizens with the opportunity for learning about the technical and political facets of the risk management options and for enabling them to discuss and evaluate these options and their likely consequences according to their own set of values and preferences. The participants are informed about the potential options and their consequences before they are asked to evaluate these options. Since the process requires time for the educational programme and the evaluation of options, the panels are conducted in seminar form over three to five consecutive days. All participants are exposed to a standardized program of information, including hearings, lectures, panel discussions, videotapes and field tours. Since participants are selected by random procedures, every individual in the affected population has an equal opportunity to participate in the process. In reality, however, only 5–40% of the randomly selected citizens decide to become active participants. In contrast to consensus conferences, however, the number of people who can participate is limited only by available resources and time. Several hundred citizens can be involved in one exercise. All participants are grouped in panels of 20–25, with an identical educational programme and evaluative tasks. If most of the panels come up with similar conclusions, one can be sure that this is (or would be) the will of the informed public. Planning cells require a large investment of time and money and are not suitable for all types of problems and all contexts. If the problem is highly technical, it may be impossible to bring citizens up to the necessary level of understanding. Furthermore, if the decision options are too narrowly restricted and there is not enough room to allow trade-offs on decision criteria, then the process will fail. Citizen panels may also face the problem of being legitimate consultants to policy-makers in an adversarial climate.

10.3.5 Synthesis of Components

The three pools of instruments provide a sufficient number of choices for matching the instrument with the risk problem at hand. It is more difficult, however, to find the right and appropriate combination if instruments from several pools must be combined. For example, if risks are characterized by high complexity, uncertainty and ambiguity, one needs an integrated process that includes a sequential chain consisting of at least one instrument from each pool. Or if the risk is highly complex and uncertain but raises little controversy, only instruments from pools 1 or 2 have to be selected. The pools provide tool boxes and, depending upon the nature of the risk problems and what risk mangers know about them, the selection has to be made from one or more of the three pools.

The selection of a specific sequence and the choice of instruments depend upon the risk issue, the context and the regulatory structure and culture of the country or state in which such a process is planned. Different countries have developed diverse traditions and different preferences when it comes to deliberative processes (O'Riordan and Wynne 1987; Löfstedt and Vogel 2001). The selection of instruments from the three pools, therefore, needs to reflect the risk nature, the regulatory system and the respective political culture.

One possibility for a risk management agency selecting one instrument from each pool might be, for example, to organize an expert hearing to understand the knowledge claims that are relevant for the issue. Afterwards, the agency might initiate a roundtable for negotiated rule-making in order to find the appropriate trade-offs between the costs of over–regulation and under–regulation in the face of major uncertainties. The agency could then convene several citizen advisory committees to explore the potential conflicts and dissenting interpretations of the situation and the proposed policy options. Each component builds upon the results of the previous component.

However, the requirements of an integrated participation program are not met by merely running three or more different components in parallel and feeding the output of each component as input into the next component (Renn 2004b). Each type of discourse has to be embedded in an integrated procedural concept. In addition, there is a need for continuity and consistency throughout the whole process. Several participants may be asked to take part in all three instruments, and an oversight committee may be necessary to provide the mandated links. One example for such an integrated hybrid model is the "cooperative discourse" approach (Renn et al. 1993; Renn and Webler 1998; Renn 1999).

10.4 The Model of Cooperative Discourse

10.4.1 Structure of the Cooperative Discourse

The model of "cooperative discourse" meets the three risk challenges by assigning specific tasks to different groups in society. These groups represent three forms of knowledge and values:

- Knowledge based on technical expertise (epistemic discourse)
- Knowledge and values derived from social interests and advocacy (reflective discourse)
- Knowledge and values based on common sense, folklore wisdom and personal experience (participatory discourse)

These three forms of knowledge and values are integrated into a sequential procedure of three consecutive steps (Renn et al. 1993). The *first step* refers to the identification of objectives or goals that the process should reflect (Gregory 2004). The identification of concerns and objectives is best accomplished by asking all relevant stakeholder groups (i.e. socially organized groups that are, or perceive themselves as being, affected by the decision) to reveal their values and criteria for judging different options (reflective discourse). This can be done by a process called value-tree analysis (Keeney et al. 1987; von Winterfeldt 1987), which is explained later. The evaluative criteria derived from the value trees are then transformed into indicators by the research team or an external expert group.

With different policy options and criteria available, the *second step* involves the actors with special knowledge and evidence on the subject. Experts representing multiple disciplines and plural viewpoints about the issue in question are asked to judge the performance of each option on each indicator (epistemic discourse). For this purpose, the group Delphi method is used (Webler et al. 1991; see description in Sect. 9.3.2).

The *third and last step* is the evaluation of each option profile by one group, or several groups of randomly selected citizens, in a participatory discourse. We refer to these panels as citizen panels for policy evaluation and recommendation (Renn et al. 1993; Renn and Webler 1998:81 ff.). The objective is to provide citizens with the opportunity for learning about the technical and political facets of policy options and for enabling them to discuss and evaluate these options and their likely consequences according to their own set of values and preferences. The idea is to conduct a process loosely, analogous to a jury trial with experts and stakeholders as witnesses and advisers on procedure as "professional" judges (Crosby 1995; Stewart et al. 1994). For meaningful and productive discourse, the number of participants is limited to about 25. Discourse proceeds in citizen panels with the research team as discussion leaders who guide the group through structured sessions of information, personal self-reflection, and consensus-building.

The whole process is supervised by a group of official policy-makers, major stakeholders and moral agents (such as representatives of churches). Their task is to oversee the process, test and examine the material handed out to the panellists, review the decision frames and questions, and write a final interpretation of the results. This oversight committee represents a major component of the model. It provides the integrative envelope over the different sequential elements and creates the necessary link to the legitimate decision-makers. It cannot, and should not, change the recommendations of the panels, but should put them into the right frame for processing by the political institutions that manage or regulate risks.

Finally, the research team has the primary task of providing first drafts of the three products. The functions and procedure of the policy model are illustrated in Fig. 10.2. This figure shows that all actors involved (the experts, the stakeholder groups, the citizens, the sponsor, the oversight committee, and the research team) play a role in each step; but their influence is directed towards the type of knowledge and rationality that they can offer best (these are highlighted in bold face in Fig. 10.2). The stakeholders are asked to join a roundtable or dialogue forum (from pool 2). Their deliberations lead to the end product of a value tree, which the citizen panels or the experts may augment during a later stage.

A group of experts from different disciplines and backgrounds is asked to engage in a group Delphi process (pool 2): they are principally responsible for constructing performance profiles for each option, taking into consideration the institutional knowledge of the sponsor and the specific knowledge of the various stakeholder groups. The major task of the citizen panels (an instrument taken from pool 3) is to evaluate options and generate or modify policies, assisted by expert and stakeholder witnesses. The role of the sponsoring risk management agency is limited to making suggestions about options, to providing testimony to the citizen panels and to participating in the oversight committee.

The oversight committee has the task of exercising external control over the whole process, providing the necessary links between the three steps and ensuring the compatibility of the results with the political institutional frames in which the results are going to be processed. Finally, the research team has the primary task of providing first drafts of the three products (joint value tree, performance profiles and citizen report) in order to gain approval for these products from the respective actors and to feed them back into the process. This division of labour introduces checks and balances into the process and constitutes a structural order that is logical and transparent.

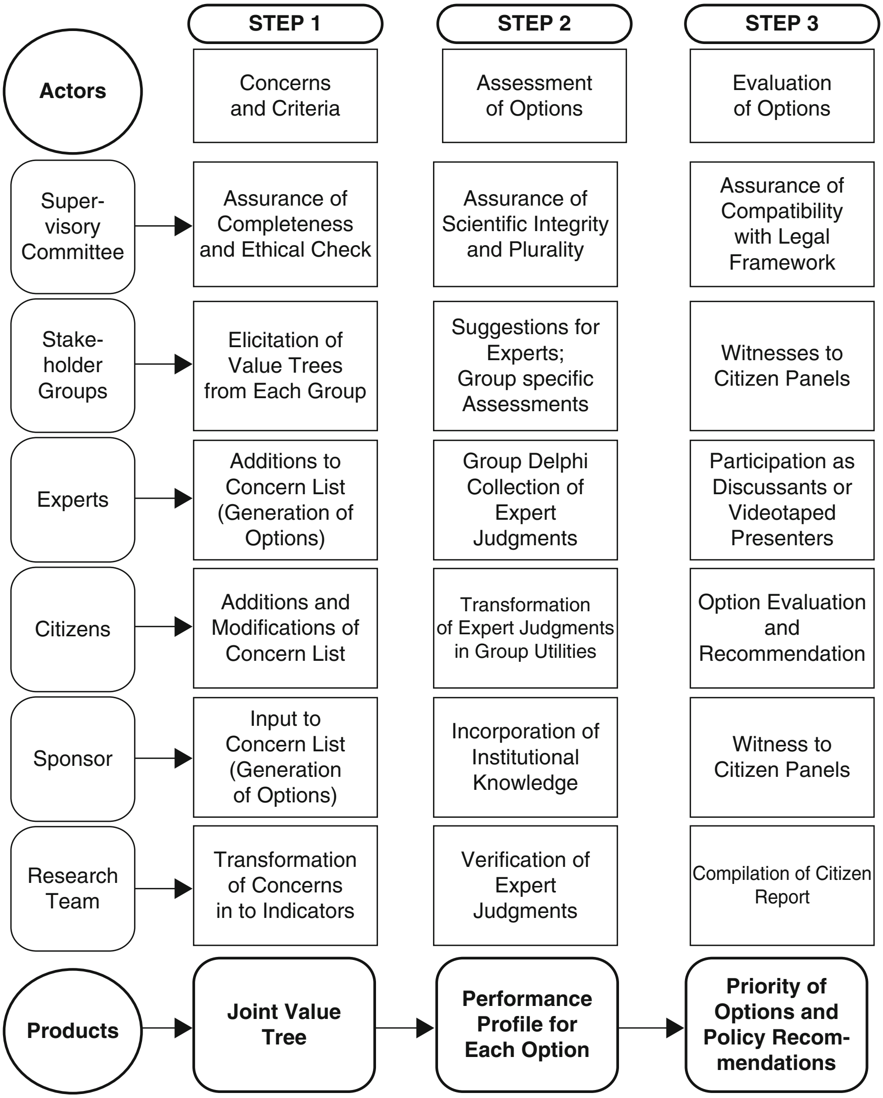

Fig. 10.2 Basic concepts and elements of the cooperative discourse model (adapted from Renn 1998:20)

10.4.2 *Experiences with the Cooperative Discourse Model*

Applications of the cooperative discourse model in Germany, Switzerland and the US emerged from the early experiences with citizen panels in urban planning in various German cities and communities (Dienel 1989). Based on these experiences, further testing and developments of the cooperative discourse method were conducted, first in Germany and later in other countries. This section describes several large-scale applications in three countries:

The most comprehensive study dealt with the evaluation of national energy policies in Germany. In August 1982, the German Ministry of Research and Technology initiated a large research project to investigate the preferences of the German population with respect to four energy policy options developed by a parliamentary commission in 1979 (Renn et al. 1985; Renn 1986). The government was interested in eliciting reliable information on the energy scenario which was the most appealing to the population and on the basis which citizens would evaluate the policy options laid out in each scenario. A research team conducted a 3-year study to collect data on public preferences and to analyze the motivations and underlying reasons for the judgement process of evaluating the predefined energy scenarios. The study operated with 24 citizen panels (each including approximately 25 participants) drawn from seven communities in different parts of West Germany. The panels unanimously rejected a high reliance on energy supply and opted for an energy policy that emphasized energy conservation and efficient use of energy. Nuclear energy was perceived as a non-desirable but (at least for an intermediate time period) necessary energy source. The panellists recommended stricter environmental regulation for fossil fuels even if this meant higher energy prices. They developed a priority list for policies and drafted recommendations for implementing high-priority policies (Renn et al. 1985).

A regional study was conducted from 1994 to 1996 in the northern part of the black forest (southern Germany). The objective was to have stockholders and citizens take part in planning a waste management programme (Schneider et al. 1998; Renn 1999). A stakeholder dialogue based on the model of roundtables was organized in 1994 to develop waste reduction policies and to assess the potential recycling potential of the area (using the method of value trees). The same group was also asked to find the most suitable technical solution for waste processing before final disposal. After these decisions were made, 200 randomly selected citizens from potential host communities were asked to find the most appropriate site for the types of facilities that had been previously chosen by the representatives of the roundtable. The most outstanding result was that panellists were even willing to approve a siting decision that would affect their own community. All ten citizen panels reached a unanimous decision based on tolerated consensus, which involved the recommendation to construct a small state-of-the-art incinerator in the centre of the most populated town within the region. The reason for this surprising recommendation was that citizens wanted to present a visual reminder to their fellow citizens. They were not to forget the need to reduce waste, to burden those who contribute most to the problem and to put the incinerator near the political power centre as a “clever” means of ensuring compliance with environmental standards: “Since the mayor resides right next door to the facility, he will make sure that nothing harmful will happen”. The decision was given to the regional planning board, which approved the recommendations with some minor modifications. The responsible county parliaments and the city council of the largest city within the region, however, refused to accept the recommendations and took the "easy way out" and exported the waste to another region.

In 1992, the Building Department (*Baudepartement*) of the canton Aargau (northern part of Switzerland) initiated the organization of a cooperative discourse for siting one or several landfills in the eastern part of the canton. The mandate of the research team was to organize a cooperative discourse with four citizen panels. These panels had the task: first, to develop criteria for comparing the different sites; second, to evaluate the geological data that were collected during that period; third, to eliminate the sites that were not to be further considered; and, fourth, to prioritize the remaining sites with respect to their suitability to host a landfill (Renn and Webler 1998; Renn 1999). Four citizen panels were formed, each one consisting of two representatives from each potential site community. With the exception of one community, every town sent eight people to the panels. Not one of them dropped out during the process. Between January and June 1993, the panels met seven to nine times before they attended a workshop of 2 days to come up with the final decision. All participants rated each site on the basis of their self-selected evaluative criteria, their personal impressions, the written and oral information, and the results of a workshop with experts on the basis of a group Delphi. All four panels composed a list of prioritized sites for the landfill. The most remarkable outcome was that each panel reached a unanimous decision based on tolerated consensus. In December 1993, the result of the participation process was made public. The canton government approved the results and entered the next phase of the licensing procedure. Currently, the selected site still stands; but the creation of a landfill has been postponed since the amount of waste has sharply decreased over the last few years.

There has been one major attempt to implement the original version of the cooperative discourse in the US. Using randomly selected citizens for policy-making and evaluation is not alien to the US. The Jefferson Center in Minneapolis has conducted numerous projects with citizen juries (Crosby et al. 1986; Crosby 1995). Several community planners have experimented with the model of citizen panels, which were composed to reflect a representative sample of the population (same model as in: Kathlene and Martin 1991). In 1988 the Department of Environmental Protection of New Jersey took the initiative to apply the cooperative discourse model to sewage sludge management problems (Renn et al. 1989). The objective of the project was to give citizens of Hunterdon County, New Jersey, the opportunity of designing the regulatory provisions for an experimental sludge application project on a Rutgers University research farm located in Franklin Township, New Jersey. Although much smaller in scale, the project provided many new insights and experiences that partially confirmed the European observations and partially documented the need for adjustments to the US political culture. The citizen panels were conducted on two consecutive weekends. The desired goal was to elicit recommendations for regulatory provisions that were to be included in the permit for the land application of sewage sludge on the site in question. The factual issues were discussed in a group Delphi with eight sludge experts (Webler et al. 1991). The results of the Delphi were fed into the panels' deliberation process.

The envisioned programme for the citizen panels was radically altered after the participants, particularly the landowners abutting the site, made it clear that they rejected the project of land application and that they felt more comfortable conducting their own meetings without the assistance of a third party. The citizens met several times without the help of a facilitator and formulated recommendations which were forwarded to the sponsor (the New Jersey Department of Environmental Protection). In addition to the policy recommendation to reject the land application proposal, the process provided valuable information about citizens' concerns and values. Whereas most of the consulted experts were convinced that citizens' concerns focused on issues such as odour, traffic and contamination of groundwater, the citizens' value tree analysis revealed that their major concerns were the expected change of community image from an agricultural community to a "waste dump" and the long-term effects of pollutants on farmland (Webler et al. 1995).

In summary, the applications of cooperative discourse method provided some evidence and reconfirmation that the theoretical expectations linked to this method can be met on the local, regional and national level. Eliciting the preferences and educated responses of citizens in a rather short time has proved a valid instrument. Evaluation studies by independent scholars confirmed that the objectives of effectiveness, efficiency and social acceptability were largely met in the Swiss, as well as in the German case studies (Rymann 1993; Roch 1997, Vorwerk and Kämper 1997; Löfstedt 1999). The US study was not externally reviewed. The evaluators agreed that the main interests and value groups were adequately represented, that the process and the results were cost effective, and that the outcomes of the process were judged as reasonable and competent suggestions by technical experts. However, the evaluators were rather sceptical about the legitimization function of these trials and criticized the lack of trust in these procedures by the political authorities. In all cases, the results of the deliberation were not implemented, at least not to their full extent. The evaluations emphasized the need for a stronger role of the supervisory committee (which was installed in the Swiss case) and the inclusion of the actual decision-makers in these committees as a means of bridging the gap between the deliberative bodies and the political risk management institutions.

10.5 Lessons Learned for Stakeholder and Public Involvement

A combination of analytic and deliberative instruments (or stakeholders and the public) is instrumental in reducing complexity, necessary for handling uncertainty and mandatory for dealing with ambiguity. Uncertainty and ambiguity cannot be resolved by expertise only, even if the expertise is uncontested. In situations of high uncertainty, economic balancing between overprotection and underprotection requires subjective evaluations of fair benefit-sharing and risk-sharing. Furthermore, the interpretation of ambiguous consequences requires the input of public preferences and values. Neither agency staff nor scientific advisory groups are able or legitimized to represent the full scope of public preferences and values. This is a compelling reason for broadening the basis of decision-making and including those who have to "pay" in terms of bearing the cost for stricter regulatory requirements or being exposed to a hazard.

How can and should risk managers collect public preferences, integrate public input within the management process, and assign the appropriate roles to technical experts, stakeholders and members of the public? This chapter suggests making use of the distinction between three different pools of participatory instruments. Each of the three pools is predominantly suited to dealing with problems of complexity (pool 1), uncertainty (pool 2) and ambiguity (pool 3). The objective is to design a combination of two or more of the available instruments from each pool depending upon the diagnosed characteristics of the risk. One candidate for such an integrated process is the model of "cooperative discourse" that has been developed and tested over the last three decades.

Based on experiences with the model of cooperative discourse in several countries, it is concluded that the model provides a theoretically ambitious and practically feasible method of putting an analytic–deliberative process into action (Renn 2004b). It provides an opportunity for addressing all three challenges of risk (type of risk problems). It ensures that the state of the art in systematic knowledge is included in the deliberation; it ensures a fair representation of public interests; it emphasizes reflective and normative competence; and it builds upon well-proven techniques of efficient decision-making such as the application of multi-attribute scaling techniques (see review in Rippe and Schaber 1999).

Many arguments in favor of analytic–deliberative processes and their theoretical foundations provide ample evidence for their potential contribution to improving risk evaluation and management. It is still an open question whether deliberation can deliver what it promises in theory. The empirical account is still open and incomplete. Being active in developing and testing analytic–deliberative processes, we are confident, however, that over time we will not just prove, theoretically, the merits and potentials, but also the practical feasibility and superiority of analytic–deliberative processes in different political cultures and among a variety of regulatory styles. The time for analytic–deliberative processes is here to come.

Chapter 11
Case Study 1: Risk Governance of Nanotechnology

11.1 Introduction

As explained throughout this book, the IRGC's Risk Governance Framework offers an integrative approach that includes four consecutive stages and one continuous activity, see simplified version in Fig. 11.1. The process starts with the stage of pre-assessment and problem framing, continues with appraisal, i.e. the assessment of risks and concerns, which leads to the stage of characterization and evaluation, and, finally, to the management phase, including implementation.

11.2 Pre-assessment

The purpose of the pre-assessment phase is to capture the variety of mental frames that are associated with the risk. This includes indicators, routines, and conventions or value patterns from different stakeholders, their attitudes and associations (IRGC 2005). This phase should be used as a tool for framing the problem for designing early warning systems, for screening the knowledge base, and for determining the methods and research protocols for the next stage: risk and concern assessment. For Nanotechnologies the following challenges are described as crucial for this early phase of risk governance:

(a) *Definition:* After decades of research and an intensive stakeholder debate at different international levels, we are still unable to define what is meant by nanotechnologies and nanomaterials. Of course, several terms have been clarified by the ISO (2008a, b) and adopted by the OECD. However, the principle problem of setting limits, inclusions and exclusions seems to be inherent to the label "nanotechnology". Or, using the words of Hodge et al. (2007):

T. Aven and O. Renn, *Risk Management and Governance*,
Risk, Governance and Society 16, DOI 10.1007/978-3-642-13926-0_11,

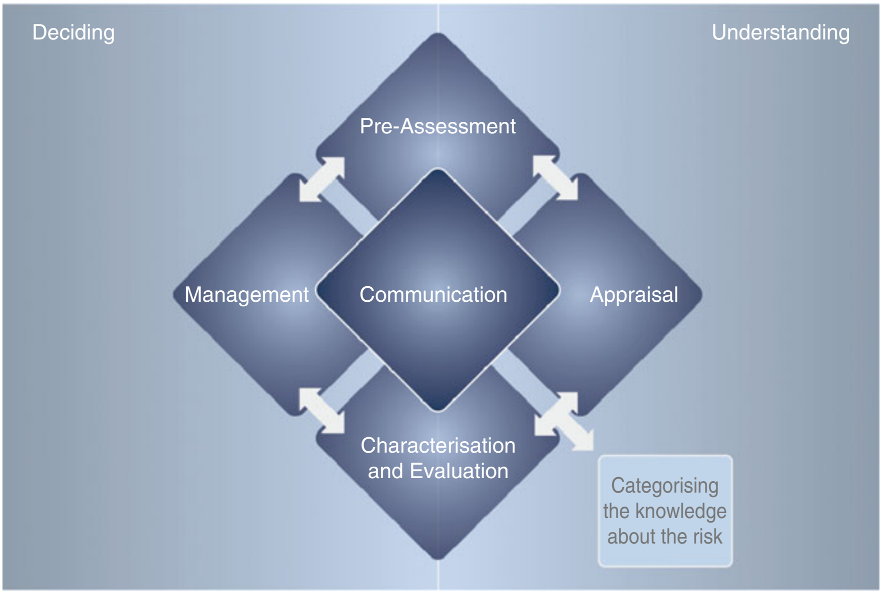

Fig. 11.1 A simplified version of the Risk Governance Framework (IRGC 2009:13)

> But this label is not an accurate description of the immense range of technologies that fall under the nanotechnologies umbrella.

This inconsistency of the term nanotechnology gives rise to many questions that should be addressed in the pre-assessment phase (IRGC 2009:16):

How and where should the line be drawn between nanoscaled and larger-scaled particles? How can the effects of agglomeration and de-agglomeration be taken into account? This is crucial, for example, in the textile industry where most of the "nanomaterials", which are producing the water- and dirt repellent surfaces, are around 800 nm, or in the food and cosmetic area where the encapsulated systems are around 300 nm.

(b) *Difference between naturally occurring and manufactured nanoparticles:* There is also no consensus of where to draw the line between naturally-occurring and manufactured nanomaterials. Lipids, proteins, starch and sugar are used in different nano-delivery-systems, in the pharmaceutical sector, in cosmetics and foods. Conventional processing methods are often sufficient to produce these materials. Again, it is a question of interpretation if these applications are categorized as manufactured nanomaterials, or as naturally occurring materials.
(c) *Properties:* Should we use the term nanomaterial only for those substances that provide new or novel properties when applied in nanoscaled dimensions? How should we treat materials that have been in use for many years, or show up only slightly improved properties or even none if downscaled to nano-level?

Each narrow definition would result in an exclusion of applications that seem to fit our intuitive understanding of nano-materials. European regulators try to cover the broad range of materials by retrieving to highly generalized requirements for the registration, the evaluation and the assessment of chemical substances (REACH), which have to be applied independently of their size. Or, they publish diverse directives on how to handle products for certain applications such as the food area, including "novel food" (European Parliament: Food 2009), or cosmetics (European Parliament: Cosmetics 2009). However, the inherent problem of nanotechnologies will remain: On the one hand, the focus of regulation and the need for precise risk assessment protocols require clear and unambiguous definitions. On the other hand, each limitation will exclude applications that do not match the preconceived definitions but might cause harm to human health and the environment because new properties are invoked due to particle size (independent whether this is nano or not). Regulatory processes looking into new research and innovations based on nanotechnologies have to remain open for constant revisions – depending on new scientific findings and societal appraisals. The Risk Governance Framework can serve as a reminder to risk managers and regulators to be aware of the flexible limits about what nanomaterial means and what this implies for risk assessment and management. Furthermore, the framework emphasizes that pre-assessment is meant as an ongoing observation that runs parallel to the full governance cycle including constant updating of knowledge and continuous involvement of critical stakeholder groups. It is logically the first step in the risk governance model but it is also a continuous process accompanying each phase of the cycle.

11.3 Risk Appraisal

Risk appraisal incorporates:

(a) *Risk assessment,* which covers the identification and analysis of measurable, physical, chemical or biological characteristics as well the harmful (physical) effects if exposed to nanoparticles or nanotechnologies.
(b) *Concern assessment,* which covers the associated and perceived consequences for organized stakeholders and the broader public (risk perception, social concerns and socio-economic impacts).

Both assessments use probabilities to express uncertainties. With respect to risk assessment, most of the currently discussed recommendations are calling for a "case-by-case"-approach (SCENIHR 2009; NIOSH 2009; German NanoKommission 2009; Swiss Government 2008). A case-by-case approach is, of course, very cumbersome and requires major resources and commitments by companies in terms of testing facilities and time allocation for conducting such tests on each substance. In addition, the conventional testing strategies (dose–response-models) are often inadequate for testing the side effects of nanomaterial since, for example, the surface-to-mass ratio may be more important than the overall dose. There is a lack of standardized, comparable test methods for risk assessment and eco-efficiency testing (European Parliament 2009). It is an open question of how a case-by-case assessment can be combined with new assessment protocols and how public authorities should handle the huge amount of results from case-by-case approaches based on the variety of applications and formulations and a broad range of assessment criteria.

With respect to *concern assessment*, the data base reflects the three major risk characteristics that the IRGC framework highlights: high complexity, high uncertainty and high ambiguity. When summarizing the results of the numerous surveys of risk perception in the US (Kahan et al. 2007; Hart 2007), Europe (BFR 2008; European Commission: Eurobarometer 2006), Australia (DIISR et al. 2008) and Japan (Sekiya 2008; Sekiya et al. 2007) one can conclude that the knowledge base and the level of awareness is still low in most industrialized countries. At the same time, most people show positive expectations when asked about the future of nanotechnologies and a majority of people expect that the benefits will outweigh the risks. The majority of the survey participants – independent from their cultural background – do not appraise nanotechnologies based on information or a reasoned risk–benefit-ratio decision. The reasons supporting their attitudes differ, however, from country to country and from study to study. Some authors indicate a general positive attitude towards innovations that are extended to nanotechnologies, for example in Germany (Grobe et al. 2008), others stress the importance of trust in the actors, who advocate nanotechnologies (Macoubrie 2005); affective or emotional responses and value patterns (Kahan et al. 2007), long term religious patterns and short term media influences (Scheufele et al. 2008). However, all of these interpretations should be taken with caution. Due to the different methods and questions, there is only a weak base for intercultural comparisons between the US and Europe, the Asian countries or Australia. We are still in a phase of exploring tendencies (IRGC 2008).

The second reason why we claim that perceptions are as complex and ambiguous as the physical risks lies in the differentiation between the various fields of application. In some surveys participants had the opportunity to make clear distinctions between desired and undesired fields of applications. Other surveys limited their questionnaires to cover general attitudes only. The opposition to nanotechnologies were strongest when military applications were mentioned followed by nanomaterial in food. Nanomaterials in paint and other consumer products were seen as much more benign (Macoubrie 2005; Grobe et al. 2008; DIISR et al. 2008). It is still unclear how attitudes on single applications influence the appraisal of nanotechnologies in general. Depending on personal priorities with respect to each application (for example persons who are particularly sensitive to food risks may generalize their negative attitude towards nanoparticles in food to an overall negative attitude) or short term media influences focussing on one application at the time of the survey, the response to general questions vary from survey to survey.

Given these fluctuations, attitudes appear to be fragile and volatile for two reasons: first, because they are not founded in solid knowledge but on premature intuition, and, second, because they represent a wide variety of responses as a function of application and wording of the questions. At this time, the general attitude of the public is difficult to characterize: the overall positive direction can easily erode if the media stresses the risks and health impacts or if stakeholder groups succeed in mobilizing parts of the public. A general drop in attitudes in one area of application may easily be a trigger a general shift of attitudes towards nanotechnology as a whole.

Summarising the situation that we face in risk appraisal, we have to admit that we are just at the beginning of a longer lasting process of generating more reliable knowledge. As long as the knowledge base tends to be insufficient and, subsequently, public attitudes remain volatile, there is no alternative to an approach of continuous involvement, participation and dialogue. For both, the risk assessment and the concern assessment, there is more work to be done before a sufficient database will be available and appropriate risk management measures can be initiated.

The need to fill the knowledge gaps and to consolidate methods and routines requires more not less stakeholder involvement. Such involvement can help to collect and integrate the knowledge of all stakeholders and to find a precautionary but also progressive way to improve the knowledge base and, at the same time, proceed with the development of sustainable applications.

11.4 Characterization and Evaluation

The stage of characterization and evaluation has been described as "*the most controversial phase*" in the Risk Governance Framework. This phase describes the process of delineating a judgment about the acceptability and tolerability of the risk. Risk is deemed "acceptable" if risk reduction is considered unnecessary, it is deemed "tolerable" if it is pursued because of its benefits and if it is subject to appropriate risk reduction measures. The process of judging includes (a) a scientific (evidence-based) "risk profile" focused on risk assessment and concern assessment; and (b) a societal (value based) balancing of benefits and risks. Considering the uncertainties and ambiguities in the data base, the lack of appropriate measurement methods and monitoring systems, a systematic process of balancing all the pros and cons seems to be far away. However, in spite of these uncertainties and ambiguities acceptability decisions have to be made. Again deliberative methods can be of great help to deal with such difficult evaluation tasks and they can provide the best methods to balance the interests of those at risk and those who may gain most of the benefits. So it comes to no surprise that evaluations of risk have been performed in stakeholder dialogues. One example is the German NanoKommission's preliminary assessment tool that structures nanomaterials in three categories, the so called "*levels of concerns*" (German NanoKommission 2009:9, 38ff.):

- Group 1: probably hazardous – concern level high. Exposure occurs, high mobility, reactivity, persistence or toxicity. A concept is required for measured to minimise exposure or to avoid certain applications.

- Group 2: possibly hazardous – concern level medium. Exposure cannot be ruled out; incomplete knowledge on agglomeration or de-agglomeration, solubility, biodegradability, releases uncertain. A concept is required for measures to reduce exposure on humans and the environment.
- Group 3: probably not hazardous – concern level low. Exposure can largely be ruled out, solubility or biodegradability, bound in a matrix, stable aggregates or agglomerates.

Another example is the Swiss "Precautionary Matrix for Synthetic Nanomaterials" with the criteria of relevance, life cycle, potential effects, physical surroundings, exposure of human beings and the environment (Hoeck et al. 2008). The powerful Swiss retailers have strongly recommended their suppliers to use this precautionary matrix if they want to sell products enabled by, or produced with nanomaterials. In spite of the vagueness of some of these criteria, the mere attempt to use them and the willingness of the actors involved to monitor effects have certainly increased the awareness of industry to pay more attention to risk related questions.

11.5 Risk Management

Risk management aims to generate or to select appropriate strategies in order to avoid, reduce, transfer or retain unintended effects of activities and decisions. Depending on the outcomes of the tolerability and acceptability judgement, the measures are more or less severe and can range from labelling over mandatory insurance to exposure standards or even bans. Within the phase of management, option generation, selection, implementation, monitoring and collecting feedback from the stakeholders are all included. Two major challenges are linked to risk management with respect to nanotechnologies and nanomaterials. First, companies have to follow the precautionary principle if not enough reliable data are available ("no data – no market"). The majority of companies interpret the precautionary principle as a request to minimize the exposure and to apply technical and personal protection measures. This is accomplished by a Material Safety Data Sheet for informing the value chain about the characteristics and risks (VCI 2008). This practice causes doubts within other stakeholder groups (Friends of the Earth 2008, 2009; Which? 2008) if this may be sufficient for human health and environmental safety over the entire life cycle. Adequate and effective stakeholder inclusion is therefore a huge challenge during the risk management phase.

The principle questions of "*how safe is safe enough*" is further complicated by the lack of transparency and the limits of stakeholder involvement which leads to the second challenge. On the one hand, highly ambiguous risk problems require adequate stakeholder involvement in order to create tolerable and acceptable solutions. On the other hand, intellectual property rights of a company set limitations for transparency. The question of how risk management can be evaluated and monitored without providing all the necessary information to regulators and stakeholders and, at the same time, ensuring that proprietary knowledge is preserved has not yet found an adequate response. The recent attempts to deal with this challenge were not very successful (DEFRA et al. 2008; VCI/BAuA 2007). Several initiatives have been launched to implement monitoring systems (European Commission: DG SANCO 2008; German NanoKommission 2009). However, these systems have to be based on reliable and comparable data – and exactly there is the problem of (a) having access to these data bases and (b) this data base has to refer to comparable test methods. At this point we are back to the stage of pre-assessment, because this is the phase where knowledge gaps are being identified and where the status quo of the current scientific and societal debate on the risk assessment of nanotechnologies and nanomaterials is assessed.

11.6 Risk Communication

The framework places communication – or better a two-way-communication (Renn 2008) – in the middle of the risk governance cycle. Communication should enable stakeholders and civil society to understand the rationality (or different rationalities of the stakeholders involved) of the process and the results of the risk and benefit appraisal – even if they have not been directly involved. It is the key to an informed choice – not only for the consumers but also for decision-makers, who are obliged to include "soft issues" such as the public hopes and concerns. The two major challenges of communication can be described by two antinomies': "*the contemporary of the non-contemporary*" and "*the win and the loss of identity*".

The antinomy "contemporary of the non-contemporary" characterises the challenge of different timeframes within and between the stakeholder and the public debate. There is an unavoidable time delay between the professional, the stakeholder and the public due to the informational gap between the three groups. Risk governance addresses this challenge of time integration and inclusiveness. Problems occur if representatives of civil society call for more transparency and information and this demand cannot be met partially because scientific results are still contested and remain uncertain among professionals or if data is protected by proprietary laws. Without a transparent communication about the reasons why information is withheld stakeholders will develop a feeling of mistrust and an impression of a "hide-and-seek"-game (European Commission: DG SANCO 2007). It should be emphasized that this loss of trust is not the fault of any of the actors but rather a product of insufficient and ineffective communication arrangements among the actors and between the actors and the public at large. The more obvious current knowledge gaps become known to stakeholders and the public the more they demand better information. At the same time, the providers of such knowledge are getting more nervous since they face the same problems of uncertainty and ambiguity. However, instead of sharing their doubts and questions with a wider audience, they hide behind either legal provisions (proprietary knowledge) or communication stereotypes such as "we will never market unsafe products" that generate even more distrust and suspicion among the civil society stakeholders and the public. One should concede, however, that several early dialogues have been organised with the goal to share all information and to address both the risk assessment results as well as public concerns in an early stage of the debate. In addition, the call for more deliberative methods and for an integration of scientific analysis and risk perceptions has been echoed in several suggestions for codes of conduct (European Commission: Code 2008; IRGC 2008). However all parties will not be immune against backlashes, i.e. falling back into old patterns, such as influencing decision-making processes behind closed doors or withholding information that may pose challenges with respect to uncertainty and ambiguity.

The second antinomy refers to "*the win and loss of identities*", which could cause a similar effect of disappointments and backlashes. The more successful a two-way communication approach works and the more stakeholders include the patterns and concerns of the other stakeholders in their own considerations, the more they can reach a common understanding, but the higher is the risk of losing the identity of an organization. First examples occur where media is blaming NGOs for participating in risk assessment research projects and finding shared results with the industry instead of criticizing them (Meier 2009). However, this risk of an accommodation of identities is true for all stakeholder groups. It is hence a difficult balance to keep between reaching a compromise between the various stakeholders and saving one's face if confronted with the expectations of one's own group members. Keeping a strong identity is one of the important mechanisms to reduce complexity and to make behavior predictable. It is therefore an important prerequisite for stakeholders to keep their identity in a dialogue. There are manuals and guidelines available of how to facilitate consensus or common agreements without compromising the identity of each group (OECD 2002; NRC 2008). One of the main requirements is that the whole group is given the opportunity to follow the same learning sequence as the spokespersons in the dialogue process. Constant feedback and transparent processes of dialogues are two major conditions for assuring a parallel learning process between spokespeople and their constituents. Innovative forms of dialogue and public communication are therefore essential in the nanotechnology arena. The call for sustainable innovation in the field of nanotechnologies needs to be accompanied by an equally urgent call for same innovative communication strategies that bridge the gap between reaching a joint conclusion and saving each partner's identity.

11.7 Stakeholder Involvement

11.7.1 Overview

In 2005, the development of the Risk Governance Framework was not targeted especially to nanotechnologies, but as shown in the previous sections, the framework seems to fit right into the present debate on nanotechnologies, their risks and opportunities. In this section we would like to return to the three normative assumptions behind the risk governance framework, i.e. integration, inclusion and good governance principles and discuss how these three premises can be used to analyze and design better stakeholder involvement processes in the area of nanotechnologies.

11.7.2 Integration

Starting with the issue of "*integration*", it can be stated that the necessity of taking public perception, value patterns and social concerns into account is nearly common knowledge at this time – driven by the experiences in the debate on Genetically Modified Organisms (GMOs). Different communications from NGOs (Friends of the Earth 2006, 2008; ANEC 2009), companies (BASF 2009; L'Oreal 2008) and their associations (CEFIC 2008; VCI 2007, 2008; COLIPA 2009), public authorities (European Commission: DG SANCO 2007; European Commission: DG SANCO 2008), and research programmes (European Commission: Code 2008) provide evidence for the unanimous conclusion that the concerns of organized stakeholders and the broader public have to be taken into account. Most of the publications stress the two sides of *integration:*

(a) The integration of an appropriate scientific knowledge base into risk assessment and evaluation.
(b) The integration of stakeholder values and interests onto risk management and decision making.

Both elements are commonly identified as criteria for societal acceptability of nanotechnologies.

11.7.3 Inclusion

However, there is hardly any consensus among all the actor of how to accomplish this integration. This leads us to the second issue: *inclusiveness*. Of course it has to be considered that a growing group of companies, associations or public authorities are taking part in stakeholder involvement exercises, but it would be much too idealistic to presume that all actors share this proactive attitude. Many chemical or cosmetic companies that have a good reputation in proactive involvement of stakeholders are much more cautious in the nanotechnology debate and have adopted a policy of "wait and see" or "to let sleeping dogs lie". Other sectors such as the food and feed, paints, sport articles, household products, electronic equipment or the automotive industry are focused on the benefits of nanotechnologies, and emphasize research potentials and market development due to the broad acceptance of their products by the consumers. However, recent surveys suggest that the assumption of wide social acceptance is based on optimistic interpretations of survey data and rests on the knowledge that most people have not formed any persistent attitude towards nanotechnology. As described in Sect. 3.2, people at this time are indeed not biased against this technology. This can dramatically change, however, if people are exposed to information about potential negative side effects or when they are confronted with an incident. Then attitudes can move from one extreme to the other. Attitudes at this stage in opinion formation are very fragile (Grobe et al. 2008).

In addition, more stakeholder inclusion is demanded by the stakeholders themselves. If this demand is not met, the affected groups may mobilize their followers and organize opposition or campaigns against nanotechnology. So it is in the best interest of all sides, industry, regulators and NGOs to invest in *inclusion*. There is some evidence for a successful inclusion of critical stakeholders in dialogue exercises. These exercises were directed towards aligning the strategies for innovative products with defined criteria of acceptability through the entire life cycle (NanoRiskFramework 2007).

At this time, three challenges of inclusion have to be met: first, the extension of risk assessment dialogues towards including those industries that apply nanotechnologies or nanomaterials in their products, with the goal to gather the consumer relevant product safety data (European Commission: DG SANCO 2009:1; German NanoKommission 2009:11); second, the early inclusion of the political decision makers in stakeholder dialogues on risk related questions to avoid different levels of knowledge in the debate on regulation (European Parliament 2009), and finally, the involvement of experts on ethical questions and societal concerns. Currently, the necessary ethical discourse is confined to an encircled group of scientists and only few projects take this issue into the open discourse (NanoObservatory 2009).

Since stakeholder dialogues need a focus of application due to the broad field of nanomaterials and – technologies, the challenge of integration and the limited resources of all stakeholders generate a need for more coordinated and focused activities directed towards an international comprehensive dialogue setting that brings the various actors together, comprises the major findings of scientific research, reviews the innovative product developments, reports about health, safety and environmental impacts as well as about societal and ethical questions. As described above, the diversity of nanotechnologies leads to a higher specification of the working groups, which are running the risk of exclusion of relevant stakeholders. Unfortunately the broader dialogues are targeted to the same community of experts. Therefore, they are often seen as repetitions. Yet it is better to condense forces into a few powerful, broad and inclusive discourse activities – including the political decision makers – supported by well coordinated small and effective working groups.

11.8 Criteria of Good Governance for Nanotechnologies

The third group of premises are the "*criteria of good governance*" which are the key for a successful communication. We will deal with each criterion and relate it to the debate on nanotechnologies:

Transparency is one of the most controversial items in stakeholder dialogues, mostly demanded by NGOs (ETC-Group 2005; Which? 2008; Friends of the Earth 2009) or international bodies (FDA 2007; European Commission: Code 2008). It consists of three dimensions. First, it includes *reliable market surveillance* about what kind of products are produced or enabled by which kind of nanomaterials and nanotechnologies. This creates transparency for public authorities and, in a further step, for consumers and their organizations. Secondly, it includes *information* about the status of scientific knowledge with respect to potential side benefits and side risks regarding health, safety and environment. Thirdly, *transparent information* about the product's ingredients is required. Consumers want to know whether products contain, or have been enabled by nanomaterials, or if they are creating a "nano-effect". They want to know something about the properties, the functionalities, and about the effects on health and the environment (Grobe et al. 2008:71). The overall aim is to enable consumers, regulators and insurers to make informed choices.

The call for *effectiveness and efficiency* of risk governance processes and especially for a better coordination of dialogues and the information exchange is typical for advanced phases of an inclusive risk debate (SCENIHR 2009; OECD 2009). In the first phase of risk governance the focus lies on the establishment of a working dialogue and on the recruitment of the relevant stakeholders. When this is done, the call for more effectiveness and efficiency will immediately arise since some stakeholders are already advanced in knowledge and risk evaluation while others need more time and expertise to get prepared for the exchange of arguments. Sometimes it is in the interest of one or the other stakeholder to delay the process and demand more time and resources in order to buy time. This situation calls for an experienced and skilled mediator who has experience in dealing with diverse stakeholder groups, understands their needs but also their strategies and find ways to keep the process efficiently moving ahead without losing or offending one of the stakeholders. It is always important to explore the delicate balance between efficiency on one hand side and fairness towards each actor on the other side. Therefore, effectiveness, efficiency and fairness have to be seen as belonging to the same package right from the beginning of the risk governance process.

The next criterion is *accountability* enabling trustful relations between the actors and providing the foundation for monitoring and controlling the impacts of risk management outcomes. Accountability implies that claims posed by stakeholders can be substantiated and that scientific results that are brought into the discourse can be validated. The need for factual accountability is mentioned in several codes of conduct (IRGC 2008; ResponsibleNanoCode 2008; Responsible Care 2006; European Commission: Code 2008; NanoRiskFramework 2007). However, accountability comes often to its limits if the delegates in a dialogue are required to represent a diversity of actors. This may be true for many industrial sector associations, umbrella organizations of the NGOs or citizen interest groups. It can never be excluded that, although consultation processes have been carefully designed and completed, there will be no agreement on the facts, let alone the actions necessary for risk reduction.

Furthermore, due to complexity, uncertainty and ambiguity, the dialogue participants are often confronted with competing truth claims and it is then difficult to decide which of these claims can be taken as valid evidence and which can or should be dismissed. Joint fact finding is frequently employed in these situations, which may or may not lead to isles of consensus. This is difficult to predict. One can be sure that it is in the interest of at least one actor to either exaggerate or suppress the uncertainties. What counts as evidence is therefore a subject of intense debate and often compromises are needed to find an agreement or at least an arrangement of how to deal with competing truth claims.

Due to the unavoidable diversity of interests, a *shared strategic focus* of the risk governance process is another key criterion for good governance. Similar to effectiveness and efficiency, a shared strategic focus is one of the possible structuring and simplifying elements, which are essential for handling complexity, uncertainty and ambiguity. The term “shared” point to the difference between a societal, dialogue-driven communication approach and a conventional public relations or information strategy. A “shared strategic focus” reflects the experience that stakeholders pursue their own strategies for reaching the required goals. Being strategic is not per se a problem for dialogue. On the contrary, only when all actors are aware of the goals and strategies of each other can a reasonable process for finding win-win solution emerge. The problem is when these strategic perspectives contradict each other. Unfortunately, this is commonly the case, particularly if each of the stakeholders pursues his or her own agenda and is not ready to negotiate a common goal or strategy. This could be, for example, the goal to influence regulation, or the mandate to respond to public inquiry or opposition or simply the need to demonstrate leadership, competence and capacity. Many dialogues have failed because there was no way to find an agreement about the shared strategic focus. For risk governance processes one of the fundamental conditions for success is the task of exploring the common denominator that may link diverse strategic angles and to prepare the ground for finding or constructing a shared strategic focus such as the “sustainable use of nanotechnologies”. Another focus should be on an agreement on the procedures and methods for conducting risk assessments, including public concerns, making trade-offs and identifying the most appropriate risk management options.

Turning to *sustainability*, or in general the responsible use of nanotechnologies and nanomaterials, one could claim that this could serve as the lead criterion for a shared strategic focus. The overall aim is to promote innovation in a societal acceptable and legitimate manner so that technological progress is served and public acceptance and ethical acceptability is enhanced. The reason why sustainability as a concept is so attractive to all stakeholders is the inclusion of the three dimensions of ecology, economy and social aspects (Strange and Bayley 2008). Therefore, the term “sustainability” has become a main criterion in most of the currently discussed codes of conduct for nanotechnologies (IRGC 2008; ResponsibleNanoCode 2008; Responsible Care 2006; European Commission: Code 2008; NanoRiskFramework 2007).

Lastly, risk governance processes are shaped by personal relations and the nature of interactions among and between different stakeholders. Deliberating about acceptable risk and appropriate risk management measures relies on a communication style that is characterized by mutual trust and individual accountability of all actors involved in the process. The IRGC framework mentions the following criteria for characterizing the quality of decision-making processes: "*equity and fairness*", "*respect for the rules of law*", "*politically and legally realisable*" and "*ethically and publicly acceptable*" (IRGC 2005:11).

All the criteria mentioned in this section are important hints for designing and evaluating dialogues on nanotechnology. The IRGC framework is inspired by the need for a combination of analytic rigor and deliberative argumentation. This combination has been labelled as analytic–deliberative style in the literature (Stern and Fineberg 1996; NRC 2008). It presents a framework that can help risk managers to improve the conditions for risk assessments, to include the knowledge and values of the major stakeholders and to gain public trust in demonstrating accountability and consideration for public concerns.

11.9 Conclusions

This first case study has demonstrated that governing risks in the nanotechnology field is a complex and difficult task. Without an integration of risk assessment and public concerns it is hardly imaginable that the path of innovation will be smooth and uninterrupted at least in pluralist democratic countries. Considering the opportunities nanotechnologies can provide, for example, in the area of medicine, water purification, or environmental technologies it is certainly worth the effort to improve risk governance and to design a process that provides accountability, effectiveness, efficiency, fairness and sustainability.

There are no simple answers to the question: "*Are nanomaterials dangerous, or not*". However, the stereotypical answer of many stakeholders "*it depends*" will not be sufficient to meet either media interest or public concerns. As much as a case-by-case analysis is required in the present state of knowledge, it does not satisfy public scrutiny if the reasons for having this high degree of uncertainty and ambiguity are not discussed. The wide array of nanotechnologies does not allow for a universally valid attempt to cluster, categorize or classify nanomaterials in general. This would result in a long list of exceptions, exclusions and specifications. Society has to live with these complexities.

In spite of the unique features of each application and the complexity of the issue, there are common aspects related to handling the unavoidable problems of high uncertainty and ambiguity when dealing with nanotechnologies. We make a strong plea for early and comprehensive stakeholder inclusion in all stages of the governance process as a means to find the most appropriate response to high uncertainty and ambiguity rather than denial or suppression. This method of inclusion should not be seen as a linear but rather as an evolutionary process in several loops. It does not make much sense to press complex, uncertain and ambiguous risk problems into the old patterns of reductive decision-making.

Risk governance offers a suitable frame for the reflexion and development of appropriate, mutually acceptable management strategies to handle the processes of *inclusion and exclusion, acceleration and deceleration, transparency and protection* and *continuous adjustments and the necessity of clear orientations*. Such a process is continuous, time and resource consuming, and exhausting. Maybe, this is the price we have to pay if we want to benefit from the huge and diverse innovative potential of nanotechnologies in a sustainable and acceptable way.

We could start to get used to the challenges of sustainable innovation by using a dialectical understanding of the IRGC Risk Governance Framework consisting of a slight re-interpretation of the four stages in a positive, proactive way:

- Pre-assessing the "isles" of approved scientific knowledge, of the opportunities inherent in the existing regulatory frame and the societal needs – together with the stakeholders.
- Appraising the innovation potential by modifying the development of new technologies and applications so they can meet commonly shared criteria for desirable outcomes, such as safety criteria for humans and criteria for protecting the environment or ensuring sustainability through the entire life cycle. This also includes measuring all relevant impacts that reflect public concerns.
- Designing processes for reaching a shared tolerability and acceptability assessment in conjunction with stakeholders.
- Implementing these applications and monitoring their success in joint oversight processes in which all the affected stakeholders take part.

The Risk Governance Framework broadens the stakeholder's views towards an interactive, dialogical and systematic tool for reflecting the best available knowledge on physical risks as well as societal concerns and designing decision-making processes that consider both the likely consequences of the management measures as well as their impact on the various groups in society.

Chapter 12
Case Study 2: Cash Depot and Third Party Risk

12.1 Pre-assessment

A company, NOKAS, performs both Norwegian central bank tasks and other cash processing services for private banks. In April 2004 NOKAS was just to move into new premises in the city of Stavanger when a robbery at one of the existing facilities took place. Approximately seven million Euros were taken, and one policeman was killed during the attack. This brutal robbery gave rise to a huge concern among the neighbors of the new NOKAS facility which resides in a residential area, and is located only eight metres from a kindergarten.

The risk decision problem can be formulated as follows: Is the risk for the neighbors acceptable? Should the NOKAS facility be moved? Should risk reducing measures be implemented? The problem is categorized as both an uncertainty induced problem and a normative ambiguity induced problem.

There are large uncertainties about the possible occurrence of an attack (robbery) in the future and the possible consequences. If we look at all such companies in Norway, it is very difficult to predict the number of robberies and the form they will take during the next 10 years. The statistical data are not necessarily relevant. The criminal groups develop, and who knows their coming strategies? For example, will it be more common to take hostages? This is also a normative ambiguity induced problem as there are different stakeholders views related to the values to be protected and the priorities to be made. The main stakeholders are the neighbors, the NOKAS Company and the politicians.

The case raises a number of interesting issues, including:

- Should a technical risk assessment be carried out? And if yes, how should risk be described?
- How should risk acceptance be judged?

In the following we review and discuss the way the risk assessments and the risk management (government) process were carried out in this case. Our starting point is the description of the analysis (the analysis process) as it was carried out in 2005

T. Aven and O. Renn, *Risk Management and Governance*,
Risk, Governance and Society 16, DOI 10.1007/978-3-642-13926-0_12,

(Vatn 2005, 2007). We have, however, made some adjustments, to be in line with the principles adopted in this book (based on Aven 2008a). The presentation shows only excerpts from the assessments and the process, it is simplified, and all the numbers have been changed. We refer the reader to Sect. 12.3.2 for some comments regarding the differences between our presentation and the original assessment. The objective of the assessment is to present a risk picture with respect to third parties, i.e. the residents of the area (called Frøystad), children and the staff at the kindergarten, including the parents of children attending the kindergarten. The assessments build on:

- System knowledge concerning the design and operation of the NOKAS facility
- Relevant statistical material relating to robberies
- Discussions with the NOKAS personnel, the police, and third parties
- Statements and considerations from experts
- Statements and considerations from third parties

The work is carried out by a group of risk analysts, supported by experts in the areas of risk perception and communication.The assessment is then followed up politically. Is the safety level acceptable? What types of measures are required to reach an acceptable level of safety?

12.2 Risk Appraisal

12.2.1 Risk Assessment

Risk assessment comprises the following steps:

1. Identification of hazards/threats
2. Cause and consequence analysis
3. Risk description

12.2.1.1 Identification of Hazards/Threats

The following list includes the main hazard/threat scenarios that were identified:

- Robbery of a money conveyance without intention to enter the cash depot
- Hijacking of a money conveyance with the purpose of getting inside the NOKAS facility
- The use of explosives to gain entry into the NOKAS facility
- The use of hostages to gain entry into the NOKAS facility
- The use of “insiders” to gain entry into the NOKAS facility
- Robbery of a large money conveyance
- Others

This list was drawn up by examination of earlier studies of this type, historical events and special threat identification sessions run by the analysis team. The seventh category, "Others", was added, because it is of course conceivable that robberies in the future may not occur in any of the ways described by the scenarios 1–6. Although we deem this as not very likely, it must still be addressed. It is a part of the risk picture (uncertainty picture) that also needs to be included. If we overlook a potential threat, then the associated risk is not taken into account in the results.

12.2.1.2 Cause Analysis

Most robberies of large cash holdings are aimed at money conveyances. The immediate objective of such robberies is to seize by force the money inside the vehicle. In Norway, there has not been a systematic increase in the number of such robberies, but Sweden has experienced a tripling the past 7 years.

On the average, there have been six robberies or attempted robberies per year of money conveyances in Norway in the past 5 years. The number of "destinations" (NOKAS facilities) is calculated to be 20. A historically based probability that an attempt will be made to rob a money conveyance on its way to/from the NOKAS facility at Frøystad is then $6/20 = 0.30$, i.e. 30% per year. Historically, few robberies have taken place close to the destination, or in the vicinity of where the money conveyance picks up the cash, because of more safety precautions there than on the "highway".

One can of course discuss the reference numbers used here. Which year should be used as the starting point? Why the past 5 years? Why not the past 10 years or the past 3 years? If, rather than using the number of depots (NOKASs) as a basis, one looks at the number of money conveyances, the number of cash depots, etc., then the exposure level would indicate that the NOKAS facility represents less than the assumption of 1 in 20 used above.

Some would argue that the future will bring more robberies where force is used. The arguments are:

- Organized crime is a problem that is on the increase both in Norway and elsewhere in Europe.
- Norway is experiencing that certain criminal groups, from certain countries, are establishing themselves in the country.
- The extension of the EU to the east, and the opening up of borders in the Schengen agreement, promises a "free movement of crime".
- Recent events have indicated an increase in the use of force in robberies and attempted robberies.

There are however, many arguments supporting that the frequency of robberies will decrease:

- Systematic safety and security work is being undertaken by the industry to counteract the conditions noted above.

- In particular, the NOKAS facility is characterized by an entirely different standard of safety/security than those facilities that have been robbed in recent years.
- It is Norwegian currency that is exposed here, and this currency is more difficult to dispose of than, for example, euros.
- From the available statistics, we do not see any negative developments; rather we see a slight trend for the better.

The number of robbery occurrences is an observable quantity that can be used as a risk indicator. A sharp change in the number of such occurrences would provide a basis for concluding that the risk has changed correspondingly. This argument is, however, built on a “reactive” way of thinking – we first observe the event, and then take action. The main point of a risk assessment is, of course, to be proactive, so that decisions can be made before the serious events occur.

Based on historical figures, a prediction can be made that one event will occur over the next 3 years. However, the uncertainties are considerable. What will be the nature of the robbery? If such an event should take place, is there reason to believe that this will affect the rate of attacks? Or the attack approach? Yes, it may absolutely do so, as shown by the 2004 robbery in Stavanger, when a police officer was killed.

Depending on the assumptions made, the analysis group will arrive at different probabilities for an attack. Some examples are:

- The use of historical data as mentioned above: 30%
- Use a larger data set for money conveyances (not only depots): 5%
- Strong growth in aggravated robbery groups: 50%
- The robbery milieu is keeping a lower profile following the 2004 robbery: 10%

However, it is not a major point whether one should use 30%, 10%, 50%, or some other percentage. There exists a threat that the NOKAS facility will be exposed to such an event over the next years, and the figures above give a picture of the risk level. The analysis group uses 10% as its basis value.

Up to now, we have looked at a total probability for a robbery attempt corresponding to the various threat scenarios. Each of these threat scenarios will be analyzed and the uncertainties will be described and discussed. Let us look at one example, Threat scenario 4: “the use of hostages to gain entry to the NOKAS facility”.

One can envisage a variety of situations where hostages are taken. In Norway, there is one example of third parties being taken hostage in connection with a robbery. In this case, the hostages were taken soon after the robbery, and at a different location from where the robbery occurred. This incident took place more than 10 years ago. Examining the number of robberies of money conveyance, banks, and post offices, the historical fraction of hostage taking after a robbery is less than 1%, assuming that a robbery has indeed occurred.

Recently (2004), however, there was a hostage situation in Northern Ireland (Vatn 2005):

> *It wasn't until around midnight on Monday, six hours after thieves had robbed the Northern Banks head office in the centre of Belfast, that the police obtained a report on the robbery. By then, the robbers had long since disappeared, with proceeds of between 20 and 30 million British pounds. On Sunday, the bank robbers took as hostages family members of the two bank managers, and held them in their own homes. Under threat that the hostages would be harmed, the robbers forced the two executives to go to work as usual. The two were at work all day Monday. None of the other staff noticed anything unusual with the two. When the bank closed for the day on Monday, the two remained, and the robbers gained entrance into the bank.*

In this scenario, the families of the employees were taken as hostages. Threats were made against the bank staff, who then "opened the doors" for the robbers without anybody else knowing what was afoot. The fact that employees or their families can be threatened in this way is therefore highly realistic. One can also envisage neighbors or persons at the kindergarten facility being taken as hostages.

Those who are taken as hostages, and their families, will no doubt become very negatively affected from such an event. At the outset, the most likely possibility is that persons who have ties to NOKAS will be taken as hostages, as opposed to neighbors or others in the vicinity. Historically, if one omits those persons directly servicing the money conveyances (drivers or reception staff), there are few events where persons are taken as hostages in order to enable robbers to gain money by force. But such reasoning does not take into account that "surprises" happen. We must expect that if thieves intend to rob NOKAS, then they will search for new methods, and various extortion methods may become relevant.

The extent to which hostages will be seriously injured or killed depends on the evolution of the situation. The analysis group does not have access to relevant statistics, but views the probability as being relatively large. We are talking here about armed robberies. A probability of 10% is assigned.

12.2.1.3 Consequence Analysis

Starting from the initiating events, traditional event tree analyses were carried out. An example is shown in Fig. 12.1, based on the threat: "Attack on money conveyance upon arrival at, or in the vicinity of, the NOKAS facility, with the objective of seizing by force the money contained in the money conveyance". The different branches in the event tree require separate analysis. We choose here to look at the branches, "hostages taken" and "shooting occur while fleeing the scene", and our focus is on third parties.

Hostages taken: If an attack is carried out, many types of stressful situations involving shooting could arise, and hostages may be taken. Note that this scenario is not the same as threat scenario 4, which relates to the planned taking of hostages to enter the facility. A relatively high probability is given for the use of hostages, and for possible injuries and deaths during such stressful situations:

P(hostage taking|stressful situation) = 0.2,
P(fatalities|hostage taking, stressful situation) = 0.2, and
P(injuries|hostage taking, stressful situation) = 0.5.

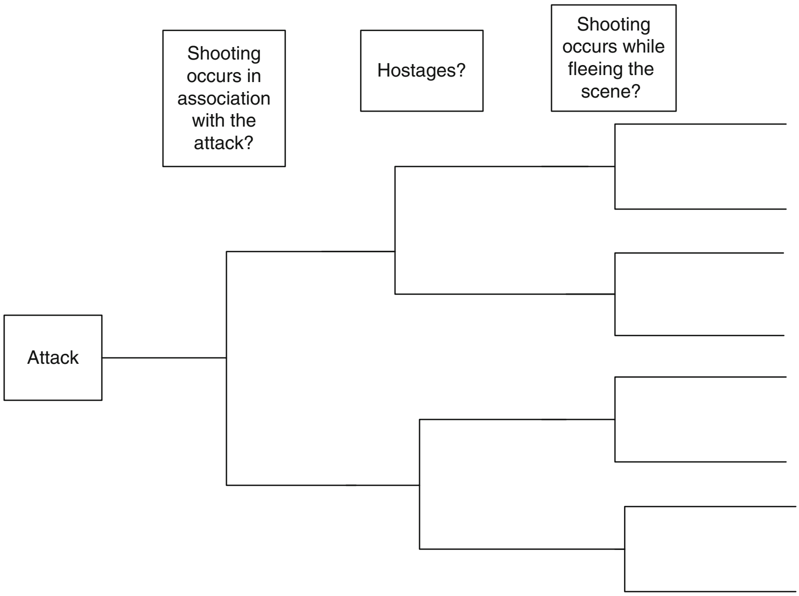

Fig. 12.1 Event tree for the threat attack

Shooting occurs while fleeing the scene: While the robbers are fleeing the scene, shooting could occur. A probability of 10% is assigned for such an event, given that the two first branch events have not occurred. The probability is rather low because of the safety philosophy of the police. This policy implies that third parties are not to be put in danger in order to arrest criminals. This means that if a robbery comes about, and the police are notified, then they will first conduct a reconnaissance of the area. Prior to the police potentially taking an action at the facility itself, the area will be evacuated. Regarding possible car chases, a stronger competence level is required for the police, than for the fire department and ambulance personnel. Furthermore, there has been a shift from not "giving up on a car chase", to that one now gives up on the car chase as soon as it is judged that the chase represents a danger for third parties, or for those being chased (or the police itself). On "paper", there is therefore no hazard associated with either gunfire or car-chases if the police is involved. One can, however, not exclude conflict situations. Such situations can arise from misjudgment of the situation by the police, or by them not handling the situation by the book.

If one or both of the previous branch events have occurred, significant higher probabilities are assigned. If the police enter into a situation where a critical state has already set in (for example NOKAS staff or a third party is in immediate danger), it is much more likely that shooting occurs while fleeing the scene.

In case of such a scenario it is likely that persons in the escape route could be injured or killed. One may expect groups of children and adults in the escape area. During an escape, one or more of these persons may be injured or killed. The analysis group assigns a probability of 5% that someone will be killed under such a situation, and 25% that someone will be injured. There are no available statistics concerning figures killed and injured for this type of escape situation. It is, however, very rare that third persons are killed in an escape situation with the police involved. On the other hand, it is not unusual for those being pursued to be injured or killed.

Barriers: In the NOKAS facility there are many barriers to prevent attacks, and to limit losses in the event of an attack:

- There is a reinforced perimeter with installed alarms on windows, doors, and vehicular entry/exit locks.
- Money conveyance vehicles must enter through the vehicular locks (vehicle reception room), and dedicated control processes are in place to allow entry for these vehicles.
- Within the outer perimeter there is another perimeter with personnel entry locks into the internal reception room (valuables zone). Only one person at a time can enter, and timed barriers are installed to deter many persons from entering within a short time period.
- Between the vehicular room and the reception room (valuables zone) there is only one lock for valuables alone, i.e. neither persons nor vehicles can move between the vehicle room and the reception room.
- The vault itself is located inside the valuables zone.
- To control taking money out of the vault, the doors to the vault are equipped with time-delay locks.
- There are systems in place to destroy/secure the money in a robbery situation.

We cannot discuss these conditions in any more detail here. Based on these analyses, one can calculate probabilities for the two chosen consequence categories: injured and killed (see below).

12.2.1.4 Risk Description

Based on the above analysis a risk picture can be established. A series of threats (initiating events) have been identified and the consequences analyzed. On this basis, a list of possible scenarios has emerged. Furthermore, important factors influencing the initiating events and consequences are discussed. Quantitative analyses are carried out to determine how likely the different events and scenarios are. The analyses yield the following probabilities (for a 1 year period):

- A probability of 10% for an attack associated with the NOKAS facility.
- A probability of 0.01% that a third-person will be seriously injured or killed as a result of a NOKAS related attack.

There are, in particular, two uncertainty aspects that apply:

- Possible trends within the robbery environment.
- The scenario development in the case of an attack.

Depending on the assumptions made with respect to these aspects, one can arrive at different probability figures. Our assumptions are drawn from the analysis above. A particularly important point is the manner in which a possible attack will take place. A possible scenario is that an attack will occur in an innovative, surprising and brutal way. The use of hostages is a clear possibility during such an attack, and the result could easily be injuries and fatalities. If one assumes a strong increase in the aggravated robbery environment, we will arrive at a probability of 0.1% for a third-person being seriously injured or killed as a result of a NOKAS related attack.

The above figures relate to events expressing that at least one person is seriously injured or killed. If we wish to calculate individual risk, then we must focus on the event in which one specific person is seriously injured or killed. Given that there are approximately 100 persons who are exposed, the figures above must be divided by 100.

An event can result in a number of injuries and fatalities. The drama inherent in an attack suggests that each and every attack discussed above must be viewed as a major accident. Even if only one person is injured or killed, the character of the event is violent and could lead to considerable ripple effects, both for those in the vicinity of the facility, and for the community as a whole. The psychological strain can be strong and can lead to long-term suffering and trauma. Using such arguments, we arrive at a probability of 0.1–1% for a major accident, depending on the assumptions made.

12.2.2 Concern Assessment and Risk Perception

A dialogue process based on group meetings was initiated to reveal the perceived risk by the relevant stakeholders. Our concern here is the (1) neighbors with children in the kindergarten, (2) neighbors without children in the kindergarten, (3) employees from the kindergarten, (4) the police, and (5) employees from NOKAS. The group meetings were carried out as follows (Vatn 2007):

> All participants were individually asked to express what kind of fear and threat scenarios they found most relevant. Next, all participants were individually asked to express what could be done in order to reduce or eliminate these threats. The facilitator of this process made a summary of all arguments that came up during the group discussions. The focus in these summaries was on the arguments and topics. Who said what was not recorded All participants got access to a draft version of the summary for their own group in order to make corrections in case of anything was misunderstood etc. Then all the corrected summaries were distributed to all groups. In the next phase of the dialogue process one representative of each group was selected to meet in a joint group meeting. In this group meeting each representative presented the main findings from his group. The idea was to present the threats and possible measures without interference from the other representatives. A summary report of this joint group meeting was also made. Finally a complete report was issued summarizing the entire dialogue in these group meetings.

The main findings of the process are (Vatn 2007):

- The perceived risk was an important issue for the neighbors and the employees in the kindergarten. The risk to children and other people was the main emphasis, but juridical and moral responsibility in case of an incident was also emphasized. These representatives argued in terms of that something *will* happen, the question is *when* it will happen. Finally, these representatives wanted a political decision to move the NOKAS facilities.
- The representatives from NOKAS and the police had sympathy to the neighbors wish to have more information related to the security issues. A central dilemma is that some information cannot be communicated opened, e.g. information about security systems, and the arrangements made by the police force. However, it was stated that much of the information about security issues could be communicated without problems.
- From the neighbors' point of view, lack of information, and lack of control leads to increased perceived risk.
- A relatively large number of risk reducing measures were proposed. These measures covered both the short and the long time horizon.

12.3 Tolerability and Acceptability Judgement

12.3.1 Risk Characterization

In order to judge the level of risk, we draw attention to some reference values:

- The number persons killed in accidents in Norway in recent years has been, on average, approximately 1,700 per year. This means that an "average person" has a probability of 4×10^{-4} of being killed in an accident over the course of 1 year. 20% of these accidents take place in a residence or in a residential area, while 20% result from traffic accidents.
- It is common to require a probability of death of a third-person associated with exposure from an industrial plant to be less that 10^{-5} (for 1 year).
- It is usual to require a probability for a "major accident" to be less than 10^{-4} (for 1 year).
- There are very few accidents where children are killed during the time they are attending a kindergarten. Statistics on fatalities in kindergartens and in playgrounds show 0.7 fatalities per year. This corresponds to a yearly probability of 4×10^{-6} that a child will be killed in an accident in a kindergarten, or at a playground (the statistics do not distinguish between playgrounds and kindergartens).
- The "average, historical probability" of being killed in a robbery, or in an assault is 10^{-5} per year.

- The German MEM principle (MEM: Minimum Endogenous Mortality) refers to a basic risk, and makes the point that any new activity must not produce an additional risk that is significant compared to the basic risk. The MEM principle means that an additional risk is unacceptable if it represents an individual risk greater than 10^{-5} per year.
- There is usually a lower acceptance for risk concerning children than for adults.
- The risk we accept is linked to the benefits we gain from the activity. Considerable risk is accepted for driving a car, as we derive a great benefit from this activity. The benefit for the residents of Frøystad from the NOKAS facility, however, is small.

From the analysis figures, and comparison of these with the reference values, in particular the MEM principle, the individual risk does not come out too badly. If we however, consider a robbery to be a major accident, the assessment would be different. In such a case, the figures would be relatively high.

There is significant uncertainty associated with whether we will experience an attack linked to the NOKAS facility in the future, and what the course of events will be if an attack should actually occur. This fact calls for the application of the cautionary principle. The level of caution adopted will of course have to be balanced against other concerns, such as costs.

12.3.2 Risk Evaluation

The results of the risk appraisal and characterization provide a basis for a political decision in Stavanger. Formally NOKAS had got all necessary permissions to start operating from their new locations. Hence the final political decision was either to move NOKAS, or the kindergarten. The expenses had to be covered by the city of Stavanger.

The city bureaucrats prepared the case on behalf of the city manager. The statement of the case from the city manager to the politicians in the City of Stavanger concluded that the societal security related to third persons in the neighborhood of the new NOKAS facilities is not worsened in such a way that moving the kindergarten nor the NOKAS facilities is necessary. However, some risk reducing measures need to be implemented and the city of Stavanger will need to actively contribute to reduce the perceived risk in the neighborhood by allocating necessary resources for dialogue and communication.

This conclusion was based on the result and process actually carried out. Our approach as outlined above differs from the approach adopted (Vatn 2007) in several ways, the most important being:

- The risk description is different. We place a stronger emphasis on the uncertainty dimension, in addition to the probabilities.
- We expand the basis for judging about acceptance of the risk by considering an event of type 1–6 as a major accident.

- We stress that traditional cost–benefit analysis do not properly reflect risk (refer Sect. 12.2.4), and as a result, is not well suited to show the appropriateness of safety measures.

Whether these differences would have changed the process, is difficult to say. As our perspective provides a broader risk characterization, highlighting the large uncertainties involved, the normative conclusions made by the city manager, would have been harder to justify. The politicians would be more involved. The consultant may be criticized for being too weak in guiding the bureaucrats in writing the background documents for the politicians. The result of the actual process was that the city manager gave too much weight to the quantitative part.

12.4 Risk Management

12.4.1 Risk Reducing Measures

Various measures were suggested, including:

- Relocation of the NOKAS facility
- Relocation of the kindergarten
- The erection of a wall between the NOKAS facility and the kindergarten
- Covering the NOKAS facility with panels
- Review of the emergency preparedness procedures for the kindergarten

We will take a closer look at two of these measures below:

Relocation of the NOKAS facility: The measure that obviously has the greatest risk reducing effect for third parties is to relocate the NOKAS facility. If the facility is relocated to an area that is zoned exclusively for commercial activity, using an appropriate location plan, there will be few persons (third parties) exposed compared to the threat scenarios identified above. The analysis group's assessment is that the risk then would be practically eliminated. The cost of relocating the NOKAS facility is calculated to be 50 million kroner (NOK) (about €6 million). For a period of 30 years, the expected number of saved lives (ICAF) will be 0.03 (calculated on the basis of 0.001 per year) and that means that the cost per expected number of lives saved will be: 50/0.03 = 1,700 (million NOK).

This is a very high number, and normally one would conclude that the cost is disproportionate compared to the benefits gained. The argument here, however, is a traditional cost–benefit analysis and as discussed in Sect. 3.3, this approach is not very suited for expressing the benefits of the safety measure. The risk reduction is greater than the changes in the computed expected value, as argued in the previous section. How much is it worth to remove this risk? The question is about assigning weights to various concerns, including risk, and this issue is the responsibility of the politicians. It is clear that significant emphasis must be given to the cautionary principle if one is to be able to justify this measure.

Erection of a wall: If a wall is built between the kindergarten and the NOKAS facility, the risk is judged to be significantly reduced. Such a wall is assumed to protect people against gunfire and may also facilitate escape in crisis situations. The total risk reduction by erecting such a wall is calculated at 30%. The cost of erecting such a wall is 500,000 NOK. This gives the following cost–benefit ratio: 0.5/0.01 = 50 (million NOK).

This measure is also relatively expensive, from this perspective, but one is now closer to values normally used to justify safety investments. But as for the first measure, a broader evaluation process must take place to judge the appropriateness of the measure.

Various arguments have been presented from the residents in connection with such a measure. Some have expressed their interest in such a wall providing it is aesthetically constructed. Others have pointed out that to erect such a wall shows that NOKAS constitutes a real threat, and that it will serve to intensify the existing negative risk perception.

12.4.2 Decision-Making

The city bureaucrats prepared the case on behalf of the city manager. The statement of the case from the city manager to the politicians in the City of Stavanger contained two parts. Part one covered the risk characterization, based on the risk appraisal. Part two was an explicit proposal to vote about. This proposal read (Vatn 2007):

- The societal security related to third persons in the neighborhood of the new NOKAS facilities is not worsened in such a way that moving the kindergarten nor the NOKAS facilities is necessary.
- The city of Stavanger will actively contribute to reduce the perceived risk in the neighborhood by allocating necessary resources for dialog and communication.
- The city of Stavanger assumes that those measures NOKAS had suggested based on the risk assessment will be implemented.

In the final political meeting the proposal was voted on. Only two representatives voted against the proposal. The discussion preceding the voting was very short. The normative element of the proposal was that “the societal risk has not been worsened in such a way that moving the kindergarten nor the NOKAS facilities is necessary”. The background for this is (1) the risk assessment conducted, and (2) an argument by the bureaucrats that this risk could not defend the costly operation of moving NOKAS facilities or the kindergarten. These normative elements were not discussed in the political meeting.

Now, five years after the political decision, the case is politically dead. During the process the case was debated almost daily in the local newspapers. But after the decision was made the case does not exist in the public sphere. The city of Stavanger has offered the kindergarten a new building cite free of charge, and also assistance to treat preparedness training. These offers have been rejected. The wall between the kindergarten and the NOKAS facility has been built, and the traffic pattern for the money conveyance has been changed (Vatn 2007).

12.5 Risk Communication

Risk communication and dialogue were highlighted in the process. In parallel to the group meetings a dialogue with the media was established. The press was invited to the first mass meeting. A special press conference was arranged where the consultant presented the scope of work, and gave a "lecture" on risk an vulnerability analysis in general, theory related to perceived risk, and opened an internet cite where the press and all other could follow the process (Vatn 2007).

An increasing trust among the stakeholders was observed during the process. However, when the results from the quantitative assessment were available and it became clear that the bureaucrats recommended not to move the NOKAS facilities, the frontiers became more evident again, and some initiatives were steps backwards relative to the dialogue path (Vatn 2007).

Chapter 13
Case Study 3: Year-Round Petroleum Activities in the Barents Sea

13.1 Pre-assessment

In this example the decision problem is whether or not to open the Barents Sea area (including the Lofoten area) for year-round petroleum activities on the Norwegian sector. This is a decision problem that has recently been considered by the Norwegian Government. The background is a growing interest in Barents Sea exploration: The Barents Sea has a great resource potential, the area has not generally been explored much, and it is assumed that the Arctic contains a significant part of the world's undiscovered petroleum resources. In order to give decision support for year-round petroleum activities in the Barents Sea, a number of assessments were carried out, including assessments of the consequences related to economy, the environment, safety, employment and the fisheries (OLF 2003). Since the area in the Barents Sea is considered vulnerable from an environmental point of view, special attention was given to the consequences related to the environment.

13.2 Risk Appraisal

13.2.1 Risk Assessments

A number of standard risk assessments were carried out. A main focus was the possible occurrence of a hydrocarbon blowout and the environmental consequences. For example in Scandpower (2003) probabilities of events causing large oil spills were calculated. The assessments covered oil spills due to blowouts, pipeline leakages, and spills from FPSOs (Floating Production, Storage and Offloading). The calculations were based on historical data and assumptions concerning activity level, field locations, and possible blowout rates. The historical data were based on both Norwegian and international experience.

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Some 1,000 wells have been drilled over almost 40 years on the Norwegian Continental Shelf – including 61 in the Barents Sea – without any accidental spills which have had environmental consequences. Only one serious blowout has occurred during the operations phase over the same period – the Ekofisk Bravo accident in 1977 – and only one significant spill from oil and gas pipelines.

Special focus was related to the ship transport related to year-round petroleum activities in the Barents Sea area. It was found to be a major contributing factor for the probability of accidental oil spills. Based on the analyses, a probability of 1–10% is calculated for an oil release during the period 2005–2020, depending on what will be the activity level.

The assessments were based on worst case scenarios, assuming no effect of the oil emergency preparedness when assessing consequences. Relative effects of the oil spills were indicated on a crude scale for various vulnerable resources. For sea birds the data turned out to be old and limited, and the results were classified as very uncertain. The topic was identified as an area with lack of scientific knowledge. The risk assessments were subject to strong critique from the Norwegian Petroleum Directorate (now Safety Petroleum Authority Norway) NPD (2003) and the oil companies (OLF 2003), in particular the use of worst case scenarios. OLF (2003) writes:

> "In the process of consequence analysis conservative premises have been chosen for a number of circumstances that do not give an overall realistic impact picture. This includes:
>
> - The highest level of activity has on the whole been assumed.
> - High estimates of combinations of discharge/emission rates and duration.
> - Incidents are expected to occur at the worst possible time.
> - Zero effect of emergency preparedness when assessing consequences.
>
> The probability of a "worst case" is very small. The approach is used to "identify the most extreme conflict potential". In OLF's opinion such an approach complicates the risk communication. A risk-based approach based on a more realistic development scenario, where the expected effect of emergency preparedness is also taken into account, would in OLF's opinion to a greater extent enable assessing the risk".

13.2.2 Concern Assessment

The authorities place stringent requirements on oil and gas activities in the north, including the premise of zero discharges of produced water during normal operations. Based on this premise the consequences for the marine environment during normal operations will be minimal, and fishery and fish farming as well as other industries will hardly be affected by the activities.

New activities will, however, lead to increased emissions of CO_2 and NO_x. The NO_x emissions will not exceed the tolerance limits set by the authorities, and regional and local consequences will generally be small for all of the activity levels assessed. Increased CO_2 and NO_x emissions are, however, a challenge in relation to Norwegian emission commitments.

The activity will provide important growth impulses for the northern part of Norway and create a basis for new investments and jobs. The positive consequences for society in having petroleum activities in the area is judged as considerable with regard to employment, both in a development period and in a more long-term operating period.

13.3 Risk Tolerability and Acceptability

13.3.1 Risk Characterization

The assessments concluded that the probability of accidental spills in the Barents Sea is no greater than on other parts of Norway's continental shelf. The physical environment does not present significantly greater technical or operational challenges than players face elsewhere on the Norwegian Continental Shelf. A probability of 1–10% is calculated for an oil release during the period 2005–2020, depending on what will be the activity level. Technology exists such that the Government's ambition about no releases to sea from drilling operations can be achieved.

In other words, the daily releases to sea will be negligible and the probability for an uncontrolled release is so small that it is judged acceptable.

13.3.2 Risk Evaluation

The Norwegian Petroleum Directorate (NPD) – now Petroleum Safety Authority - which answered to the Government on matters relating to resource management, and safety and working environment for the petroleum activities on the Norwegian Continental Shelf, were positive to continuous operations. The conclusion was that the activity is acceptable from an environmental risk point of view.

This was very much in line with the view of the oil industry. OLF (2003) concluded that consequence analysis in general gives a good and sufficient basis for taking a position on year-round petroleum activities in the assessment area. According to OLF, it is currently quite possible to achieve co-existence with other industries and a focus on good environmental policy in all areas of the Norwegian Continental Shelf. The assessment should therefore allow for restarting of activities in existing licenses and opening of unopened areas. OLF concludes that the knowledge basis in general is good, and that operations in these areas will not provide very different challenges from those we are familiar with further south.

However, many researchers and NGOs came to the opposite conclusion. There is a lack of scientific knowledge and the precautionary principle should apply. Two examples of statements in this direction:

> The World Wide Fund for Nature in UK (WWF 2003) argued that the marine environment of the Lofoten Islands is one of the most wildlife-rich areas in the world (BBC 2003). According to WWF oil drilling there would destroy this unique cold water habitat, and it will not even provide a significant number of new jobs. WWF is concerned that oil development would not only endanger wildlife but disrupt tourism and fishing, on which the island community relies.
>
> "The Lofoten Islands are the heart of the spawning area for the large Arctic Norwegian cod stock living in the Barents Sea", says Ole Arve Misund, head of department at the Institute of Marine Research in Bergen, Norway (BBC 2003). "There is a major risk that this spawning area might be destroyed in the event of an oil spill. This is why we have advised against any oil development in the area".

The Government came to the same conclusions as NPD, but not for all areas. Except for certain especially valuable areas (Lofoten area), the risk was considered acceptable. The Government found that it had not been demonstrated that adequate consideration to the fisheries and the environment can be attended to if petroleum activities are allowed in the area.

13.4 Risk Management

13.4.1 Risk Reducing Measures

The Government's proposal is based on the fundamental condition that safety and oil spill protection are fully ensured. Oil spill protection must be strengthened compared to today's level. In co-operation with other relevant authorities, the Ministry of Oil and Energy (2003) will implement strict conditions with regard to oil spill protection in the area.

A number of measures to reduce the probability of incidents related to the associated ship traffic, and the extent of the incidents, were identified. This includes traffic separation traffic center, extended territorial limits and increased tow power in the area.

13.4.2 Decision Making

The Government in December 2003 decided to permit all-year petroleum activity in the Barents Sea, except for certain especially valuable areas. One of the exceptions referred to petroleum activities in the Lofoten area. The special character of this area as a spawning ground for important fish stocks and as a major fishing ground has been important for this decision. The issue of all-year petroleum activity in this area will be considered when the integrated management plan for Barents Sea is completed.

13.5 Risk Communication

The Government decision was based on a standard political process, allowing the various stakeholders to submit consultative statements and take part in the public debate. Before the Government made its decision, there was intense debate in the media about the issue. A number of the statements addressed the lack of time to do proper assessments. The consequence assessments were said to not meet international standards for such assessments.

13.6 Discussion

This risk characterization established by the government was criticized by both the governmental agency NPD and the oil industry (NPD 2003; OLF 2003). The main problem was the use of worst-case scenarios, which indicated that a large oil spill is likely to occur in the coming 20 years. Others were more concerned about the lack of scientific knowledge for the consequences of a possible oil spill. However, some experts concluded that we had sufficient knowledge about the phenomena of interest and there was no need for the Government to defer its decision. Of course, significant uncertainties exist about some aspects of the consequences of possible oil spills (for example to sea birds), as well as the efficiency of the oil protection systems. The main issue for the conclusion about allowing year-round petroleum activities is however about values (normative ambiguity), how we weight the different concerns and uncertainty and risk in particular.

We do not know what will be the outcomes of a year-round activity in the Barents Sea. An oil spill could occur. There are considerable uncertainties what will happen – there is risk. This risk is not acceptable for the environmentalists and some political parties. The income aspect is not of interest. Let us not take chances, is the main line of thinking. Vulnerable environmental resources are at stake.

The other perspective is to look at what the activities generate of benefits for the society and for the individuals. If we do not take any risks, there is no life, as all human activities are exposed to possible losses and damages. In this case the risks are not higher than for other areas, so why should we not allow such activities?

Chapter 14
Conclusions

Our analysis has shown that narrow risk concepts based on probabilistic risk assessments, which produce numerical probabilities derived from experiments, models, expert judgements, and/or scenario techniques, provide society only with a limited scope of what humans might value. The economic, psychological and social science perspectives on risk broaden the scope of undesirable effects, includes other ways of expressing possibilities and likelihood, and expand the horizon of risk outcomes by referring to "socially constructed" or "socially mediated" realities. The psychological, social and cultural experience of risk includes the perception of actual damage; but it is more focused on the evaluation of the risk context, the non-physical impacts and the associations between the risk and social or cultural artefacts. If all society cared about was to reduce the amount of physical harm done to its members, technical analyses and some form of economic balancing would to large extent be sufficient for effective risk management. Included could be the perspective of organizational sociology to make sure that technical safety measures are paralleled by institutional control and monitoring (Perrow 1984; Freudenburg 1992). Psychology and the social sciences would only be needed to sell the risk management packages to the "misinformed" public via risk communication. But society is not only concerned with risk minimization (Douglas and Wildavsky 1982; Leiss 1996; O'Malley 1996). People are willing to suffer harm if they feel it is justified or if it serves other goals. At the same time, they may reject even the slightest chance of being hurt if they feel the risk is imposed upon them or violates their other attitudes and values (Fischhoff et al. 1985; MacLean 1986; Linnerooth-Bayer and Fitzgerald 1996). Context matters. So does procedure of decision-making, independent of outcome. Responsive risk management needs to take these socially mediated consequences into account.

Needed is therefore a more comprehensive risk concept that spans the different perspectives of risk and provides an integrated approach for capturing the physical and socio-cultural aspects of risk. Such a concept should be guided by the rigor and specificity of the technical and natural science approaches and inspired by the richness and plurality of the economic, psychological and social science approaches.

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Are there candidates that would be able to meet these two, on first sight contradictory demands?

The risk governance framework proposed in this book might provide a first attempt to meet this challenge. It offers an innovative, comprehensive and consistent, yet flexible set of guidelines for identifying, understanding and addressing the elements that are the essential components of sound risk governance. It is not intended as a recipe or a checklist which can guarantee that no relevant aspects gets overlooked while assessing, managing and communicating risk. The framework cannot replace thinking or, for that matter, creativity. It is however hoped that, by building into conventional "risk analysis" soft issues such as societal values, concerns as well as perceptions of risk and by looking into the interactions required between the various actors involved in the process, it can contribute to the development of better balanced and more inclusive risk governance strategies.

What benefits can scientists and policymakers gain from using the risk governance framework?

- Science-based risk assessment is a beneficial and necessary instrument of pragmatic technology and risk policy. It is the only means by which relative risks can be compared and options with the highest expected costs–benefit ratio selected. However, it cannot and should not be used as a sole guide for risk policy making. The price for its universality is abstraction from context and the overshadowing of other rational and meaningful perception characteristics. Without taking context and situation-specific supporting circumstances into account, decisions will not, in a given situation, meet the requirement of achieving collective objectives in a rational, purposeful and value-optimizing manner.
- Context and supporting circumstances are significant characteristics of risk appraisal in the IRGC framework that we have taken as the best available model for dealing with risk in a complex and globalized world. Appraisal includes public concerns and perceptions. These social concerns stem from cultural evolution, are tried and trusted concepts in everyday life and, in many cases, control our actions in much the same way as a universal reaction to the perception of danger. Their universal nature across all cultures allows collective focus on risk and provides a basis for communication (Rohrmann 1995). While the effectiveness of these intuitive perception processes depends on ingrained values and external circumstances, they remain ever-present and measurable despite cultural reshaping (Brehmer 1987). Intuitive mechanisms of risk perception and intuitive evaluation have practically universal characteristics that can be shaped by sociocultural influences. However, the fact that a perception model has its roots in evolution is not sufficient to lend it normative force. Such practices are at best reference points in the search for explanations that must follow the rules of normative debate, independently of the factual existence of such practices. Therefore, both scientific assessments of the physical risks as well as social science assessments of people's concerns and perception are the input for the stage of risk characterization and evaluation, where all facets of the risk issues are considered and deliberated.

- From a rational standpoint, it would appear useful to systematically identify the various dimensions of intuitive risk perception and public concerns and to measure those dimensions against prevailing, empirically derived characteristics. In principle, the extent to which different technical options distribute risk across the various groups of society, the extent to which institutional control options exist and to what extent risk can be accepted by way of voluntary agreement can all be measured using appropriate research tools. Risk perception supplies lessons in the need to incorporate these factors into policymaking. This is based on the view that the dimensions (concerns) of intuitive risk perception are legitimate elements of rational policy, but assessment of the various risk sources must follow rational, scientific procedures in every dimension.
- The incorporation of public concerns and stakeholder interests does not guarantee rational policy. Just as technical risk assessment should not be made the sole basis for decision-making, stakeholders' beliefs or perceptions of risk should not be made the political measure of its acceptability. If we know that certain activities, like passive smoking, can lead to serious illness, then policies to reduce risk are appropriate even if there is a lack of awareness of the problem among the general public. Many risks are ignored because no-one wants to deal with them. This applies especially to risks that are triggered by natural forces. To allow oneself to be guided by ignorance or obviously false perceptions hardly meets the prescription of pragmatic risk and technology policy. Knowledge of these perception patterns can, however, be used to structure and implement informational and educational measures in a beneficial manner. The inability of many people to understand probabilistic statements or to recognize the long-term risk from familiar risk sources is surely one problem area in which targeted education and information can be of benefit (Renn and Levine 1991). What is really needed is mutual enhancement between technical risk assessment and intuitive risk perception. Risk policy should neither be purely science-based nor purely values-based.
- During the phase of evaluation and risk management, options for risk reduction or mitigation will be generated and assessed. Setting option trade-offs requires policy weighting between the various target dimensions. Such trade-offs are dependent both on context and on the choice of dimension. A full fledged risk appraisal offers important pointers concerning the selection of dimensions for focus. In addition, stakeholder participation in pre-assessment and evaluation ensures that important aspects of potential damages or benefits are not forgotten. The fairness factor plays a significant role in such trade-offs and in weighting the various dimensions. In their roles as scientists, experts have no authority to take such things into account. This is where risk comparison reaches its limits. Even if we remain within the semantic context accepted by most people – a pool of comparable risks – multidimensionality in the intuitive risk model and variable targets in risk management prevent risk policy from focusing one-sidedly on minimization of expected impacts.

But who has the authority to make these decisions and how can the decision-making process be justified? There are no general and intersubjectively binding answers. Greater involvement of those affected by the potential impacts, greater transparency in decision-making, rational and non-hierarchical discourse, two-way risk communication – these are all potential solutions that we recommend policy makers to pursue vigorously.

Actual acceptance relies on numerous factors of which many can hardly be described as normative principles of political action. Perceptions rely partly on erroneous judgements and simple lack of knowledge. Opinions on risk are often tied to symbolic attributes that are only indirectly related to the advantages and disadvantages of a specific risk source, preferences among the population are often inconsistent and, finally, the question of how to aggregate individual preferences "for the good of all" remains unsolved (Meyer-Abich 1989). Should the majority decide, even if only a minority is affected? Who has the right to make collectively binding decisions? The simple solution – leaving the conflict surrounding risk to the powers that be – may well increase the acceptability of political decisions, but hardly their sustainability.

In spite of the illusiveness of public perceptions and values, normative acceptability of risks cannot be entirely removed from factual acceptance. In a democratic society, it is the people who determine the circumstances under which they wish to shape their future. The political task of risk management will lie in explaining the anticipated advantages and disadvantages to those affected, i.e. the risks and opportunities of the available options, and, on this basis, communicating to them the possibility of rational judgement.

The further development of pragmatically oriented risk policy will depend on how much more is learned about all the stages within the risk governance cycle. Available knowledge on risk assessment and risk perception, including the perception of combined risks, improved methods of including stakeholder concerns, interest and values and more refined methods to generate and test risk reduction options may be the route to choose for improved risk governance. Conflict resolution and risk communication programmes are likely to be rejected by the general public as long as the process of pre-assessment and appraisal is not made transparent and open to public demands. While public perception and common sense cannot replace science and policy, they can certainly provide impetus for the decision-making process. At the same time, if decision-makers take into account the factors and needs of public perception, then public willingness to accept rational models for decision-making is likely to increase.

At any rate, a comprehensive, informed and value-sensitive risk management process requires a systematic compilation of results from risk assessment, risk perception studies and other context-related aspects as recommended and subsumed under the category of risk appraisal. Risk managers are thus well advised to include all the information related to the risk appraisal in evaluating the tolerability of risks and in designing and evaluating risk reduction options. The crucial task of risk communication runs parallel to all phases of handling risk: it assures transparency, public oversight and mutual understanding of the risks and their governance.

Appendix

A Classification Scheme for Socio-economic Concerns by Vanclay (2002)

Box A: Indicative Health and Social Well-Being Impacts

- Death of self or a family member –personal loss.
- Death in the community – loss of human and social capital.
- Nutrition – adequacy, security and quality of individual and household food supply.
- Actual health and fertility (ability to conceive) of family members.
- Perceived health and fertility.
- Mental health and subjective well-being – feelings of stress, anxiety, apathy, depression, nostalgic melancholy, changed self image, general self esteem (psycho-social factors).
- Changes aspirations for the future for self and children.
- Autonomy – changes in an individual's independence and self-reliance.
- Experience of stigmatisation or deviance labelling – the feeling of being "different" or of being excluded or socially marginalised.
- Uncertainty – being unsure about the effects or meaning of a planned intervention.
- Feelings (positive or negative) in relation to the planned intervention – which may result in formation of interest groups.
- Annoyance – a feeling/experience such as due to disruption to life, but which is not necessarily directed at the intervention itself.
- Dissatisfaction (betrayal) due to failure of a planned intervention to deliver promised benefits.
- Experience of moral outrage – such as when a planned intervention leads to violation of deeply held moral or religious beliefs.

Box B: Indicative Quality of the Living Environment (Liveability) Impacts

- Perceived quality of the living environment (i.e. work and home environment or neighbourhood) – in terms of exposure to dust, noise, risk, odour, vibration, blasting, artificial light, safety, crowding, presence of strangers, commuting time etc.
- Actual quality of the living environment.
- Disruption to daily living practices (which may or may not cause annoyance).
- Leisure and recreation opportunities and facilities.
- Aesthetic quality – visual impacts, outlook, vistas, shadowing etc.
- Environmental amenity value – the non-market, non-consumptive aesthetic and moral value ascribed to a location or experience.
- Perception of the physical quality of housing.
- Actual physical quality of housing.
- Perception of the social quality of housing (homeliness) – the degree to which inhabitants feel that their house is their "home".
- Availability of housing facilities.
- Adequacy of physical infrastructure – impact on the existing infrastructure of the community (water supply, sewage, land, roads, etc.).
- Adequacy of social infrastructure – change in the demands for and supply of basic social services and facilities, such as education, police, libraries, welfare services, etc.
- Perception of personal safety and fear of crime.
- Actual personal safety and hazard exposure.
- Actual crime and violence.

Box C: Indicative Economic Impacts and Material Well-being Impacts

- Workload – amount of work necessary in order to survive and/or live reasonably.
- Standard of living, level of affluence – a composite measure of material well-being referring to how well off a household or individual is in terms of their ability to obtain goods and services. It is also related to the cost of living, and is affected by changes in local prices, etc.
- Access to public goods and services.
- Access to government and/or other social services.
- Economic prosperity and resilience – the level of economic affluence of a community and the extent of diversity of economic opportunities.
- Income – both cash and in-kind income.
- Property values.
- Occupational status/prestige and type of employment.

(continued)

- Level of unemployment in the community – underutilisation of human capital.
- Loss of employment options.
- Replacement costs of environmental functions – the cost of replacing a product or service that was formerly provided by the community, such as clean water, firewood, flood, protection, etc.
- Economic dependency or vulnerability – the extent to which an individual or household (or higher entity) has control over economic activities, the degree of incorporation into larger production systems.
- Disruption of local economy – the disappearance of local economic systems and structures.
- Burden of national debt – such as the intergenerational transfer of debt.

Box D: Indicative Cultural Impacts

- Change in cultural values – such as moral rules, belief, ritual systems, language, and dress.
- Cultural affrontage – violation of sacred sites, breaking taboos and other cultural mores.
- Cultural integrity – the degree to which local culture such as traditions, rites, etc. are respected and likely to persist.
- Experience of being culturally marginalised – the structural exclusion of certain groups.
- Because of their cultural characteristics, thus creating a feeling of being a second class citizen.
- Profanisation of culture – the commercial exploitation or commodification of cultural heritage (such as traditional handicrafts, artifacts) and the associated loss of meaning.
- Loss of local language or dialect.
- Loss of natural and cultural heritage – damage to or destruction of cultural, historical, archaeological or natural resources, including burial grounds, historic sites, and places of religious, cultural and aesthetic value.

Box E: Indicative Family and community Impacts

- Alterations in family structure – such as family stability, divorce, number of children ar home, presence of extended families.
- Changes to sexual relations.
- Obligations to living elders.
- Obligations to ancestors.
- Family violence – physical or verbal abuse.

(continued)

- Disruption of social networks – impacts on the social interaction of household members with other people in the community.
- Changed demographic structure of the community.
- Community identification and connection – sense of belonging, attachment to place.
- Perceived and actual community cohesion.
- Social differentiation and inequity – creation of perceived or actual differences between various groups in a community or differentiation in level of access to certain resources.
- Social tension and violence – conflict or serious divisions within the community.

Box F: Indicative Institutional, Legal, Political and Equity Impacts

- Workload and viability of government or formal agencies – capacity of the formal institutions to handle additional workload generated by a planned intervention.
- Workload and viability of non-government agencies and informal agencies including community organizations.
- Integrity of government and government agencies – absence of corruption, competence in which they perform their tasks.
- Loss of tenure, or legal rights.
- Loss of subsidiarity – a violation of the principle that decisions should be taken as close to the people as possible.
- Violation of human rights – any abuse of the human rights, arrest, imprisonment, torture, intimidation, harassment etc., actual or fear or censorship and loss of free speech.
- Participation in decision making.
- Access to legal procedures and to legal advice.
- Impact equity – notions about fairness in the distribution of impacts across the community.

Box G: Indicative Gender Relations Impacts

- Women's physical integrity – refers to the right of women to be able to make informed decisions about their own body, health and sexual activity, having control over fertility and childbearing and child-rearing practices, and having the resources to implement those decisions safely and effectively, and to be free from coercion, violence and discrimination in the exercise of those decisions.

(continued)

- Personal autonomy of women – the level of independence, self-reliance and self-respect in physical, economic, political and socio-cultural aspects.
- Gendered division of production-oriented labour – refers to the unequal distribution of workload between men and women in relation to production, in terms of cash cropping, subsistence food production, wage-labour and other husehold (cash) income strategies.
- Gendered division of household-labour – refers to the gendered and uneven distribution of workload in relation to the maintenance of the household, that is fetching water and fuel, preparing food, eashing, cleaning and decorating the house.
- Gendered division of household-labour – refers to the gendered and uneven distribution of workload in relation to thecare and maintenance of the household members, that is the personal burden of childbearing and childrearing.
- Gender-based control over, and access to, resources and services – including land, water, capital, equipment, knowledge, skills, employment opportunities and income, and services such as health facilities, education and agricultural extension services.
- Equity of educational achievement between girls and boys.
- Political emancipation of women – women's influence on decision making at household, community and society level.

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