Risk Analysis
Volume 22 Issue 6 Page 1071 - December 2002 A New Approach to Risk Evaluation and Management: Risk-Based, Precaution-Based, and Discourse-Based Strategies [1] Andreas Klinke [2] and Ortwin Renn [3]

INTRODUCTION

We define risks as the possibility that human actions or events lead to consequences that harm aspects of things that human beings value (Kates & Kasperson, 1983; Hohenemser, Kates, & Slovic, 1983). [4] This definition implies that the severity of experienced harm depends on the causal relationship between a stimulus (human activity or event) and the consequences. If we take a nonfatalistic viewpoint, consequences can be altered either by modifying the initiating activity or event or by mitigating the impacts. Therefore, risk is both an analytic and a normative concept. If the vast majority of human beings assess potential consequences as unwelcome or undesirable, society is coerced to avoid, to reduce, or, at least, to control risks.
To reduce or control risks, social institutions are formed to evaluate and manage risks. In this context, we understand risk evaluation as the process by which societal institutions such as agencies, social groups within society, or individuals determine the acceptability of a given risk. If a risk is judged as unacceptable, adequate measures for risk reduction are required. The process of reducing the risks to a level deemed acceptable by society and to assure control, monitoring, and public communication is covered under the term "risk management" (Kolluru, 1995; Zimmerman, 1986:436). The debate on how to evaluate and manage risks focuses on three major strategies (Stirling, 1999).

**Risk-based approaches, including numerical thresholds (quantitative safety goals, exposure limits, standards, etc.).**

Past experiences demonstrate that there is no simple recipe for evaluating and managing risks. 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 required 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 easy-to-implement protocols.
Our main thesis in this article will be to offer a new classification of risk types and management strategies that promises scientific accuracy, a reflection of social diversity, and political feasibility. The proposal we describe in this article certainly needs adjustment to the political and regulatory culture in which it will be used, but it might offer some elementary building blocks for a variety of culturally adapted pathways to risk evaluation and management. The article explains our approach to risk evaluation, classification, and management. The authors developed this proposal during their tenure at the German Government's Advisory Council on Global Change (WBGU, 2000). [5] The proposal includes criteria for evaluating risks, a classification of risk types and risk management strategies, and suggestions for institutional procedures aimed at implementation and testing. A crucial element of the proposal is the integration of analytic-deliberative processes into the regulatory framework (Stern & Fineberg, 1996). [6] The extent to which deliberation and analysis need to be mobilized is contingent on the type and circumstances of the risk under consideration. To support this reasoning, the article starts with an overview of the current issues in risk analysis and management (Section 2). We then use the five major issues

identified in Section 2 as the guiding elements for presenting our analytical approach toward rational risk decision making, including risk evaluation and risk classification (Section 3). Section 4 deals with corresponding risk management strategies that can be derived from the preceding risk classification. Section 5 provides further considerations about the applicability of analytic-deliberative procedures within risk management. The last section summarizes the results of this article and points to the main issues that need to be resolved.

## CONTROVERSIAL ISSUES IN RISK MANAGEMENT

Risk analysis has become a routine procedure in assessing, evaluating, and managing harm to humans and the environment. However, there has been a fierce debate over the legitimate role of risk analysis for regulatory decision making. The debate centers around five major themes. 1 1.

1. Realism versus constructivism.

2. The relevance of public concerns revealed through perception studies as criteria for risk regulation.
3. The appropriate handling of uncertainty in risk assessments.
4. The legitimate role of "science-based" versus "precaution-based" management approaches.
5. The optimal integration of analytic and deliberative processes.

The following sections will first introduce each of these five themes in more detail and develop some major insights for risk evaluation and management. These insights will then serve as heuristic tools for the presentation and explanation of our own approach to risk evaluation and management.

### 2.1. Realism Versus Constructivism

The first major debate in the risk management community touches on the philosophical question of constructivism versus realism. For a philosophical review of the two "risk camps," see Shrader-Frechette (1991), Bradbury (1989), and Clarke and Short (1993:379-382). Many risk scholars have questioned the possibility of conducting objective analyses of risk. The issue here is whether technical risk estimates represent "objective" probabilities of harm or reflect only 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. Reviews of the implications of a constructivist versus a realist concept of risk can be found in Bradbury (1989) and Renn (1992). A pronounced constructivist approach can be found in Hillgartner (1992), Luhmann (1993), Adams (1995), or in a recent German book by K. Japp, *Soziologische Risikotheorie* (1996). Realist perspectives in the social sciences on risk and environment can be found in Catton (1980), Dunlap (1980), Dickens (1992), and Rosa (1998). The *constructivist camp* claims that risk assessments constitute mental constructions that can be checked at best against standards of consistency, cohesion, and internal conventions of logical deduction. However, these assessments cannot assume any validity outside of the group's logical framework. In contrast, the *realist camp* is convinced that technical estimates of risk constitute true representations of observable hazards that can and will affect people as predicted by the calculated results regardless of the beliefs or convictions of the analysts involved. For many technical experts, the philosophical position of constructivism seems absurd; for many social scientists and philosophers, the realism of the scientists seem naive at best and imperialist at worst. The debate has produced severe repercussions on the issue of risk evaluation and management: if risk assessments are nothing but social constructions, they have no more normative validity for guiding regulatory action than stakeholder estimates or public perceptions. If they do represent the objective reality, risk managers should use them as the guiding principles for handling risks. Other competing estimates by stakeholders or individuals may serve as additional input for strategic purposes, for example, to honor public concerns, to enlighten one's communication with the public, and to reconcile conflicts among stakeholders. Risk management agencies are well advised to reflect on this debate. To focus on the objectivist perspective only ignores the social processing of risk information; to rely only on the constructivist perspective may lead to more fatalities and other adverse effects than necessary under the condition that there are only limited societal resources available for risk reduction (cf. Shrader-Fredehtte, 1991).

**2.2. Public Concerns as Criteria for Risk Regulation**

The second major debate is closely linked to the first. It refers to the issue of inclusion. Many social scientists, in particular those who claim that risk is a social construction rather than a representation of real hazards, have argued in favor of integrating public concerns into the regulatory decision process (e.g., Freudenburg & Pastor, 1992). The key issue here is public involvement in defining tolerable risk levels (Lynn, 1990). Since it is the people, so goes the argument, who are affected by the potential harm of technologies or other risk-inducing activities, it should be their prerogative to determine the level of risk that they judge tolerable for themselves and their community (Webler, 1999; Harrison & Hoberg, 1994). Many technical experts have argued forcefully against this proposition: they argue that sensational press coverage and intuitive biases may misguide public perceptions. Ignorance or misperceptions should not govern the priorities of risk management. Spending large sums of money for reducing minor risks that fuel public concerns and ignoring risks that fail to attract public attention may lead to a larger number of fatalities than necessary (cf. Leonard & Zeckhauser, 1986; Cross, 1992; Okrent, 1996). If one spends a fixed budget in proportion to lives saved, the public at large would benefit the most.

The debate on the legitimate role of risk perception in evaluating and managing risks has been going on for the last two or three decades.[7]. Defining risk as a combination of hazard and outrage, as Peter Sandman suggested, has been the fragile but prevailing compromise in this debate, at least in the United States (Sandmann, 1988). Although the formula of "risk equals to hazard and outrage" does not provide any clue of how to combine scientific assessments with public perceptions, it provides a conceptual, though often ritual, foundation for the general attitude of risk management agencies. Again, the debate has not come to an end (and probably will never come to an end), but any reasonable risk management approach needs to address the question of inclusion.

**2.3. The Appropriate Handling of Uncertainty in Risk Assessments**

The third debate in the professional risk community centers around the handling of uncertainty (van Asselt, 2000). This topic has been one of the most popular themes in the professional community for many years, but is has reemerged in recent time for several reasons. Philosophers of science and risk have pointed out that the term "uncertainty" implies a portfolio of different aspects that are often neglected or amalgamated in risk analysis (cf. Funtowicz & Ravetz, 1990).

Advances in mathematics and modeling have made it possible to be more precise in calculating variability among humans or other risk targets. The general convention of using safety factors of 10 or 100 as a means to include interindividual variation can now be replaced by more precise and adequate modeling techniques (Hattis & Minkowitz, 1997).

The new global risks such as climate change or sea-level rise have turned the attention of many analysts to issues of indeterminacy, stochastic effects, and nonlinear relationships. Although these topics are not new to the risk community, they have triggered a new debate over the umbrella term "uncertainty" and how it should be decomposed and handled (Wynne, 1992; Lave & Dowlatabadi, 1993).

Several suggestions have been made in the past years to distinguish several components of uncertainty. It is obvious that probabilities themselves represent only an approximation to predict uncertain events. These predictions are characterized, however, by additional components of uncertainty. It seems prudent to include these other uncertainty components in one's risk management procedure. Which other components should be included? There is no established classification of uncertainty in the literature (see von Hasselt, 2000, for a review; cf. Stirling, 1998:102). Authors use different terms and descriptions, such as incertitude, variability, indeterminacy, ignorance, lack of knowledge, and others. A new risk management approach should look into these different types of uncertainty and find appropriate ways of dealing with them.

### 2.4. "Risk-Based" Versus "Precaution-Based" Management Approaches

The fourth debate picks up the question of how to evaluate uncertainties and transfers this problem into the domain of risk management. As stated in Section 1, the assessment of risks implies a normative mandate. Most people feel a moral obligation to prevent harm to human beings and the environment. Risk analysts are asked to provide the necessary scientific input to assist risk managers in this task. Since there are more risks in the world than society could handle at the same time, risk management always implies the task of setting priorities. The conventional solution to this problem has been to design risk reduction policies in proportion to the severity of the potential effects (Crouch & Wilson, 1982; Mazur, 1985). Severity has been operationalized as a linear combination of magnitude of harm and probability of occurrence. Risk-risk comparisons constitute the most appropriate instrument in this perspective for setting risk management priorities (cf. Merkhofer, 1987; Wilson & Crouch, 1987; Cohen, 1991).

The most significant argument against the proportional risk management approach comes from the analysis of uncertainty (Cooke, 1991; Marcus, 1988). Most risk data constitute aggregate results over large segments of the population and long-time duration (Funtowicz & Ravetz, 1987). In addition, there are problems of extrapolation and dealing with random events and ignorance. The risk community has been trying to respond to this challenge by sharpening its analytical tools, particularly with respect to characterizing and expressing uncertainties. Progress has been made, particularly in modeling variability, but some issues, such as the treatment of indeterminacies, remain unresolved.

An alternative approach has been to change management strategies and add new perspectives to the way of coping with uncertainties. Rather than investing all efforts to gain more knowledge about the different components of uncertainty, one can try to develop better ways to live or co-exist with uncertainties and ignorance. The new key words here are: resilience, vulnerability management, robust response strategies, and similar concepts (Collingridge, 1996; WBGU, 2000). According to these concepts, risk management is driven by making the social system more adaptive to surprises and, at the same time, allowing only those human activities or interventions that can be managed even in extreme situations (regardless of the probability of such extremes to occur).

In the risk management literature these two approaches have been labeled science-based and precaution-based strategies (cf. O'Riordan & Cameron, 1994; Stirling, 1999; Klinke & Renn, 2001). This labeling is rather problematic since the second approach, which rests on precaution and resilience, needs at least as much scientific input as the first approach (cf. Charnley & Elliott, 2000). We prefer the term "risk-based strategy" for the first approach. With the denotation of "risk" it becomes clear that management relies on the numerical assessment of probabilities and potential damages, while the denotation of "precaution" implies prudent handling of uncertain or highly vulnerable situations. Over the last few years, advocates of risk-based and precaution-based approaches have launched a fierce debate over the legitimacy of each of their approaches. Advocates of the risk-based approach argue that precautionary strategies ignore scientific results and lead to arbitrary regulatory decisions (Cross, 1996). The advocates of the precautionary approach have argued that precaution does not automatically mean banning substances or activities but would imply a gradual, step-by-step diffusion of risky activities or technologies until more knowledge and experience is accumulated (Bennett, 2000).

To nobody's surprise, environmental groups have rallied around the precautionary approach, while most industrial and commercial groups have been fighting for the risk-based approach. Again, the issue is not resolved, and the debate has become even more pronounced with the defeat of the European Community in the recent WTO settlement of hormones in beef. The European Community failed in providing sufficient evidence that the precautionary approach could justify the restriction of imported beef treated with hormones. In January 2000, the European Union issued a White Paper on the precautionary principle in which it confirmed its position of applying this principle to hazard management (European Commission, 2000). Since the application of the precautionary approach may have lasting implications and repercussions on regulatory decisions and international trade, the stakes in this debate are not merely theoretical or academic. Depending on the approach chosen, regulatory actions may vary considerably and shape economic competitiveness, public health levels, and environmental quality.

**2.5. The Optimal Integration of Analytic and Deliberative Processes**

The fifth and last debate in the risk community focuses on the legitimate role of deliberation in risk analysis and management. A highly debated report by the National Research Council emphasized the requirement for a combination of assessment and dialogue, which the authors framed the "analytic-deliberative" approach (Stern & Fineberg, 1996). Analytic-deliberative processes encompass procedures that are constructed to provide a synthesis of scientific expertise and value orientations. Deliberation is the term that many authors adopted to highlight the style and nature of a discursive process that they believe is capable of dealing with the problems of uncertainty and ambiguity in risk management (Webler & Tuler, 1999). The word "deliberation" implies equality among the participants, peer review as a means for verifying understandings (i.e., holding knowledge claims up to public scrutiny), and an orientation toward resolving conflicts in consensual rather than adversarial ways (cf. Habermas, 1991; Webler, 1995). As much as this concept found support among many analysts and regulators, its practical value has been questioned in recent publications (Breyer, 1993; Coglianese, 1999; Rossi, 1997). Cary Coglianese mentions six potential "pathologies" of consensus-seeking deliberation (Coglianese, nd).

1. Tractability having priority over public importance.
2. Regulatory imprecision.
3. The lowest common denominator problem.
4. Increased time and expense.
5. Unrealistic expectations.
6. New sources of conflict.

One of the major arguments has been that public preferences do not match the real interests of the public since the preferences are clouded by misinformation, biases, and limited experience. Other arguments against the use of deliberation in risk management are that such processes are economically inefficient (Rosenbaum, 1978), that lay people are technically incompetent (Cross, 1998), that stakeholders are biased and unable to represent the common interest (Coglianese, 1999; Reagan & Fedor-Thurman, 1987), and that deliberation incites conflict and further unrest (Huntington, 1970). Hence, regulatory agencies are confronted with a serious dilemma (Zeckhauser & Viscusi, 1996; Bohnenblust & Slovic, 1998): the determination of acceptable or tolerable environmental impacts relies on subjective judgment and commonly shared social values but there is no clear procedure to amalgamate social concerns and values in a pluralist society and to find nonambiguous means for resolving value conflicts. Even if preferences and tradeoffs were known, a process is needed to integrate divergent views, subjective rationalities, and preferences into an effective setting for discussion about compromise or consensus. In most cases, dominant (i.e., Pareto-optimal) options are not available so that a compromise or a consensus must be based on bargaining, compensation, voting, or a legal verdict (Fischhoff, 1996). The question of whether more deliberative procedures are able to resolve this problem of ambiguity is contested in the literature (Chess, Dietz, & Shannon, 1998). However, any new approach to risk management should demonstrate how it includes the resolution of ambiguities and conflicting values in its decision-making procedures.

### 2.6. Requirements for Regulatory Reform

Any attempt to develop a new approach for risk evaluation and management must be reviewed and tested against the five challenges mentioned above. How does a new approach to risk management deal with the constructivism-realism debate? How does it incorporate physical consequences and social concerns? How does it deal with the different components of uncertainty? What are the normative inferences drawn from the resolution of the first and second debate and how are these inferences transformed into appropriate risk management tools? What role can deliberation play in all of this?

## 3. A NOVEL APPROACH TO RISK DECISION MAKING: RISK EVALUATION AND RISK CLASSIFICATION

### 3.1. Realism Versus Constructivism: The Dual Nature of Risk

There is no doubt that the term "risk" refers to the experience of something that people fear or regard as negative. It is also clear that this fear is extended to an event or a situation that has not yet occurred but could occur in the future. Obviously, there are different dimensions of what people label as negative impact or harm. People might fear damage to their health, their wealth, their well-being, their self-esteem, or be concerned about violations of their central beliefs and values, cultural convictions, social status, and prestige. Within the professional communities on risk, most analysts would agree that damage to human health and the environment are at the fore of what we call risk analysis and risk management.

However, even if one excludes illusive phenomena such as value violations or cultural taboos and concentrates only on human health and environmental quality, there are still ambiguities. Human health and, particularly, environmental quality are difficult to appraise from a purely objectivist viewpoint. Psychosomatic impacts, such as the multichemical syndrome or the sick-house syndrome, make sense only when viewed as a combination of exposure and psychological anxieties (Renn, 1997). Even more so, the appraisal of environmental quality rests on the attitude of the observer. For example, are alien species a risk or an enrichment for a given ecosystem? Does the fertilization of fields through anthropogenic airborne nitrogen increase the risks or reduce the risks for agricultural plants?

These questions are closely associated with the debate on constructivism versus realism. Are the endpoints of risk assessments constructions of human minds or do they represent physical entities that are independent of subjective judgments? Since risk refers to a potential of "real" consequences, in our opinion it is both a social construction and a representation of reality. We agree on this point with Jim Short and Eugene Rosa who insist that risk cannot be confined to perceptions and social constructions alone (Short, 1989; Rosa, 1998). Neither can it be reduced to objective outcomes in terms of injuries, fatalities, and other types of losses. Both the cultural attributions as well as the physically measurable outcomes form the content of the term "risk." How people select issues of concern and how they model likelihood may indeed be a result of cultural conventions and rules. The threat of being affected by these consequences, however, is real in the sense that people might suffer or lose their lives if the risk manifests itself in an accident or a release of hazardous material.

The dual nature of risk 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 magnitude of risks, however, should reflect technical expertise as best as possible, since "real" victims are on stage. Following this dual approach, setting priorities within risk management would imply that social or political forces determine the criteria of judging tolerable levels of risk, whereby the technical assessments are used as one important input among others to quantify the extent of potential damage in time and space.

Based on these considerations, we propose to enrich the set of criteria used to characterize risks. For making risk evaluation and management consistent with the best scientific knowledge and the most appropriate social values, we consider it to be justified and necessary that both physical criteria as well as social concerns are integral parts of these evaluations (Fiorino, 1989). Our list of criteria includes physical as well as social indicators. Such a distinction rests on two assumptions.

1. It is possible and necessary to distinguish physical from social and psychological attributes of risk.
2. Both sets of criteria are important for evaluating and managing risks.

We believe these assumptions are reasonable and reflect the dual nature of risk. The physical elements should be measured independent of social and psychological criteria unless there is clear evidence of a common link. The psychological and social criteria should be treated as criteria in their own right and not be regarded as modifiers of the physical consequences. In addition, risk assessments should include those physical components of risk that generate social concern. If someone is worried about a risk because it is ubiquitous or persistent, this risk characteristic should be included in the evaluation process. Having included such a concern does not imply using the intuitive assessments (or guesses) of lay persons to judge any given risk on this criterion. On the contrary, the best technical estimate is needed to give justice to the legitimate concern of the citizens. Even the person who might suggest a new criterion for risk evaluation would agree that experts are needed to apply this criterion and to measure or calculate the likely impacts of each decision option on this specific criterion. Our approach is based on the idea that criteria for evaluating risks should be developed from the social discourse about concerns, while the "objective" measurement should be performed by the most professional experts at hand. These measurements may turn out to be wrong, uncertain, or ambiguous, but they are on average still more reliable than pure intuition or common sense since no methodological rules are available for judging the quality of intuition in advance.

**3.2. Inclusion of Public Concerns: Additional Criteria for Evaluation**

Once we decided to include more than the classic componentsextent of damage and probability of occurrencethe question remains: Which other physical and social impact categories do we want to include and how can we justify our selection? The identification of public concerns is not a trivial task. Empirical research has shown that people tend to evaluate risks on a large set of evaluative criteria of which only few may claim universal validity. The following contextual variables of risk have been found to affect the perceived seriousness of risks in varying degrees (Boholm, 1998; Sjöberg, 1999; Slovic, 1987, 1992; Rohrmann & Renn, 2000).

The expected number of perceived fatalities or losses.

The catastrophic potential.

Qualitative risk characteristic such as voluntariness, personal control, familiarity, dread, and others.

Emotional associations with the risk (stigma).

Trust in regulatory agencies and risk-handling institutions.

Social and cultural beliefs associated with the cause of risk or the risk-handling actors.

If the need for including public concerns into risk evaluation is accepted, one should use the results of the existing perception studies as the major heuristic rule for selecting the relevant criteria. Since the list of relevant criteria is long and not identical for different groups, selection poses a serious problem. The German Government's Advisory Council on Global Change (WBGU) has addressed this problem in its 1998 Annual Report (WBGU, 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 United Kingdom, Denmark, the Netherlands, and Switzerland (cf. Piechowski, 1994; Beroggi *et al.*, 1997; Hattis & Minkowitz, 1997; Hauptmanns, 1997; Löfstedt, 1997; Petringa, 1997; Poumadère & Mays, 1997). They asked experts to provide special reports on this issue to the authors. 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. The experts, for example, were asked to characterize risks on those dimensions that they would use for substantiating a judgment on tolerability. These dimensions were compared in common discussion sessions and those distilled that appeared most influential for characterizing different risks. These criteria are listed in Table I. The last category, "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, we decided to unfold the compact "mobilization index" and divide it into four major elements.

1. Inequity and injustice associated with the distribution of risks and benefits over time, space, and social status (thus covering the criterion of equity).
2. Psychological stress and discomfort associated with the risk or the risk source (as measured by psychometric scales).
3. Potential for social conflict and mobilization (degree of political or public pressure on risk regulatory agencies).
4. Spill-over effects that are likely to be expected when highly symbolic losses have repercussions on other fields such as financial markets or loss of credibility in management institutions (Kasperson *et al.*, 1988; Renn *et al.*, 1992).[8]

The social criteria measure the additional effect with respect to psychological or social responses beyond the expected effect from acknowledging the performance of each risk on the other physical criteria. A similar decomposition has been proposed by the UK government (Environment Agency, 1998; Pollard *et al.*, 2000; Kemp & Crawford, 2000). This proposal includes two main criteria and three subcriteria each.

*Anxiety*, divided into dread, unfamiliarity, and notoriety.
D*iscontent*, divided into unfairness, imposition, and distrust.

We believe that the inclusion of social criteria into the formal risk evaluation process is still in its infancy and needs more refinement. Several agencies are now preparing such an extended evaluation process.

Expanding the scope of criteria for risk evaluation poses a risk in itself. Are risk management institutions able and capable of handling a set of nine criteria (further decomposed into subcriteria) within the time constraints under which they must operate? Is it realistic to expect risk managers to consider a larger set of formal criteria in addition to damage and probability? Our suggestion is to stick with all the criteria but to make the decision-making protocol easier to perform. To make the assessments on multiple criteria operational for risk managers, we distinguish, as practiced in many countries, three categories for handling risks (see Fig. 1): the *normal area*, the *intermediate area*, and the *intolerable area* (Piechowski, 1994).

The *normal area* is characterized by little statistical uncertainty, low catastrophic potential, small numbers when the product of probability and damage is taken, low scores on the criteria of persistency and ubiquity of risk consequences, and reversibility of risk consequences; in other words, normal risks are characterized by low complexity and are well understood by science and regulation. In this case, the classic risk formula probability times damages more or less identical with the "objective" threat. For risks located in the normal area, we follow the advice of most decision analysts, who recommend risk-risk comparisons and risk-benefit analysis as the major tool for risk reduction or control (National Research Council, 1982). Such an analysis should be based on a risk-neutral attitude. Risk aversion does not seem prudent to apply to these risks.

The *intermediate area* and the *intolerable area* cause more problems because the risks touch areas that go beyond ordinary dimensions. Within these areas the reliability of assessment is low, the statistical uncertainty is high, the catastrophic potential can reach alarming dimensions, and systematic knowledge about the distribution of consequences is missing. The risks may also generate global, irreversible damages, which may accumulate during a long time or mobilize or frighten the population. An unequivocal conclusion about the degree of validity associated with the scientific risk evaluation is hardly possible. In this case, the attitude of risk aversion is appropriate because the limits of human knowledge are reached and the remaining uncertainties are hard to characterize, let alone quantify

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**3.3. The Handling of Uncertainty: Distinction of Five Components**

Since the issue of uncertainty is one of the major topics of debate in the risk community, we tried to improve our conceptual understanding of this term. The first component of uncertainty is the identification and justification of probabilities linked to specific adverse effects or distribution of effects. The term "probability of occurrence" is used in the risk sciences for such events for which we have data on past trends, information about cyclical events, logical inferences from experiments or systematic observations (such as modeling dose-response relationships), or even simple beliefs based on personal or institutional experience. These data sources form the building blocks for estimating the relative frequency of an adverse effect over time, space, or subjects (such as human beings, animals, or ecosystems) (IEC, 1993). Uncertainty in a broader sense includes more than just probabilities. To be more systematic on this complex topic, we suggest the following decomposition, reflecting the broader concept of uncertainty (von Hasselt, 2000).

*Variability*. Observed or predicted variation of individual responses to an identical stimulus among the individual targets within a relevant population such as humans, animals, plants, landscapes, etc. In risk management, safety factors have been used to cover this variability.

*Systematic and random measurement errors*. Imprecision or imperfection of measurement, problems of drawing inferences from small statistical samples, extrapolation from animal data, biosurveys, or other experimental data onto humans, uncertainties of modeling, including the choice of functional relationships for extrapolating from large to small doses; all of these usually expressed through statistical confidence intervals.

*Indeterminacy*. Resulting from a genuine stochastic relationship between cause and effect(s), apparently noncausal or noncyclical random events, or badly understood nonlinear, chaotic relationships.

L*ack of knowledge*. Resulting from ignorance, from the deliberate definition of system boundaries and hence exclusion from external influences, measurement impossibilities, and others.

These components of incertitude are often highly correlated. In this case one component can serve as a general indicator for the others. In many instances, however, the four components may produce quite different results. During the deliberative process generating the WGBU annual report on global risks, we experienced a heated debate about the uncertainty connected with the application of genetic technologies for agricultural purposes (WBGU, 2000). One group of scientists assessed this risk as low and not associated with high uncertainty, while others were much more skeptical about the potential impacts on ecosystems, and particularly highlighted remaining uncertainties. The conflict was resolved when we asked the participating experts to distinguish between the different components of uncertainty. Although the first group had based their judgment on the first two components of uncertainty, the second group had considered the third and, particularly, the fourth component for deriving their final judgment. In the end, both groups insisted more or less on their original judgment but each side was now able to understand the reasoning behind the arguments of the other side.

### 3.4. Risk Classification: Six Different Risk Classes

Before addressing the remaining two major issues of risk evaluation and management outlined in Section 2, it is necessary to include an intermediary step that provides the necessary link between risk assessment and evaluation. Given the nine criteria and the numerous subcriteria, a huge number of risk classes can be deducted theoretically. But a huge number of cases would not be useful for the purpose of developing a comprehensive risk classification and corresponding management strategies. In reality, some criteria are tightly coupled and other combinations are only possible theoretically. Considering the task of setting risk management strategies, risks with one or several extreme qualities need special attention. So such similar risk phenomena are subsumed under one risk class in which they reach or exceed the same extreme qualities.
Events of damages with a probability of almost one were excluded from our classification. High potentials of damages with a probability of nearly one are clearly located in the intolerable area and therefore unacceptable. By the same token, probability heading toward zero is harmless as long as the associated potential of damage is small. We also excluded from the analysis small-scale accidents (with limited damage potential for each case) that reach large numbers of victims due to their ubiquitous use (such as car accidents). Given these specifications and exceptions, our exercise produced six different risk clusters that we have illustrated with Greek mythology (Klinke & Renn, 1999). The mythological names were not selected for illustrative purposes only. When studying the Greek mythology of the time between 700 and 500 bc, we became aware that these "stories" reflected the transition from an economy of hunters and gatherers to an economy of agriculture and animal husbandry. This transition, with its dramatic changes, implied a new culture of anticipation and foresight. It also marked the transition from a human self-reflection as being an object of nature to becoming a subject of nature. The various mythological figures demonstrate the complex issues associated with the new self-awareness of creating the future rather than just being at the mercy of fate.

#### *3.4.1. Risk Class Sword of Damocles*

According to Greek mythology, Damocles was once invited by his king to a banquet. However, at the table he had to eat his meal under a razor-sharp sword hanging on a fine thread. So chance and risk are tightly linked for Damocles and the Sword of Damocles became a symbol for a threatening danger in luck. The myth does not tell about a snapping of the thread with its fatal consequences. The threat instead comes from the possibility that a fatal event could occur for Damocles any time even if the probability is low. This can be transferred to risks with large damage potentials. Many sources of technological risks have a very high disaster potential, although the probability that this potential manifests as a damage is extremely low. So the prime characteristics of this risk class are its combination of low probability with high extent of damage. Typical examples are technological risks such as nuclear energy, large-scale chemical facilities, and dams. Beside the technological risks, natural hazards such as periodic floods, for example the 100-year floods, and meteorite impacts can be subsumed under this category.

#### *3.4.2. Risk Classyclops*

The ancient Greeks tell of mighty giants who were punished by having only a single eye, the reason they were called Cyclops. With only one eye, only one side of reality can be perceived and the dimensional perspective is lost. When viewing risks, only one side can be ascertained while the other remains uncertain. Likewise, for risks belonging to the class of Cyclops the probability of occurrence is largely uncertain, whereas the disaster potential is high and relatively well known. A number of natural hazards, such as earthquakes, volcanic eruptions, nonperiodic floods, and El Nino, belong to this category. There is often too little knowledge about causal factors. In other cases, human behavior influences the probability of occurrence so that this criterion becomes uncertain. Therefore, the appearance of AIDS and other infectious diseases, as well as nuclear early warning systems and NBC weapons,[9] also belong to this risk class.

### *3.4.3. Risk ClassPythia*

The ancient Greeks consulted one of their oracles in cases of doubt and uncertainty. The most famous was the Oracle of Delphi with the blind seeress Pythia. Pythia intoxicated herself with gases in order to make predictions and give advice for the future. However, Pythia's prophecies were always ambiguous. Transferred to risk evaluation, that means that both the probability of occurrence as well as the extent of damage remain uncertain. So the incertitude is high. This class includes risks associated with the possibility of sudden nonlinear climatic changes, such as the risk of self-reinforcing global warming or of the instability of the West Antarctic ice sheet, with far more disastrous consequences than those of gradual climate change. It further includes technological risks as far-reaching innovations in certain applications of genetic engineering in agriculture and food production, for which neither the maximum amount of damage nor the probability of certain damaging events can be estimated at the present. Finally, the Pythia class includes chemical or biological substances for which certain effects are suspected, but neither their magnitude nor their probability can be ascertained with any accuracy. The BSE risk is the best example of this.

### *3.4.4. Risk ClassPandora's Box*

The old Greeks explained many hazards with the myth of Pandora's box. This box was brought down to earth by the beautiful Pandora, who was created by the god Zeus. Unfortunately, in addition to hope, the box contained many evils and scourges. As long as the evils and scourges stayed in the box, no damage at all had to be feared. However, when the box was open, all evils and complaints were released and caused irreversible, persistent, and wide-ranging damage. A number of human interventions in the environment also cause wide-ranging, persistent, and irreversible changes without a clear attribution to specific damagesat least during the time of diffusion. Often, these damages are discovered only after the ubiquitous diffusion has occurred. A good example is the effect of persistent organic pollutants (POPs). For example, CFCs are the main cause of the hole in the ozone layer. One could also subsume under this category effects of persistent chemicals on reproductive functions, for example, endocrine disruptors. Another example is changes in the ecosystem that remain stable over long periods. Here, particular attention needs to be given to risks characterized simultaneously by high ubiquity, persistency, and irreversibility. Concerning the probability of occurrence and the extent of damage only reasonable hypotheses are available, so these criteria remain not only uncertain as is typical for Pythia risks, but the causal relationship between agent and consequences is also not yet scientifically proven plausible.

### *3.4.5. Risk Classassandra*

Cassandra, a seeress of the Trojans, predicted correctly the perils of a Greek victory, but her compatriots did not take her seriously. The risk class Cassandra dwells on this paradox: the probability of occurrence as well as the extent of damage are high and relatively well known, but there is a considerable delay between the triggering event and the occurrence of damage. That leads to the situation that such risks are ignored or downplayed. The anthropogenic climate change and the loss of biological diversity (WBGU, 2001) are such risk phenomena. Many types of damage occur with high probability, but the delay effect leads to the situation that no one is willing to acknowledge the threat. Of course, risks of the Cassandra type are only interesting if the potential of damage and the probability of occurrence are relatively high. That is why this class is located in the "intolerable" area of Fig. 2.

### *3.4.6. Risk Class Medusa*

The mythological world of the ancient Greek was full of dangers that threatened people, heroes, and even Olympic gods. The imaginary Gorgons were particularly terrible. Medusa was one of the three imaginary Gorgon sisters, feared because her appearance turns the beholder to stone. Similar to the Gorgons, who spread fear and horror, some new phenomena have a similar effect on modern people. Some innovations are rejected, despite the fact that they are hardly assessed scientifically as a threat, because they have special characteristics that make them individually or socially frightening or unwelcome. Such phenomena have a high potential of psychological distress and social mobilization in public. This risk class is only of interest if there is a particularly large gap between lay risk perceptions and expert risk analysis. A typical example is electromagnetic fields, whose extent of damage was assessed as low by most experts because neither epidemiologically nor toxicologically significant adverse effects could be proven (Wiedemann, Mertens, & Schütz, 2000). Exposure, however, is wide and many people feel involuntarily affected by this risk.

### 3.5. The Use of the Classification in Risk Evaluation: A Decision Tree

To evaluate risks and set risk reduction priorities, we propose a procedure assigning risk potentials to one of the six risk prototypes of the classification. For this purpose we use a decision tree in which five central questions must be answered (see Fig. 3).

#### *3.5.1. First Question: Do We Have Some Knowledge about the Major Characteristics of the Risks?*

If knowledge is not available on any of the criteria mentioned above, such unknown risks cannot be handled as if they were known. Nonetheless, they might have major importance because they are usually associated with desirable innovations. Therefore, the aim must be to create institutional mechanisms that provide almost automatic risk management responses once the scope of potential impacts becomes visible or detectable. The most important task here is to ensure that more knowledge about the unknown risk potential is generated. This requires three basic management strategies: the first one is to do a "quick and dirty" screening on the risk by means of analogy and comparison with similar situations; the second one is to provide sufficient public money for investigating unknown risk potentials through further research; the third one is to make those who take the risks or impose the risk on others liable for any damage that may occur (by means of insurance, for example). Insurance premiums then act as incentives for the risk originators to generate more knowledge about the potential impacts in due time. If knowledge is already available anywhere in society, institutional arrangements need to be in place to ensure that it is disseminated to the affected parties and to political decisionmakers (Zimmerman & Pahl, 1999).

#### *3.5.2. Second Question: Does the Risk Exceed Prespecified Thresholds of One or More Criteria for Risk Characterization?*

Each risk can be classified with more or less reliability on each of the nine criteria. The classification itself has no impact on regulation unless intervention levels are defined. These thresholds for action cannot be determined in abstract. It may be one of the main tasks of the screening and evaluating regulatory body to define thresholds for action based on the nine criteria. Each risk candidate can then be tested against the predefined threshold. If a risk falls below any one of the predefined thresholds, the risk potential can be judged as "normal," so that the existing structures of routine management and regulation are sufficient to cope with them. Such "normal" risks are characterized by low complexity and are well understood by science and risk decisionmakers. We locate these risks in the normal area (see Fig. 1).

If the risk potential exceeds any one of the thresholds on the evaluation criteria, it causes more problems because the risks touch areas that go beyond ordinary dimensions. In this case an assignment to one of the risk classes is inevitable. For this purpose the next question should be answered.

#### *3.5.3. Third Question: Is the Damage Potential Known and Can it be Identified?*

If the damage potential is unknown and cannot be identified by risk experts, this criterion is associated with high uncertainty and entails that the probability of occurrence is also uncertain. As a result, the overall incertitude is high. This leads to the risk classes Pythia or Pandora's box. The Pythia risk class presumes that the scientific appraisal provides sufficient proof for a causal relationship between agent and effect but that neither the quantitative extent of damage nor the probabilities can be specified. Risks within the class of Pandora are those where only credible assumptions about such a causal connection exist but no substantial evidence. Normally, such a risk would not fall into the intermediate or intolerable area. However, if the risks are classified as being ubiquitous, persistent, and irreversible, a more cautious approach is warranted. In such a case, the risks cannot be significantly reduced or even avoided if the worst case occurred and the suspicion about negative impacts became true. If the damage potential is known and can be identified, the next question will be relevant.

#### *3.5.4. Fourth Question: Does the Assessed Damage Potential Exceed the Predefined Threshold for Catastrophic Potential?*

If the experts assess the catastrophic potential as being high but the probabilities are either rated as low or as unknown, one of the two risk classes Cyclops or Sword of Damocles fits the description. The Cyclops risk class is characterized by a high extent of damage, whereas the probability of occurrence remains uncertain. The Damocles risk class is also characterized by a high disaster potential, but the probability that this potential manifests itself as concrete damage is low, sometimes even minimal.

If both the disaster potential and the probability of occurrence are high, one would normally reject such risks. Most likely, existing legal statutes would already prohibit their occurrence. But if there is relevant delay between the triggering event and the damage impact, it leads to the situation that such risks are often ignored and no one is willing to acknowledge the threat. Such risks are characterized by the risk class Cassandra.

#### *3.5.5. Fifth Question: Does the Risk Show No Significantly High Values on Any Physical Criteria But May Load High on the Social Criteria?*

If the damage potential, the probability of occurrence, the incertitude, and other physical criteria are assessed as low, such risks are usually not significant for risk decisions. The exception is if the risk potential triggers a high anxiety among individuals, violates equity values, and/or produces a high potential of social mobilization in public. In this case the damage potential as well as the probability of occurrence are widely known among scientists, i.e., any effect is below statistical significance level, although the effect must not be zero. The hazardous nature of such risks is mainly based on the subjective perception of affected people that can lead to distress, anxiety, and, sometimes, even to psychosomatic malfunctions. People may also feel unequally treated, i.e., they perceive a discrepancy between those who are able to take advantage of the benefits and those who bear the risks. These risk phenomena are subsumed under the risk class Medusa since they generate a high mobilization in the public. Once a risk is classified as producing a high mobilization potential, it is necessary to look into the three components of the social mobilization criterion in order to design the appropriate management and communication strategy. 4. FROM RISK EVALUATION TO MANAGEMENT: RISK-BASED, PRECAUTIONARY, AND DISCURSIVE STRATEGIES

This section returns us to the five issues that we addressed in Section 2. The first three issues "realism versus constructivism,""inclusion of social concerns and perceptions," and "the treatment of the different components of uncertainty"were located at the borderline between assessment and evaluation. This is why we treated those three issues under the heading of risk evaluation. The next two issues"choice of strategy" and "deliberation versus expert judgments" address topics that lie at the core of risk management. Consequently these topics will be considered in this section.

The essential objective of the proposed risk classification is to derive effective, efficient, and politically and legally feasible strategies and measures for risk reduction and mitigation. The characterization of each risk according to our proposal provides a knowledge base for risk managers to select the most appropriate risk management strategies. Regardless of which strategy they may choose, the ultimate goal of each strategy is to transform unacceptable into acceptable risks. The desired result of risk management effort is not to reduce all risks to zero but to move them into the normal area, in which routine risk management and cost-benefit analysis becomes sufficient to ensure overall safety and integrity (WBGU, 2000:18-20). By moving the risks into the normal area, they often pass through intermediary stages in which additional strategies are needed in order to reach the final destination.

### 4.1. The Three Challenges: Complexity, Uncertainty, and Ambiguity

Similar to the classification of risk classes, it makes sense to design a classification of generic risk management strategies. These strategies focus on three major challenges that characterize the handling of risk issues in society: complexity, uncertainty. and ambiguity (for more detail, see Renn, 1999c).

Complexity refers to the difficulty of identifying and quantifying causal links between a multitude of potential candidates and specific adverse effects (cf. WBGU, 2000; Schellnhuber, 1999). The nature of this difficulty may be traced back to interactive effects among these candidates (synergisms and antagonisms) (National Research Council, 1988), positive and negative feedback loops, long delay periods between cause and effect, interindividual variation, intervening variables, and other effects. It is precisely these complexities that make sophisticated scientific investigations necessary because 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 second problem refers to uncertainty. Uncertainty is different from complexity. As stated earlier, it comprises different and distinct components such as statistical variation, measurement errors, ignorance, and indeterminacy, which all have one feature in common: uncertainty reduces the strength of confidence in the estimated cause and effect chain (for a similar definition, see Priddat, 1996). If complexity cannot be resolved by scientific methods, uncertainty increases. But even simple relationships may be associated with high uncertainty if either the knowledge base is missing or the effect is stochastic by its own nature.

The last term in this context is ambiguity or ambivalence. This term denotes the variability of (legitimate) interpretations based on identical observations or data assessments. Most of the scientific disputes in the fields of risk analysis and management do not refer to differences in methodology, measurements, or dose-response functions, but to the question of what all this means for human health and environmental protection (Harrison & Hoberg, 1994). Emission data is hardly disputed. Most experts debate, however, whether an emission of x 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. One example for the first kind of ambiguity is pesticide residues in food where most analysts agree that the risk to human health is extremely low yet many demand strict regulatory actions. A classic example of the second kind is smoking: Should the government regulate smoking because the link to cancer is clearly confirmed or should it refrain from regulation since people voluntarily accept this risk (not including passive smoking, for the sake of the argument)? If we look at the practice in different countries, we can observe a variety of approaches to deal with smoking, ranging from strict to almost no regulatory actions. High complexity and uncertainty favor the emergence of ambiguity, but there are also quite a few simple and almost certain risks that can cause controversy and thus ambiguity. It is therefore important to distinguish between complexity, uncertainty, and ambiguity: these three terms are correlated but they are not identical.

### 4.2. Managing Complexity, Uncertainty, and Ambiguity

Different evaluation and management strategies follow from the analysis of these three challenges. If the problem is complexity, a risk manager is well advised to bring the best expertise together and regulate on the basis of the state-of-the-art knowledge in risk assessment. It does not make much sense to incorporate public concerns, perceptions, or any other social aspects into the function of resolving (cognitive) complexity (for a similar argument, see Charnley, 2000) unless specific knowledge of these groups help to untangle complexity (Charnley, 2000:16f). Complex phenomena demand almost equally complex methods of assessments. These methods can be offered by scientists and experts better than by anybody else. In terms of regulatory actions, quantitative safety goals and consistent use of cost-effectiveness methods are the appropriate tools to deal with complex risk problems that show little uncertainty and no ambiguity.

If the problem is uncertainty, however, knowledge is either not available or unattainable due to the nature of the hazard. Under these circumstances, risk managers have to rely on resilience as the guiding principle for action (WBGU, 2000:288-292). Most of the precautionary management tools would fall into this category. Knowledge acquisition may help reduce uncertainty and thus move the risk back to the first stage of handling complexity. If uncertainty cannot be reduced by additional knowledge, however, or if action is demanded before the necessary knowledge can be obtained, the routine management strategies for resolving complexity would be incomplete because the objective here is to act prudently under the condition of uncertainty. Acting prudently means to design resilient measures that allow flexible responses to unexpected events (surprises) (Stirling, 1998; WBGU, 2000:289ff). Management tools that would fit the resilience approach include containment in space and time (to make exposure reversible), constant monitoring, development of equi-functional replacements, and investments in diversity and flexibility (Collingridge, 1996; Klinke & Renn, 2001). Classic regulatory strategies such as the ALARA principle (as low as reasonably achievable), BACT (best available control technology), or state of technology are also elements of this approach (WBGU, 2000:217-218).

Decisions based on uncertainty management require, therefore, more than input from risk specialists. They need to include stakeholder concerns, economic budgeting, and social evaluations. The focal point here is to find the adequate and fair balance between the costs of being overcautious versus the costs of being not cautious enough (van den Daele, 2000). Since both costs are almost impossible to quantify due to the remaining uncertainties, subjective judgments are inevitable. This means that the setting of painful value tradeoffs is inevitable. The trade-off ratios determine who will bear the costseither in form of additional damages by being not cautious enough or in form of regulatory costs for being overcautious. It is obvious that those who bear either of the two costs are entitled to be the main negotiators for setting the necessary tradeoffs.

Setting tradeoffs is even more complex when it comes to resolving ambiguity. Although scientific expertise is essential for gaining a better understanding of ambiguities and dealing with them in an enlightened manner, it cannot prescribe the value tradeoffs necessary to cope with the ambiguities (Yankelovich, 1991). In addition, ambiguities cannot be resolved by increased efficiency since the outcome in itself is controversial not just the distribution of costs. Genetically modified organisms for agricultural purposes may serve as an example here. Our own surveys on the subject demonstrate that people, for social and moral reasons, associate high risks with the application of gene technology (Hampel & Renn, 2000). Whether the benefits to the economy balance the costs to society in terms of increased health risks is not a major concern of the polled public. People disagree about the social need for genetically modified food in Western economies where abundance of conventional food is prevalent. They are worried about the loss of personal agency when selecting and preparing food, about the long-term impacts of industrialized agriculture, and the moral implications of tampering with nature.[10] These concerns cannot be addressed by either scientific risk assessments or by determining the right balance between over- and underprotection. The risk issues in this debate focus on differences of visions about 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 require the inclusion of those who express or represent them. To make these concerns operational for risk management, some kind of discourse for conflict resolution and joint vision building is required. Coping with ambiguity necessarily leads to discursive management tools, i.e., communicative processes that promote rational value disputes (Rippe & Schaber, 1999). This is the place where deliberative processes are required from a social-analytical as well as normative viewpoint. The ultimate goal of risk regulation in the face of ambiguities is a consensus or a compromise between those who believe the risk is worth taking (maybe because of self-interest) and those who believe that the pending consequences do not justify the potential benefits of the risky activity or technology. Table II provides a summary of the three management styles and their basic strategies and instruments. Complex risks require sophisticated methods for assessing and regulating risks. Conflicts arise as a result of cognitive disputes over models and rationales for selecting effective as well as efficient risk reduction measures. Dealing with uncertainty involves two objectives: providing resilient strategies to be prepared for surprises and finding an adequate and fair balance between assumed over- and underprotection. Ambiguities reflect value conflicts, which need to be reconciled in consensus seeking exercises.

Most risks are characterized by a mixture of complexity, uncertainty, and ambiguity. Smoking may be a good example for low complexity and uncertainty but high ambiguity. Nuclear energy may be a good candidate for high complexity and high ambiguity but relatively little uncertainty. Endocrine disrupters could be cited as examples for high complexity, uncertainty, and ambiguity. We could continue the list forever. When looking at our own classification, however, we can bring some more order into this web of interrelationships. The two risk classes Damocles and Cyclops are characterized by high complexity and hence require mainly risk-based management strategies, the risk classes Pythia and Pandora are characterized by high uncertainty and hence demand the application of precautionary strategies, and the risk classes Cassandra and Medusa load high on ambiguity and thus require discursive management strategies for building trustworthiness, social consent, and public confidence. This distinction does not mean that within each risk class the other strategies and instruments have no place, but they do take a "back seat." The following section describes the appropriate risk management tools for each of the three management strategies.

### 4.3. The Three Management Styles: Risk-Based, Precaution-Based, Discourse-Based

#### *4.3.1. Risk-Based Management*

The risk classes Damocles and Cyclops require the application of risk-based strategies and regulation. Nuclear energy, large chemical facilities, dams, nuclear early warning systems, and NBC weapons are obvious examples. However, the appearance of well-known infectious diseases is also a representative of these risk classes. Within the risk class Damocles, both the probability of occurrence and extent of damage are relatively well known. Since the damage component is the one that triggers concern, risk managers should concentrate their efforts on reducing the disaster potential. For example, in the past, the primary strategy of nuclear energy was to reduce the probability of a core meltdown. More useful would have been a change toward reducing the catastrophic potential (meanwhile this strategy has been pursued in the development of new reactor types).

Within the risk class Cyclops, a mixture of risk-based and precautionary strategies is useful because the risk potentials are characterized by good knowledge on the extent of damage, but the distribution of probabilities is relatively unknown. To remedy this deficit, increasing research and thorough monitoring for specifying the distribution of probabilities is required. Strict liability and compulsory insurance for those generating the risks may provide an additional incentive to reduce the disaster potential and to prevent unwelcome surprises: operators are encouraged to improve their knowledge and to decrease the remaining uncertainties.

Several tools from uncertainty management are also recommended for risks with high disaster potential. Capacity building improves the institutional and organizational structures and guarantees control over procedures of licensing, monitoring, training, and so forth. Additionally, technical procedures such as redundancy, organizational security units, the integration of latitudes, buffers, elasticities, and diversification, that is, the local distribution of risk sources, can decrease vulnerabilities.

#### *4.3.2. Precaution-Based Management*

The risk classes Pythia and Pandora fall into this management category. Typical examples of these risk classes are the release of transgenic plants, specific applications of genetic engineering, the increasing greenhouse effect, persistent organic pollutants (POP), and endocrine disruptors. These risk potentials are characterized by a relatively high degree of uncertainty. Therefore, the first priority of risk management must be the application of precautionary measures and the development of substitutes. Management tools include:

Containment of application in space and time.
Constant monitoring of potential side effects.
Development of functional equivalents with less persistent or ubiquitous consequences.
Promoting diversity and flexibility.
Capacity building for organizational competence.
Building high-reliability organizations for handling uncertain risks.
Introduction of strict liability.
Classic tools such as ALARA, BACT, etc.

The improvement of knowledge constitutes an important element of dealing with those risks because further knowledge may reduce the remaining uncertainties. An ideal program softens the precautionary measures in line with the additional knowledge generated through research and by containing the distribution of the risk over time and space, i.e., limiting the scope of potentially irreversible damages.

#### *4.3.3. Discourse-Based Management*

The third category, with discursive strategies, is essential if either the potential for wide-ranging damage is ignored, due to delayed effect such as climate change, or the opposite harmless effects are perceived as threats, an example being electromagnetic fields. The risk classes Cassandra and Medusa represent these risks. They are not associated with much scientific uncertainty or complexity. In the case of Cassandra, human beings do not take the risks seriously because of the lingering delay between the initial event and the damage impact. Within the risk class Medusa, the probability of occurrence and the extent of damage are relatively well known, i.e., the assessment quality for characterizing the risks is at least satisfactory. The hazardous nature of the risk is mainly based on the subjective perception. The belief that the risk poses a serious threat produces public attention and fuels public anxiety, which leads to distress, psychosomatic malfunctions, or social outrage.

Therefore, these risk classes require strategies building up consciousness, building confidence, strengthening trustworthiness in regulatory bodies, and initiating collective efforts of institutions for taking responsibility. These are social goals that cannot be accomplished by risk experts or regulators alone. If ambiguity governs the risk debate, one needs discursive methods of deliberation and decision making clarification of facts in such discourses is not enough and will not convince people that the risks belong in the normal area. What is needed is the involvement of affected people so that they are able to integrate the remaining uncertainties and ambiguities into their own procedures of assigning tradeoffs. Ambiguities demand public participation.

## 5. IMPLICATIONS FOR ANALYSIS AND DELIBERATION

The juxtaposition of the three management styles could lead to the misperception that deliberation and public involvement are only necessary when ambiguities occur. Indeed, we claim that deliberation is not the most essential element for reducing complexity or uncertainty, but that it may be helpful even for risks that do not pose major ambiguities. As much as scientific input about the physical risk parameters provides a mandatory component of deliberative actions aimed at resolving ambiguities, so do procedures for reducing complexity and uncertainty require deliberative elements.

First, resolving complexity requires deliberation among experts. We have given this type of deliberation the title "epistemiological discourse." [11] Within an *epistemiological discourse*, experts (not necessarily scientists) argue over the factual assessment with respect to the criteria that we have proposed and described above. The objective of such a discourse is the most adequate description or explanation of a phenomenon (for example, the question of which physical impacts are to be expected by the emission of specific substances). The more complex, the more multidisciplinary, and the more uncertain a phenomenon appears to be, the more necessary is a communicative exchange of arguments among experts. The goal is to achieve a homogeneous and consistent definition and explanation of the phenomenon in question as well as a clarification of dissenting views. The discourse produces a profile of the risk in question on the selected criteria.

Second, an epistemiological discourse may reveal that there is more uncertainty and ambiguity hidden in the case than the initial appraisers had anticipated. If the cognitive discourse includes natural as well as social scientists, future controversies and risk debates may be anticipated. Risk controversies would be less surprising. Since our criteria include aspects of perception and social mobilization, these assessments may serve as early warning systems for controversies to come.

Epistemiological discourses can be organized in different forms. One popular example is the consensus conference, a method routinely applied for resolving cognitive conflicts in defining the most suitable medical treatment. In our own institution (Center of Technology Assessment) we have used group delphi techniques and meta-analytical workshops as appropriate instruments for conducting discourses on clarifying knowledge (Webler *et al.*, 1991; Wachlin & Renn, 1999).

If risks are associated with high uncertainty, scientific input is only the first step of a more complex evaluation procedure. It is still essential 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 (different classes for judging the robustness of a theory or causal statement) might be helpful to organize and classify existing knowledge (Funtowicz & Ravetz, 1999). In a second step, information about the different types of uncertainties must be collected and brought into a deliberative arena. Players in this arena are not only scientists, but also directly affected stakeholders and public interest groups (Yosie & Herbst, 1998). The objective here 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. We have coined this type of deliberation "reflective discourse." *Reflective discourse* deals with the clarification of knowledge (similar to the cognitive) and the assessment of tradeoffs between the competing extremes of over- and underprotection. Reflective discourses are mainly appropriate as a means to decide on risk-averse or risk-prone approaches to innovations. This discourse provides answers to the question of how much uncertainty one is willing to accept for some future opportunity. Is taking the risk worth the potential benefit? The classic question of "how safe is safe enough" is also an integral part of this type of discourse. We would recommend that policymakers, representatives of major stakeholder groups, and scientists take part in reflective discourses. Political or economic advising committees that propose or evaluate political options could also be established to advise this core group. Special procedures such as negotiated rule making, mediation, and roundtables are most appropriate for reaching the desired purpose of reflective discourses (Fiorino, 1995). As structuring instruments we have used value-tree analysis and other decision-aiding tools (Renn *et al.*, 1993).

The last type of deliberation, which we have called *participatory discourse*, is focused on resolving ambiguities and differences about values. Established procedures of legal decision making, but also novel procedures, such as citizen advisory panels and citizen juries, belong to this category. Participatory discourses are mainly appropriate as means to search for solutions that are compatible with the interests and values of the people affected and to resolve conflicts among them. This discourse involves subjective weighting of the criteria and an interpretation of the results. Issues of fairness and environmental justice, visions on future technological developments and societal change, and preferences about desirable lifestyles and community life play a major role in these debates. In our Center, we have experimented with citizen panels or juries (randomly selected), voluntary advisory groups, the Danish model of lay persons' consensus conferences, and other participatory techniques in order to resolve ambiguities and value conflicts (Schneider, Oppermann, & Renn, 1998).

Fig. 4 provides an overview of the different discourse requirements when one moves from simple to complex, from complex to uncertain and further to ambiguous risk issues. Although simple risks require nothing more than routine actions by regulators, more complex and uncertain risk issues demand input from external science communities and major stakeholders. Broader citizen participation is needed for dealing with ambiguities. In many cases, it may be difficult to allocate a given risk into this scheme. Obviously, one needs a screening exercise to position the risk in accordance with our decision tree and to characterize the degree of complexity, uncertainty, and ambiguity associated with the risk under investigation. We would recommend a "risk characterization panel" consisting of experts (natural and social scientists), some major representatives of stakeholders, and regulators who will perform this initial screening (WBGU, 2000). Depending on the judgment of this panel, risk information is then processed according to the risk class in which the risk is located as a result of the screening exercise and according to the type of management deemed necessary to deal with complexity, uncertainty, and ambiguity.

It is clear that all three management strategies need to be combined and all three types of discourses integrated into one major deliberative process if risks fall in all three categories. Our experiences, however, have been that it is essential to distinguish the type of discourse that is needed to resolve the issue at question. Knowledge questions such as the right extrapolation method for transferring animal data to humans should not be resolved in a participatory discourse. Similarly, value conflicts should not be resolved in epistemiological discourse settings. It seems advisable to separate the treatment of complexity, uncertainty, and ambiguity in different discourse activities since they each need a different form of resolution. Often, they need different participants, too. We have made an attempt to provide a hybrid model of deliberation called the cooperative discourse model that combines the three discourse types into one connected activity without giving up the analytical separation between the three parts (Renn, 1999b).

## 6. SUMMARY AND CONCLUSIONS

Our concept of nine risk evaluation criteria, six risk classes, a decision tree, and three management categories was developed to improve the effectiveness, efficiency, and political feasibility of risk management procedures. The main task of risk evaluation and management is to develop adequate tools for dealing with the problems of complexity, uncertainty, and ambiguity. Based on the characteristics of different risk types and these three major problems, we distinguished three types of management risk-based, precaution-based, and discourse-based strategies.

The risk-based strategy is the common solution to risk problems. Once the probabilities and their corresponding damage potentials are calculated, risk managers are required to set priorities according to the severity of the risk, which may be operationalized as a linear combination of damage and probability or as a weighted combination thereof. Within our new risk classification, the two central components have been augmented with other physical and social criteria that still demand risk-based strategies as long as uncertainty is low and ambiguity absent. Risk-based strategies are best solutions to problems of complexity and some components of uncertainty, for example, variation among individuals. If the two most important risk criteria, probability of occurrence and extent of damage, are relatively well known and little uncertainty is left, the traditional risk-based approach seems reasonable.

If uncertainty plays a large role, in particular, indeterminacy or lack of knowledge, the risk-based approach becomes counterproductive. Judging the relative severity of risks on the basis of uncertain parameters does not make much sense. Under these circumstances, management strategies belonging to the precautionary management style are required. The precautionary approach has been the basis for much of the European environmental and health protection legislation and regulation. Our own approach to risk management has been guided by the proposition that any conceptualization of the precautionary principle should be (1) in line with established methods of scientific risk assessments, (2) consistent and discriminatory (avoiding arbitrary results) when it comes to prioritization, and (3) at the same time, specific with respect to precautionary measures, such as ALARA or BACT, or the strategy of containing risks in time and space. This suggestion does, however, entail a major problem: looking only to the uncertainties does not provide risk managers with a clue about where to set priorities for risk reduction. Risks vary in their degree of remaining uncertainties. How can one judge the severity of a situation when the potential damage and its probability are unknown or contested? In this dilemma, we advise risk managers to use additional criteria of hazardousness, such as "ubiquity,""irreversibility," and "pervasiveness over time," as proxies for judging severity.

Our approach also distinguishes clearly between uncertainty and ambiguity. Uncertainty refers to a situation of being unclear about factual statements; ambiguity to a situation of contested views about the desirability or severity of a given hazard. Uncertainty can be resolved in principle by more cognitive advances (with the exception of indeterminacy), ambiguity only by discourse. Discursive procedures include legal deliberations as well as novel participatory approaches. In addition, discursive methods of planning and conflict resolution can be used. If ambiguities are associated with a risk problem, it is not enough to demonstrate that risk regulators are open to public concerns and address the issues that many people wish them to take care of. The process of risk evaluation itself needs to be open to public input and new forms of deliberation. We have recommended a tested set of deliberative processes that are, at least in principle, capable of resolving ambiguities in risk debates (for a review, see Renn, Webler, & Wiedemann, 1995).

Deliberative processes are needed, however, for all three types of management. Risk-based management relies on epistemiological, uncertainty-based management on reflective, and discourse-based management on participatory discourse forms. These three types of discourse could be labeled as an analytic-deliberative procedure for risk evaluation and management. We see the advantage of a deliberative style of regulation and management in a dynamic balance between procedure and outcome. Procedure should not have priority over the outcome; outcome should not have priority over the procedure. An intelligent combination of both can elaborate the required prerequisites of democratic deliberation and its substantial outcomes to enhance the legitimacy of political decisions (Guttman & Thompson, 1996; Bohman, 1997, 1998).

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1 The risk evaluation and classification concept was developed by the German Advisory Council on Global Change (WBGU) in its annual report in 1998 about global environmental risks. Ortwin Renn as a member and Andreas Klinke as an associate researcher have been the main contributors to the new risk concept.

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4 In economic theory, risk refers to both gains and losses. Since we are dealing here with risks to the environment and human health, we believe that the confinement to negatively evaluated consequences is more in line with the average understanding of risk in this context. One should note, however, that the labeling of consequences as positive or negative refers to genuine social judgments and cannot be derived from the nature of the hazard itself.
5 The WBGU is an independent advisory board for the German government. It includes 12 members from different scientific disciplines and an equal number of personal assistants.
6 The term "analytic-deliberative process" was introduced in the risk community by the National Research Council of the United States.
7 Cf. the special 1998 volume of *Reliability Engineering and System Safety*, *Special Issue on Risk Perception versus Risk Analysis*, *59*(1)
8 These spill-over effects have been the main target of the theory of social amplification of risk. This theory was developed by a research team at Clark University in the late 1980s.
9 A study of the Peace Research Institute in Frankfurt, Germany, indicated that the Russian early warning system and the associated nuclear forces have considerable functional and maintenance deficiencies because of human behavior. See Müller and Frank (1997).
10 The importance of the variable "tampering with nature" was brought to our attention by Lennard Sjöberg of the Swedish School of Economics (Sjöberg, 1999).
11 The following classification of discourse types was first published in Renn (1999a).

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