Prometheus Unbound

Challenges of Risk Evaluation, Risk Classification, and Risk Management

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Content

Preface and Summary

At the end of the nineties the field of risk assessment and management needs some new impulses for handling risks of nature, technologies, and human activities. This report introduces a new proposal with respect to the three main elements of risk analysis: risk assessment, risk evaluation, and risk management. First, the report demonstrates the need for new approaches in risk evaluation and management. Second, it analyzes the problems that need to be addressed when handling natural and technical disasters. Third, it presents a new classification scheme for characterizing risks. Based on this new classification, risk management requirements and desired political actions are described at the end.

For dealing with risks in a rational fashion, it is necessary to characterize risks and use the parameters of characterization as tools for designing appropriate actions. This reports suggests a set of criteria that one can use in evaluating risks. These criteria include:

- Damage potential, i.e. the amount of damage that the hazard can cause;
- probability of occurrence, i.e. the likelihood that a specific damage will occur;
- incertitude, i.e., the remaining uncertainties that are not covered by the assessment of probabilities (subdivided in statistical uncertainties, genuine uncertainty, and ignorance);
- ubiquity which defines the geographic dispersion of potential damages (intragenerational justice);
- persistency which defines the temporal extension of potential damages (intergenerational justice);
- irreversibility which describes the impossible restoration of the situation to the state before the damage occurred (possible restoration are e.g. reforestation and cleaning of water);
- delay effects which characterize the 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; and

- potential of mobilization which is understood as violation of individual, social or cultural interests and values generating social conflicts and psychological reactions by affected people.

Theoretically a huge number of risk types can be developed by combining the eight criteria. Such a huge number of cases would not be useful for the purpose to develop a comprehensive risk classification. In reality, some criteria are tightly coupled and other combinations are certainly theoretically possible, but there are not any or only few empirical examples. As a result of a tidious screening process, six different risk types were classified based on the assessment whether they reach or exceed one of the possible extreme qualities mentioned above.

For each of the six risk classes special risk management strategies were developed. With respect to natural disasters three different management regimes should be distinguished: classic risk management (dealing with risk avoidance and reduction): uncertainty management (dealing with precautionary measures and warning systems); and ambiguity management (dealing with measures to deal with conflicts among experts and between experts and social groups). The main arguments of this report will be published in a book that is scheduled to be available in the fall of 2000.

Stuttgart, October 30, 1999

Andreas Klinke Ortwin Renn

1 Introduction

1.1 Prometheus Unbound

The myth of Prometheus, the benefactor of the human race and creator of science and crafts, has not lost its visual power despite of the fact that the story was recorded more than 2.700 years ago. Its spiritual quality and its complex web of archaic images and references to a world of competing gods may leave modern audiences estranged and bewildered; but the underlying texture of courage and caution, of betrayal and suffering, of wisdom and foolishness corresponds to the universal experiences of humankind beyond the boundaries of historical context (Perls 1973, p. 238; Nennen 1989, p. 56ff). Furthermore, the juxtaposition of ingenuity and hubris, of foresight and complacency, of scientific progress and cultural disenchantment reminds society of the inevitable ambiguity of human progression. Humans are still struggling for the reconciliation of mind and soul, truth and wisdom, technological change and cultural cohesion. The German philosopher Hans-Georg Gadamer characterized the Prometheus myths as the cradle of human development (Gadamer 1993, p. 151). He writes: "To tell the history of Prometheus is to tell the history of occidental societies."

The first account of Prometheus, the creator of technology and fire-carrier, can be traced back to the two main works of Hesiod: Theogony (genealogy of the gods) and Works and Days (a farmer‘s almanac). His father was Lapatos, a descendent of the Titans, and his mother Okeanid Klymene. From his father he received strength, ingenuity, and ambition, from his mother the gift of foresight. Prometheus was able to foresee and hence to modulate the future (Lenk 1991, p. 170). In addition, Hesiod characterized him as a friend of the human race. The gifts that he received from his ancestors were transferred to the humans over time. However, Prometheus also had dark elements in his character. He was selfish, ego-centered, and deceptive. Hesiod speaks of him as the "Trickster-God" (cf. Wutrich 1995, p.10).

The first trick that he played on the gods brought him considerable trouble. During a religious ceremony, Prometheus sacrificed the inferior parts of a sacrificial animal to the gods and deceived them by disguising the worthless bones and interior parts with a thin layer of grease. He kept the meat himself. An angry Zeus punished him immediately and bound him to a rock where an eagle came during the day to eat his liver and other inner organs. During the night the body recovered and the organs revitalized. This punishment went on day and night until Herakles freed the suffering Prometheus. Once in freedom, he took revenge and stole the fire from the Gods and brought it to the human race. The humans were now able to use the fire for clearing land and producing metal instruments. Now it was Zeus' turn again to retaliate. He created the first women called Pandora who also was a master of deception. From the outside beautiful and charming, from the inside wicked and mean - so the characterization of Hesiod. He writes (quoted from Gadamer 1993, p. 152):

> Born was the mean gender,
> the roots of all females
> who for the sake of evil to succeed
> live in conjunction with men.

Prometheus was clever enough to refuse the gift of Zeus knowing that he was to be deceived. But his brother Epimetheus (literally translated: a man who thinks after the fact) was eager to accept the gift despite of the warnings of his brother. Epimetheus is described as a fun-loving, dull-witted, and simple-minded personality. Once in the house of Epimetheus, Pandora opens her infamous box and all evils that can cause human sufferings and pain escape and haunt all humans thereafter. Only hope is left in the box.

What is the reason that this ancient story written 2,700 years ago still attracts our attention? Why are we still captivated by a story that defies our logic and does not reflect our present cultural or religious beliefs? Modern scholars associate the story of Prometheus with the revolutionary change of the Neolithic revolution, i.e. the transition from a society of gatherers and hunters to a society of farmers (Wutrich 1995, pp. 140). The books of Work and Days was specifically addressed to farmers. With the mastering of fire, agriculture could flourish as well as the fabrication of instruments. The time of the bound Prometheus who provided food only to the extent that it was replenished by nature was replaced by at time of incredible opportunities through transformation of nature. This new time, however, was full of risks and dangers; in particular when complacency (Epimetheus) or hubris (Prometheus) were dominating over anticipatory planning and caution. The changes of the Neolithic revolution were fundamental and radical. They can be compared only to the industrial revolution starting in the 18th century and probably the postindustrial revolution that we may face today (Mohr 1996, pp. 46). The Prometheus myth reflects the collective human experience in major transitional periods. This is why it speaks to us even today.

It is interesting to note that during the industrial revolution many artists and authors chose the myth of Prometheus to illustrate their experience with the new era (Wutrich 1995, pp. 67). It started with Philip Marlow‘s adaptation of Dr. Faustus. The play is modeled in accordance with the main themes of the Prometheus legend; the same character was later used by Johann Wolfgang von Goethe (1749; 1832). In 1820, Perry Shelly wrote his famous play: Prometheus Unbound. The title refers to the Aeschylos play "Prometheus Bound" and reflects the second revolutionary change in human history, i.e. the liberation from the chains of feudalism. Even the revolutionary Karl Marx wrote in his dissertation: "Prometheus is the most noble saint and martyr in the philosophical almanac" (quoted from Dietz et al. 1989, p. 13). As Karl Marx in his days, modern societies are facing a new revolution, the transition from an economy of material production to an economy of information exchange and genetic engineering.

Is there anything to learn from the experiences of human societies in their efforts to cope with crucial transition times? Is there a lesson to learn from the Prometheus legend? Although myths are visions of fundamental truth, it is not possible to extract from them simple lessons for the management of human affairs. Myths imply ambiguity, fuzziness, and a holistic perspective (Perls 1973, p. 240). They are, however, reminders of the genuine forces that are inevitably present in the making of new technological eras. They can guide us through the clouds of uncertainty and ambiguity associated with new scientific advances and technological breakthroughs. Far from providing recipes for managing technologies and risks, they can help us to orient ourselves in the tension between courage and caution and to create powerful images that provide sources for understanding and handling risks in modern societies.

Inspired by the myth of Prometheus, the German Scientific Council on Global Environmental Change (WBGU) has taken images of the Greek mythology to characterize global risks to humankind and to design appropriate tools for dealing with these risks (WBGU 1999). This report bases on the approach by the Council and develops a concept for characterizing, evaluating, and managing risks.[1] The following chapter reviews the recent history of risk assessment and management. Part 2 and 3 deal with the three major steps of risk analysis: risk assessment, risk evaluation, and risk management. Part 3 also takes a dynamic perspective on risk. The focus of this chapter lies in the question: How can we accomplish a continuous movement toward a safer society? The last chap-

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[1] Ortwin Renn as a member and Andreas Klinke as an associate researcher were basically responsible for the development of the risk classification and the risk management strategies.

ter summarizes the main results and discusses the prospects and limitations in the societal efforts to cope with modern risks at the turn of the millennium.

1.2 The Recent History of Risk Analysis

Protest against the manifestations of technology and fear of risks have been present since the time of the industrial revolution (Sieferle 1985; Renn 1987). The introduction of trains, steamboats, motorcars, electric lights was always met with skepticism and public discomfort (von Winterfeldt and Edwards 1983). The history books are full of accounts of people's rejection of technological changes. Just to cite one example: In 1824 the daily newspaper of the German city of Augsburg purchased a printing machine driven by a steam engine (Mittelstraß 1998, p. 3). The second editor in chief proclaimed that he would write all his editorials in the nearby open park rather than ever entering the print shop again, another employee terminated his contract with the company and declared his life were endangered. Even pedestrians decided to avoid the street in which the building was located. Although history has recorded numerous examples of unwarranted anxieties, there have been equally worrisome accounts of overconfidence in allegedly fool-proof safety measures and human abilities to cope with disasters. The responses to the change of technology over time seem to oscillate between the carelessness of Epimetheus and the foresight of Prometheus, between the real disasters of Pandora‘s box and hope, the ultimate gift of the gods to humankind.

The patterns of hope, hubris, and disaster are also present in the recent history of technology and risk (Renn 1997). The 1950s were characterized by an almost euphoric belief in scientific and technological progress. It was the time of the triumphant Prometheus who provided the promise of unlimited energy, wealth, and comfort. These promises were echoed by his brother Epimetheus who believed that the cornucopia of technological opportunities would wipe out all evils and problems of the world. Humanity seemed to be on its peak: major infectious diseases appeared to be defeated, natural forces tamed, and technological advances secured. This bright vision of the future, however, received its first setback when scientists discovered the ecological boundaries of the economic growth machine. In the late 1960s and early 1970s the other "ego" of Prometheus was mobilized, the prophet of foresight and anticipation warned against human hubris and technological overconfidence. Yet most people were convinced that better and more technologies were the answers to the discomforting questions. The idea of unlimited consumption dominated over the concept of precaution. The social psychologist Hans Christian Röglin characterized this attitude as follows: "Modern people love the products of technology, but suppress the process by which these amenities of life are produced" (quoted from Renn 1987, p. 85).

This picture changed dramatically in 1986 when three major technical disasters occurred: the Chernobyl catastrophe, the Challenger accident and the pollution of the Rhine river after a fire destroyed a chemical storage building in Basle, Switzerland. These three events reminded society that the hubris of Prometheus is still a real threat in modern times. This reminder to human over-confidence in technology had lasting repercussions on public opinion (cf. Renn 1998, p. 50). Although trust had been eroding since the accident at Three-Mile-Island, at least in the United States, most Americans as well as European were convinced that large-scale technologies such as nuclear power or waste incinerators were necessary but highly unwanted manifestations of modernity (Covello 1983; Gould et al. 1988). Public opinion shifted towards skepticism or even outright opposition to hazardous facilities. Pandora had opened her box. People were confronted with the negative side effects of technological changes. The decade between 1986 and 1996 was characterized by a clear defensive attitude of the technological elite vis-a-vis a growing distrust in scientific expertise and risk management agencies. A powerful counter-elite was formed challenging the official risk assessments of the former experts and demanding new directions in technological policies. Many people felt that the risk assessments of the pre-1986 period were discredited by the events of the year 1986.

The technical risk professionals were either hibernating in their own communities or trying (sometimes desperately) to integrate public outrage into their decision or assessment models (Zeckhauser and Viscusi 1996). However, some of the recent conferences on the tenth anniversary of the three disasters witnessed a resurrection of the professional positions on risk (Renn 1998, p. 50). Many technical analysts argued that the so called disasters of 1986 were not as disastrous as many people had assumed. The 1996 IAEA conference on Chernobyl included a heated debate whether the number of cancer victims exceeded those who had suffered from the curable thyroid cancer, thus bringing the number of victims to a few hundreds at worst. The Rhine river accident had hardly any major long-term impact on the river ecosystem (similar, though contested claims have been made for the Alaskan oil spill) and the Challenger disaster appeared to be an exception rather than the rule. Furthermore, political and social elites showed an increased interest in numerical risk assessments and questioned the wisdom of the lay public in judging the seriousness of risks.

The present situation is full of ambiguities. Most former critics of technological changes have learned that cultural evolution rests on innovation and that innovation implies risk-taking. Opportunities rise out of uncertainties. American sociologist Aaron Wildavsky called the drive towards zero risk the highest risk of all (Wildavsky 1990). Most technical experts, on the other side, have learned that good models of risk analysis and stringent methodology in designing technologies can serve only as approximations towards a safer society. Strategies of resilience and flexibility need to accompany safety improvements. In the arena of risk management, a combination of knowledge-based and precautionary instruments for managing the risks of technologies is advocated without clear ideas of how this combination can be implemented (cf. Costanza and Cornwell 1992, pp. 15).

So at the end of the nineties the field of risk analysis needs some new impulses for handling the risks of the old facilities and preparing for the risks of new technologies. What are the circumstances under which new technologies will operate? What developments are going to modulate or even aggravate the exposure to risks in the next years? The following aspects describe the circumstances and the global context to which risks management needs to orient itself (Renn 1997):

- Increase of population and population density, which implies larger damage potential;
- coupling of independent risk sources (chemical, technological, lifestyle, social risks);
- increase of social risks;
- increased emphasis on non-fatal risks, particularly due to demographic changes (older population);
- increase of global damage potential but decrease of probability that maximum damage will be released;
- transfer of hazardous technologies to countries that may not have the institutional means or safety culture to handle the risks properly;
- human interventions in global (bio)geochemical cycles and their effects on technological structures.

The new Pandora box contains familiar threats such as heart attacks and cancer but also less familiar risks such as psychological depressions and horizontal gene transfer. The balance between opportunity and risks is always precarious. To focus merely on the desires of Epimetheus, the ultimate consumer, is not sufficient and also dangerous for humankind. One of the main challenges of the new century will be the reconciliation between the material opportunities and the psychological and spiritual needs of humans. How is society going to handle the risks associated with new technologies in modern societies? What we need is a sequential integration of risk assessment, risk evaluation, and risk management.

2 Risk Evaluation and a "New" Risk Classification

2.1 Analytical Approach

Risk is based on the contrast between reality and possibility. Only when the future is seen as at least partially influenced by human beings, it is possible to prevent potential hazards or to mitigate their consequences. The prediction of possible hazards depends on the causal relation between the responsible party and the consequences. Because the consequences are unwelcome, risk always comprises a normative concept. The society should avoid, reduce or at least control risks. Increasing potentials of technical hazards and the cultural integration of external hazards into risk calculations increase the demand for risk analysis and risk management.

Thus, risks can be described as possible effects of human actions or natural events, which are assessed as unwelcome by the vast majority of human beings. Risk concepts from various disciplines differ in the manner how these effects are grasped and evaluated. Four central questions form the focus of our attention:

1. What are welcome and what are unwelcome effects? Which criteria distinguish between positive (welcome) and negative (unwelcome) consequences of actions and events?
2. How can we predict these effects or how can we assess them in an intersubjective valid manner? Which methodical tools do we have to manage uncertainty and to assess probability and damage?
3. Are we able to arrange risks according to risk classes? Which characteristics are relevant to evaluate risks? Are there typical risk management categories?
4. Which combination and which allocation of welcome and unwelcome effects do legitimate the rejection or the acceptance of risky actions?

In order to answer these questions and to be able to carry out systematically such risk evaluations, we propose a risk classification that summarizes specific risk types and determines particular strategies for a rational management of the respective risk class.

2.2 Terminological Definitions: Main Characteristics of Risk Evaluation

The central categories of risk evaluation are the *extent of damage* and the *probability of occurrence*. *Damage* should generally be understood as negative evaluated consequences of human activities (e.g. accidents by driving, cancer by smoking, fractured legs by skiing) or events (e.g. volcanic eruptions, earth quakes, explosions).

In contrast to the measurement of damages, there does not exist an obvious method to determine the *probability of occurrence*. The term *probability of occurrence* is used for such future events of damage where information or even only presumptions about the relative frequency of the event have been given, but where the precise time remains uncertain. Risk statements always describe probabilities, i.e. tendencies of event sequences, which will be expected under specific conditions. The fact that an event is being expected once on average during thousand years, does not say anything about the time when the event will actually occur.

If indicators are available for determining the probability of occurrence as well as the extent of damage, the degree of confidence associated with the assessment of each component is called *reliability of assessment*. If the *reliability of assessment* is low, one needs to characterize the nature of the uncertainty in terms of statistical confidence intervals, remaining uncertainties (identifiable, but not calculable) and plain ignorance. Uncertainty is a fundamental characteristic of risk, whereas the reliability of assessment varies between extremely high and extremely low. Even if it is not possible to make objective predictions about single occurrences of damage on the basis of risk assessment, results of such an assessment are not arbitrary. When we have two options of action where the same unwelcome event will occur with different probability, the conclusion for a decision under uncertainty is clear: Each rationally thinking human being would choose the option of action with the lower probability of occurrence.

2.3 Rational Risk Evaluation

For a rational risk evaluation and adequate risk management we consider it to be justified and necessary that both scientific assessments as well as risk perceptions be integral parts of these evaluations (Fiorino 1989). The question arises how societies should decide about fundamental procedures of evaluation and management concerning uncertain consequences of collective actions. We want to emphasize that scientifically based risk assessments are rational procedures for coping with risks despite remaining uncertainties and ambiguities. Using science-based methodologies the criteria probability of occurrence and extent of damage can be assessed relatively well, i.e. there exists a clear data base. If the two components are associated with high uncertainty, precautionary approaches are called for. Neither scientific risk assessment nor procedures of precaution can be substituted by intuition, public opinion or political pressure. Regardless whether science-based or precautionary principle of risk evaluation and management are applied, regulatory agencies need an ethically defensible and consistent set of procedures in order to evaluate and regulate risks.

We consider it useful to include further criteria of evaluation, besides probability of occurrence and extent of damage, into the characterization of risks (Kates and Kasperson 1983; California Environmental Protection Agency 1994). These criteria can be derived from research about risk perception. They are already used or proposed as criteria in several countries such as Denmark, Netherlands and Switzerland (cf. Petringa 1997; Löfstedt 1997; Hattis and Minkowitz 1997; Beroggi et al. 1997; Hauptmanns 1997; Poumadère and Mays 1997; von Piechowski 1994). The following criteria are relevant:

- *Incertitude* (related to statistical uncertainty, fuzzy uncertainty, and ignorance);
- *Ubiquity* defines the geographic dispersion of potential damages (intragenerational justice);
- *Persistency* defines the temporal extension of potential damages (intergenerational justice);
- *Reversibility* describes the possibility to restore the situation to the state before the damage occurred (possible restoration are 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; and
- *Potential of mobilization* is understood as violation of individual, social or cultural interests and values generating social conflicts and psychological reactions by individuals or groups who feel inflicted by the risk consequences. In particular, it refers to perceived inequities in the distribution of risks and benefits.

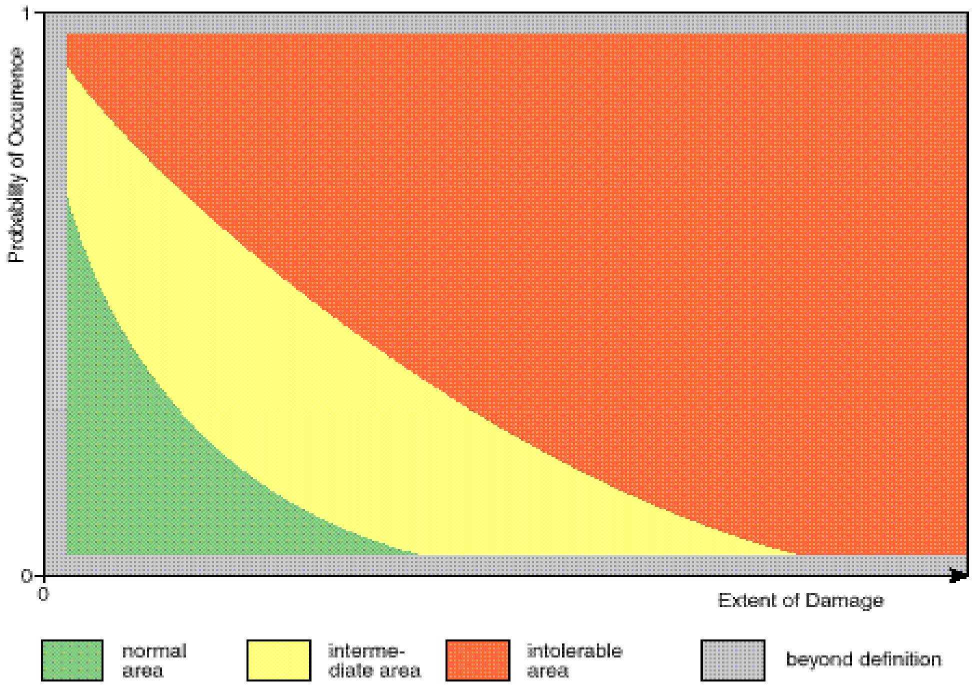

Figure 1: Risk areas: normal, intermediate and intolerable area
Source: WBGU, German Scientific Advisory Council on Global Change (1999)

As practiced in many countries, we distinguish three categories of risks for starting the rational risk evaluation process (see Figure 1): the *normal area*, the *intermediate area* and the *intolerable area* (area of permission) (cf. also von Piechowski 1994). The *normal area* is characterized by little statistical uncertainty, low catastrophic potential, low risk numbers damage when the product of probability and damage is taken, low scores on the criteria: persistency and ubiquity of risk consequences; and reversibility of risk consequences, i.e. normal risks are characterized by low complexity and are well understood by science and regulation. In this case the classic risk formula probability times damage is 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-benefit analysis as the major tool for collective decisions based on a risk-neutral attitude.

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 absolutely appropriate because the limits of human knowledge are reached. That is why a simple balancing approach such as risk-benefit ratio is inadequate, since wide-ranging negative surprises are not excluded. This is the domain for precautionary strategies of risk evaluation and control, including new models of liability, new strategies of containment and risk avoidance.

2.4 A "New" Risk Classification[2]

Theoretically a huge number of risk classes can be deduced from the eight criteria. Such a huge number of cases would not be useful for the purpose of developing a comprehensive risk classification. In reality some criteria are tightly coupled and other combinations are theoretically possible, but there are none or only few empirical examples. Considering the task of setting priorities for risk regulation, risks with several extreme qualities need special attention. We have chosen a classification where similar risk candidates are classified into risk classes in which they reach or exceed one or more of the possible extreme qualities with respect to the eight criteria (see Figure 2). This classification leads to six risk classes that were given names from the Greek mythology.

Events of damages with a probability of almost one were excluded from our classification. High potentials of damages with a probability of nearby one are clearly located in the intolerable area and therefore unacceptable. Such risks are rare with respect to technological hazards, but frequent with respect to natural hazards. By the same token, probability heading towards zero is harmless as long as the associated potential of damage is irrelevant. It is a characteristic of technological risk that the extent of damage is negatively correlated to the level of probability. The higher the damage the lower the probability.

[2] All risk examples mentioned in this chapter are described in detail in WBGU (1999).

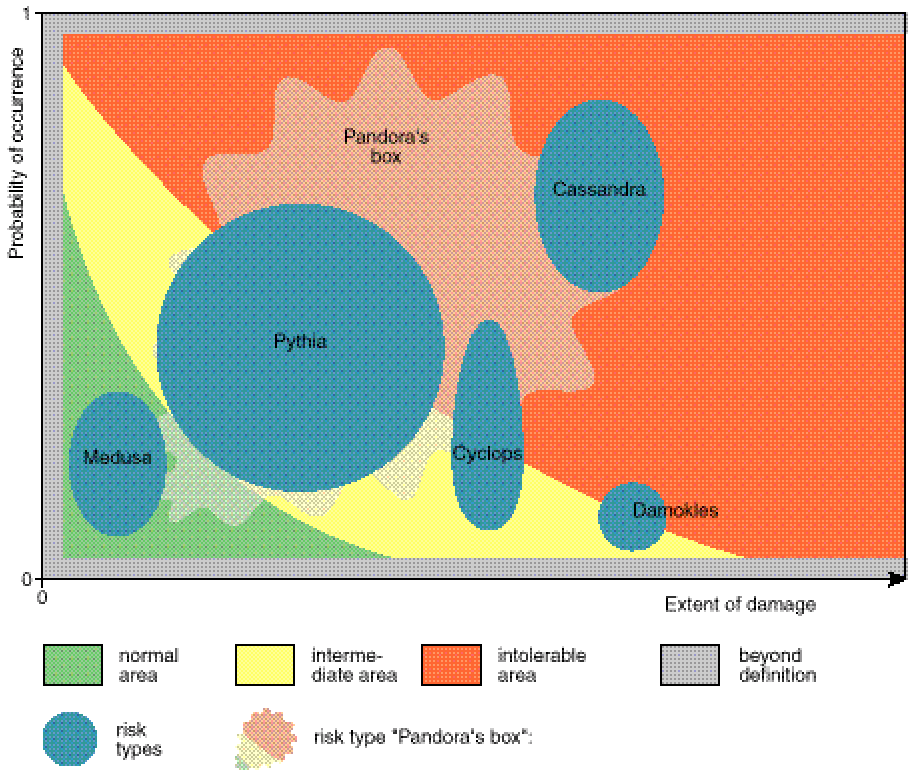

Figure 2: Risk classes
Source: WBGU, German Scientific Advisory Council on Global Change (1999)

2.4.1 Risk Class *Sword of Damocles*

Many sources of technological risks have a very high disaster potential, although the probability that this potential manifests itself a damage is extremely low. Nuclear power plants, large-scale chemical facilities, dams and meteorite impacts are typical examples. A prime characteristic of this risk class is its combination of low probability with high extent of damage. Theoretically the damage can occur at any time, but due to the safety measures implemented this is scarcely to be expected. Such risks form the risk class *Sword of Damocles*. According to the 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 up 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 rather comes from the possibility that a fatal event could occur for Damocles every time even if the probability is low. Accordingly, this risk class relates to risk sources that have very high potentials of damages and at the same time very low probability of occurrence.

2.4.2 Risk Class *Cyclops*

The Ancient Greek knew enormous strong giants who were punished despite their strength by only having a one single, round eye, which was why they were called “round eyes” or Cyclops. With only one eye only one side of reality and no dimensional perspective can be perceived. Applied to risks it is only possible to ascertain either the probability of occurrence or the extent of damage while the other side remains uncertain. In the risk class *Cyclops* the probability of occurrence is largely uncertain whereas the maximum damage can be estimated. It is often the case that risks are greatly underestimated whose magnitude can be grasped but whose probability of occurrence is uncertain or continuously changes. This refers to a constellation in which there is high indeterminacy in the assessment of the probability of occurrence, while the maximum damage is largely known. A number of natural events such as volcanic eruptions, earthquakes and floods belong in this category. There is often too little knowledge about causal parameters, or too little observation time in which to identify cyclic regularities. In other cases human behavior influences the probability of occurrence so that this criterion becomes uncertain. Therefore, the appearance of AIDS and other infection diseases as well as nuclear early warning systems and NBC-weapons[3] also belong to this risk class.

2.4.3 Risk Class *Pythia*

This risk class refers to risk potentials for which the extent of damage is unknown and, consequently, the probability of occurrence also cannot be ascertained with any accuracy. To that extent, we must assume for risk potentials of this class that there is great

[3] A study of the PRIF – Peace Research Institute in Frankfurt, Germany – indicated that the Russion early warning system and the associated nuclear forces have considerable functional and maintenance deficiencies because of human behavior (Müller and Frank 1997).

uncertainty with regard to possible adverse effects and thus also with regard to the probability of ascertainable damage. This risk class is named *Pythia*. The Greeks of the antiquity asked 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 could threaten, but the probability of occurrence, the extent of damage, the allocation and the way of the damage remained uncertain. This class includes risks associated with the possibility of sudden non-linear 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 far-reaching technological innovations in certain applications of genetic engineering, for which neither the maximum amount of damage nor the probability of certain damaging events occurring can be estimated at the present point in time. 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.

2.4.4 Risk Class *Pandora’s Box*

A number of human interventions in the environment cause wide-ranging and persistent damage. These two criteria are exemplified by persistent organic pollutants (POPs) and by biosystem changes that remain stable over long periods. Here particular attention needs to be given to risks characterized simultaneously by high ubiquity, persistency and irreversibility. These criteria are also an indication that it will be scarcely possible to compensate for damage. These risk potentials are subsumed under the risk class *Pandora’s box*. The old Greeks explained many evils and complaints with the myth of Pandora’s box – a box which was brought down to the Earth by the beautiful Pandora created by the god Zeus. It only contained many evils and complaints. As long as the evils and complaints stayed in the box, no damage at all had to be feared. However, when the box was opened, all evils and complaints were released which than irreversibly, persistently and ubiquitously struck the earth. This risk class is characterized by both uncertainty in the criteria probability of occurrence and extent of damage (only presumptions) and high persistency. Beside persistent organic pollutants and biosystem changes endocrine disruptors can be quoted as examples.

2.4.5 Risk Class *Cassandra*

This risk class refers to risk potentials characterized by a relatively lengthy delay between the triggering event and the occurrence of damage. This case is naturally only of interest if both the probability and magnitude of damage are relatively high. If the time interval were shorter, the regulatory authorities would certainly intervene because the risks are clearly located in the intolerable area. However, the distance in time between trigger and consequence creates the fallacious impression of safety. Above all, the belief that a remedy will be found before the actual damage occurs can be taken as an excuse for inactivity. Examples can be found in both the medical and the geophysical or climate arenas. These risks form the risk class *Cassandra*, because those who warn of such risks are rarely given credence. Many types of damage occur with high probability, but in such a remote future that for the time being no one is willing to acknowledge the threat. This was the problem of Cassandra was a prophetess of the Trojans who certainly predicted correctly the victory of the Greeks, but her compatriots did not take her seriously. The risk class Cassandra describes a paradox: the probability of occurrence as well as the extent of damage are known but it hardly emerges dismay in the present because the damages will occur after a long time. Of course risks of the type *Cassandra* are only interesting if the potential of damage and the probability of occurrence are relatively high. That's why this class is located in the intolerable 'red' 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. Typical examples of this effect are the anthropogenic climate change and the loss of biological diversity.

2.4.6 Risk Class *Medusa*

The risks belonging to this risk class refer to the potential for public mobilization. This criterion expresses the extent of individual aversion to risk and the political protest potential fueled by this aversion, both of which are triggered among the lay public when certain risks are taken. This risk class is only of interest if there is a particularly large gap between lay risk perceptions and expert risk analysis findings. We call this risk class *Medusa*. The risks associated with electromagnetic fields are typical representatives of the risk class *Medusa*. The risks are primarily due to the intensities and frequencies of electromagnetic fields (EMF). Being below the excitation threshold, these fields are not registered by human sensory organs. This is not a matter of physical disorders underpinned by objectively verifiable data, but rather of statements on subjective malaise or subjective impairment of human functional capacity, which can ultimately lead to psychosomatic disorders. The mythological world of the ancient Greek was full of dangers that menaced common people, heroes and even the Olympic gods. The imaginary Gorgons were particularly terrible. 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. Some innovations are 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 combated by effective argumentation, further research and communication in public. According to the best knowledge of experts risks of this type are located in the normal area. Because of specific characteristics these risk sources frighten people and lead to heavy refusal of acceptance. Often a large number of people are affected by these risks but harmful consequences cannot statistically be proven.

2.4.7 Summarizing the Risk Classes

Table 1 lists all six risk classes in tabular form, describes their main characteristics, and provides examples for each type. The classification is the first step for designing appropriate management strategies. These will be explained in the following chapter.

RISK CLASS	**PROBABILITY**	**MAGNITUDE**	**OTHER CRITERIA**	**TYPICAL EXAMPLES**
Damocles	low	high	not decisive	nuclear energy, dams, large-scale chemical facilities
Cyclops	uncertain	high	not decisive	nuclear early warning systems, earthquakes, volcanic eruptions, AIDS
Pythia	uncertain	uncertain	not decisive	greenhouse effect, BSE, genetic engineering
Pandora	uncertain	uncertain	high persistency	POPs, endocrine disruptors
Cassandra	high	high	high delay	anthropogenic climate change, destabilization of terrestric ecosystems
Medusa	low	low	high mobilization	electromagnetic fields

Table 1: Overview of the risk classes, their criteria and typical representatives

Each risk class is indicative for a different pattern of incertitude. The term incertitude describes the level of knowledge, uncertainty or ignorance with respect to the two main criteria probability of occurrence and extent of damage. The following table provides an overview:

Degree of incertitude	**Main criteria**	**Risk classes**
Known distribution of probabilities and corresponding damages	Probability of occurrence and extent of damage are *known*	• Sword of Damocles • Cassandra • Medusa
Uncertainty	Probability of occurrence or extent of damage or both are *uncertain* (because of natural variations or genuine stochastic relationships)	• Cyclops • Pythia
Ignorance	Probability of occurrence and extent of damage are *highly unknown* to science	• Pandora‘s box

Table 2: Overview of different degrees of incertitude with respect to the main criteria and the risk classes

2.5 The Application of the Risk Classification in the Political Decision Making Process

For a rational risk evaluation, profound scientific knowledge is required, especially, with regard to the main criteria of risk evaluation – probability of occurrence, extent of damage and certainty of assessment – and to the additional criteria as well. This knowledge has to be collected by scientists and risk experts who are recognized and leading authorities in the respective risk area. The experiences of risk experts from different technological or environmental fields crystallize into a comprehensive risk knowledge. This 'state of the art' enables scientists and experts to provide the data base for each of the eight evaluation criteria and to assign risk potentials to the respective risk classes. If there is dissent among experts, special techniques of classification such as Delphi procedures or meta-analyses may be required to overcome superficial disagreements and to produce defensible arguments for different positions. If there is no controversy about the data base, the classification can be performed almost automatically. For practical reasons, scientific advisory bodies or specialists of risk managing agencies should take the responsibility for the classification.

In the framework of the latest annual report about the management of global environmental risks the 'German Scientific Advisory Council on Global Change' proposed the above mentioned rational risk evaluation including the eight evaluation criteria and the six risk classes (WBGU 1999). The Council characterized 21 global risk potentials that were collated then to the respective risk classes (WBGU 1999). The results of these considerations have been communicated to the respective ministries (environment as well as science and research).

It should be emphasized that process of classification is not a scientific task, but builds upon the deliberative function of expert opinions for political decision making. On the national level, advising committees assembled by scientists and other experts can fulfill this deliberative function as long as they are integrated into democratic structures. On the European and international level, equivalent structures are either lacking or need to be strengthened. To classify technological and environmental risks within the European and international governance, for example, the EU-commitology structure could be amended in order to provide the necessary deliberative function and so reduce the deficit of knowledge input. Joerges and Neyer (1998, p. 230) suggested the idea of a "deliberative supra-nationalism" for the European Union, in which the activity of the commitology will be constitutionalized. The commitology should convince the Commission of the necessity of collective problem solving, appropriate platforms should be stabilized and structured for public discourse so that arguments of affected people can be heart and exchanged as well as principles and rules for structuring the decision making can be developed.

If contentious issues prevail and the rating of risks remain controversial, scientific input is only the first step of a more complex classification 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 using the 'Pedigree Scheme' by Ravetz and Funtowicz (1990) might be helpful to organize the existing knowledge. In a second step, the information, including all uncertainties and ambiguities, needs to be assessed and evaluated by a political body. We recommend discursive and deliberative methods of decision making within such bodies. In addition, if the scientific risk evaluation is questioned by the public and lead to a high degree of mobilization, a public discourse among scientists, political decision makers and citizens is required to classify these risks. Without consulting public interest groups and those who are affected by the decision, a synthesis of expert opinion and public concern cannot be achieved. In this deliberative process it is relevant that the actors mutually learn. The report of the National Academy of Sciences about "understanding risk" stresses the need for a combination of evaluation and discourse characterized as 'analytical-deliberative approach' (Stern and Fineberg 1996). Especially the risks of the risk classes *Cassandra* and *Medusa* – as we will see in the next chapter – need the linkage of risk evaluation and discourse in order to introduce learning processes for building consciousness and confidence. But also the science-based and precautionary risk classes require an analytical-deliberative procedure, if questions and problems of evaluation and classification are contentious and resolving strategies of risk management generate dissent.

3 Risk Management: Science-Based, Precautionary and Discursive Strategies

In democracies many political and societal problems and their resolutions remain contentious, albeit the actors in the political arenas attempt to achieve compromises or even consensus on the choice of the appropriate political strategies, regulations and measures. It would be politically practical and effective, if the actors agree on norms and procedures as a result of a deliberative process to evaluate political decisions or to manage controversial questions and issues. If the achieved outcomes are rational and reflect the previous discourse, the legitimacy of the political decisions, i.e. the selected political strategies and regulations, increases (cf. Miller 1993). What are the requirements that would satisfy the need for a competent, knowledge-based, fair and deliberative decision making process?

Risk managers are faced with a difficult dilemma: On the one hand, technical expertise is a necessary but not sufficient condition to make prudent decisions on risk. On the other hand, public perceptions reflect the preferences and values of those affected by decisions on risks, yet these perceptions are at least partially driven by biases, anecdotal evidence, false assumptions about dose-effect-relationships, and sensation (Okrent 1998). There is an additional complication: Neither the experts nor the various groups of the public are monolithic blocks, either. Risk managers are faced with a multitude of competing cognitive claims, values, and interpretations from experts and public groups alike (Cross 1998). We live in pluralist societies and in a heterogeneous “world society” with different value systems and worldviews. Who can legitimately claim the right to select the values or preferences that should guide collective decision making, in particular when health and lives of humans are at stake?

Our proposal for risk evaluation, risk classification and risk management is the attempt to initiate a deliberative process, in which rational criteria of evaluation are used, public values inserted, and effective strategies communicated to those who are affected by the decision.

To identify public values and integrate facts and values into a joint decision making effort, a communication process is needed that build upon intensive dialogue and mutual social learning. Without consulting pubic interest groups and those who are affected by the decision, a meaningful synthesis of expertise and public concerns cannot be accomplished. The before mentioned report “Understanding Risk” compiled by the National Academy of Sciences calls for an integration of assessment and discourse forming an "analytic-deliberative" approach (Stern and Fineberg 1996). Using similar arguments, modern theorists of public planning have questioned the validity of the traditional paradigm of instrumental rationality, which assumes that experts and public servants have almost perfect knowledge about the most likely outcomes of different planning options as well as about public preferences with respect to each bundle of outcomes (Forester 1989; Sager 1994). The new paradigm of transactive planning or disjointed incrementalism is based on procedural rationality, which builds on communicative actions. The objective is to design cooperative planning processes in which uncertain outcomes are discussed with representatives of the affected public and the evaluation of options is performed in an active dialogue between experts, stakeholders, and members of the general public (Fiorino 1990; Hadden 1989).

How can and should risk managers collect public preferences, integrate public input into the management process, and assign the appropriate roles to technical experts, stakeholders and members of the public? A dialogue among experts, stakeholders, regulators, and the public at large can be organized in many different forms. Practical experiences have been made with advisory committees, citizen panels, public forums, consensus conferences, formal hearings, and others (Langton 1978; Bacow and Wheeler 1984; Crosby et al. 1986; Kraft 1988; Burns and Überhorst 1988; Laird 1993; Sclove 1995; Susskind and Fields 1996; Renn and Klinke 1999; see reviews in: Pollak 1985; Renn et al. 1995; Creighton et al. 1998). Democratic values can provide the means by which to construct this dialogue and the social science perspectives can help to make these forms of dialogue work, i.e. to make sure that each group can bring their own interest and values to the process and yet reach a common understanding of the problem and the potential solutions (Fiorino 1989; Keeney 1996).

The task of risk management, including the selection of political strategies, regulations and measures for action directed at each risk class, is mainly addressed to political decision makers, i.e. the addressees are national governments, the European Union and international institutions. On the national level they are obliged by national or international law or statute to legitimize response strategies and measures and to implement them effectively. On the international level international governance shaped by international regimes, conventions and organizations can provide a functional equivalent because world government is lacking.

Therefore, the essential aim of the risk classification is to locate risks in one of the three risk areas (Figure 1) in order to be able to derive effective and feasible strategies, regulations and measures for the risk policy on the different political levels. The characterization provides a knowledge base so that political decision makers have better guidance on how to select measures for each risk class. The strategies pursue the goal of transforming unacceptable into acceptable risks, i.e. the risks should not be reduced to zero but moved into the normal area, in which routine risk management and cost-benefit-analysis becomes sufficient to ensure safety and integrity.

Management	Risk class	Extent of damage	Probability of occurrence	Strategies for action
Science-based	***Damocles***	• high	• low	• Reducing disaster potential • Ascertaining probability • Increasing resilience • Preventing surprises • Emergency management
	Cyclops	• high	• uncertain	
Precautionary	***Pythia***	• uncertain	• uncertain	• Implementing precautionary principle • Developing substitutes • Improving knowledge • Reduction and containment • Emergency management
	Pandora	• uncertain	• uncertain	
Discursive	***Cassandra***	• high	• high	• Consciousness-building • Confidence-building • Public participation • Risk communication • Contingency management
	Medusa	• low	• low	

Table 3: Overview of the Management Strategies

A comparative view on the risk classification scheme (Table 3) indicates that we can distinguish three central categories of risk management, namely science-based, precautionary and discursive strategies. The two risk classes *Damocles* and *Cyclops* require mainly science-based management strategies, the risk classes *Pythia* and *Pandora* demand the application of the precautionary principle, and the risk classes *Cassandra* and *Medusa* make necessary discursive strategies for consciousness and confidence building. This distinction does not mean that within each risk class the other strategies and instruments have no place, but they take a ‘back seat’.

Table 3 summarizes the three risk management categories with the corresponding risk classes, the main criteria, and the respective strategies for action that will follow in this chapter.

3.1 Science-Based Management Strategies

The risk classes *Damocles* and *Cyclops* belong to this category, they can best be handled and managed by science-based strategies and regulation. Nuclear energy, large chemical facilities, dams, nuclear early warning systems, NBC-weapons, but also the appearance of AIDS are typical representatives for this management category.

3.1.1 Application to the Risk Class *Sword of Damocles*

For risks from the category *Sword of Damocles* three central strategies are recommended (see Table 4). The prior strategy implies knowledge-based regulations because the probability of occurrence as well as the extent of damage are relatively well-known. The task here is to address the negative effects of the risk potential. First, the potential of disasters must be reduced by research to develop substitutes and technical changes. The second most important strategy is a combination of risk reduction measures and precautionary regulations. Within the second strategy resilience must be increased, i.e. the power of resistance against surprises. The third priority is obviously based on the precautionary principle of remediation: The emphasis here is on effective emergency management. The same applies for the other risk classes with the exception of the risk class *Medusa*.

Within the scope of the *first strategy* to reduce the damage potential, we recommend more research for developing substitutes and technical measures for the reduction of disaster potential as well as the realization of measures to reduce the extent of damage. Imposing strict liability rules might provide incentives for reducing the catastrophic potential: operators are then encouraged to improve their knowledge and to reduce the remaining risks. At the same time, it is necessary to develop alternatives with a lower catastrophic potential in order to replace technologies that belong to the *Damocles* category. For establishing and testing these alternatives, subsidies might be necessary.

Strategies		Regulations and instruments
1.	***Reducing disaster potential***	• Research to develop substitutes and to reduce the potential of disasters • Technical measures for reducing the disaster potential • Stringent rules of strict liability • International safety standards authority • Subsidies for developing alternatives for the same purpose • Containment (reducing the damage extension) • International coordination (e.g. averting the hazard of meteorites)
2.	***Increasing resilience***	• Capacity building (permit, licensing, monitoring, training etc.) • Technical procedures for strengthening resilience (redundancy, diversification etc.) • Blueprint for resilient organizations • Effective licensing procedures • International control (e.g. IAEO) over licensing and operation • International liability commitment
3.	***Emergency management***	• Capacity building (protection from emergencies) • Training, education, empowerment • Technical protection measures, including strategies of containment • International emergency groups (e.g. fire service, radiation protection etc.)

Table 4: Science-based strategies and regulations for the risk class *Sword of Damocles*

Within the scope of the *second strategy* it is necessary to increase the resilience against the risk potentials. Therefore capacity building is required so that institutional and organizational structures can be improved and strengthened in order to have control over licensing, monitoring, training etc. Additionally, technical procedures to increase the resilience must be established or, if they are already exist, be improved. Such procedures include technical redundancy, organizational security units, integration of latitudes, buffers and elasticities and diversification, i.e. the local dispersion of risk sources. Resilient organization models and effective licensing procedures should be demanded when hazardous technology is transferred to other countries. International control and monitoring should also be strengthened and an international safety standards authority should be established.

The *third priority* refers to emergency management. This strategy is not regarded as insignificant, however, a strategy of damage limitation should stay behind the primary rationale of reducing risk strategies. In this domain, capacity building must be increased by developing and promoting national programs of emergency protection. Successful measures of emergency protection and techniques in forms of training, education and empowerment can be transferred to local risk manager.

In addition, technical measures of protection and measures to reduce the extent of damage have to be enforced. Finally, an international preventing disaster relief, like the „International Decade for Natural Disaster Reduction (IDNDR)“ initiated by the UN, is helpful for anthropogenically caused disasters.

3.1.2 Application to the Risk Class *Cyclops*

In the case of the risk class *Cyclops*, the uncertainty concerning the probability of occurrence is the starting point for regulative measures. Because the possible extent of damage in the case of a catastrophe is relatively well known, both science-based strategies and strategies based on the precautionary principle are required (see Table 5). First of all we recommend increased research and intensive monitoring for a better assessment of the probability distribution. Until such results are available, strategies to prevent unwelcome surprises are useful (including strict liabilities). Preventing measures for disasters are important on international level because the damage potentials within affected countries with high vulnerability can reach precarious extensions.

First priority is assigned to scientific research concerning the probability of occurrence. Additionally, international monitoring by national and international risk centers should supplement all local efforts. That could be fulfilled by the establishment of an international risk assessment board or center that has the function to set up a network among the national risk centers and to gather and assess knowledge about global risks. Something similar could be organized on the European level.

Within the scope of the second strategy unwelcome surprises have to be prevented. This could happen by improving strict liabilities or by compulsory insurance if certain conditions are met. The appropriate instruments of capacity building and technical measures correspond to the instruments listed under the risk class *Sword of Damocles*.

Strategies	Regulations and instruments
1. Ascertaining the probability of occurrence	• Research to ascertain numerical probability • International monitoring by - National risk centers - Institutional networking - International risk board • Technical measures for calculating the probability of occurrence
2. Prevention against surprises	• Strict liability • Compulsory insurance for those generating the risks (e.g. floods, housing estates) • Capacity building (permit, licensing, monitoring, training etc.) • Technical measures to provide barriers against dispersion • International monitoring
3. Emergency management or reducing the extent of damage	• Capacity building (protection from emergencies) • Training, education, empowerment • Technical protection measures, including strategies of containment • International emergency groups (e.g. fire service, radiation protection etc.)

Table 5: Science-based (and precautionary) strategies and regulations for the risk class *Cyclops*

Within the third strategy, emergency management would include the same measures that have been postulated for the risk class *Sword of Damocles*.

3.2 Precautionary Management Strategies

The risk classes *Pythia* and *Pandora* are ascribed to 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 concerning the main criteria probability of occurrence and extent of damage. As a result the assessment of these risks is connected with uncertainty on all risk characteristics.

3.2.1 Application to the Risk Class *Pythia*

Within the risk class *Pythia* the criteria probability of occurrence as well as the extent of damage have a high quality of uncertainty. The result is that science-based assessments are either highly contested or genuinely absent. Therefore, the prior risk management strategy must be precaution. This includes a strict implementation of regulations and instruments based on the precautionary principle (see Table 6). The second strategy is directed towards improving the knowledge base. More basic research is required. At the same time, strategies of prevention in particular limiting the use of the risk source in specific areas or spaces, should be encouraged because the extent of damage could reach global dimensions. Geographical and temporal measures of containment are indispensable.

Strategies	Regulations and instruments
1. Strict implementation of the precautionary principle	• Institutional regulations as ALARA, BACT, technical standards etc. • Containment (reducing the extension of damage) • Economic fund system for relief measures • International conventions for controlling, monitoring and security measures • Capacity building (permit, licensing, monitoring, training etc.) • Technical procedures for improving resilience (redundancy, diversification etc.)
2. Improving knowledge	• Research to ascertain the probability of occurrence and the extent of damage • International early warning system by - National risk centers - Institutional networking - International risk board
3. Emergency management	• Containment strategies • Capacity building (protection from emergencies) • Training, education, empowerment • Technical protection measures • International emergency groups (e.g. fire service, radiation protection etc.)

Table 6: Precautionary strategies and regulations for the risk class *Pythia*

With respect to the instruments, precautionary measures have top priority. We recommend institutional regulations such as ALARA (as low as reasonably achievable), BACT (best available control technology), technical standards and other limitations. International conventions for controlling, monitoring and safeguarding are also necessary. The instruments to reduce the extent of damage and capacity building are the same as for the risk classes mentioned above.

The improvement of knowledge has second priority so that future risk analysis can provide a higher level of validity and certainty. Research on how to ascertain the probability of occurrence and the extent of damage is needed. Additionally, an international early warning system is necessary as for the risk class *Cyclops*.

The third strategy of emergency management comes close to measures of the previous risk classes.

3.2.2 Application to the Risk Class *Pandora's box*

The risks of *Pandora's box* are characterized by uncertainty concerning the probability of occurrence and the extent of damage (only presumptions). The major problem here, however, is ubiquity and persistency. As a result, the science-based assessment of certainty is also weak. To manage such a high uncertainty, strategies based on the precautionary principle are again necessary (see Table 7).

Research efforts to develop substitutes and regulatory measures to contain or to reduce the risk sources are absolutely essential because the negative consequences of the risk sources are unknown. In the most unfavorable case, however, the consequences can reach global dimensions with irreversible effects. Containment strategies need to be implemented on the international level.

The development of substitutes has priority over all other strategies. Concerning the research and development of substitutes the measures correspond to those that we included in the list for the risk class *Sword of Damocles*. In addition, this risk type requires wide-ranging research efforts that need adequate financial support.

In a second step the risk potentials should be decreased by reducing dispersion or exposure of chemicals or by prohibiting them completely. Regulatory procedures should limit quantities through environmental standards or even more advisable by means of economic certificates. In some cases the use of strict liability is appropriate. Furthermore instruments of technical safety measures and capacity building complement the regulatory requirements.

Strategies	**Regulations and instruments**
1. Developing substitutes	• Research to develop substitutes • Supporting basic research • Incentives to develop less harmful substitutes • Subsidies for developing alternative production systems
2. Reduction and containment	• Containment with respect to local dispersion and time of release • Regulatory policy for limitation of exposure through environmental standards etc. • Use of incentive systems (certificates) for reducing quantities • Strict liability, if useful • Improving and developing technical procedures of support • Capacity building (technical know-how, technology transfer, education, training etc.) • Joint implementation
3. Emergency management	• Capacity building (protection from emergencies) • Technical protection measures, including strategies of containment • Training, education, empowerment • Relief funds

Table 7: Precautionary strategies and regulations for the risk class *Pandora's box*

The third strategy of emergency management corresponds to the other risk types. An international emergency group combating unwelcome surprises should be installed. The international emergency group for nuclear decontamination of the International Atomic Energy Agency (IAEA) can serve as an example.

3.3 Discursive Management Strategies

The third category with discursive strategies is essential, if either the potential for wide-ranging damage is ignored, due to a delay effect as e.g. climate change and the loss of biological diversity, or – the opposite – harmless effects are perceived as threats without such hard evidence. The risk classes *Cassandra* and *Medusa* represent these risks who are not associated with scientific uncertainty. In the case of *Cassandra* human beings take the risks not 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 known, i.e. the science-based assessment of each criterion is at least satisfactory. The threat of the risks is mainly based on the subjective perception that can lead to stress, anxiety and psychosomatic malfunctions.

3.3.1 Application to the Risk Class *Cassandra*

The risks of the risk class *Cassandra* are not associated with scientific uncertainty, but people take the risks not seriously because of the lingering delay between the initial event and the damage. The probability of occurrence as well as the extent of damage are relatively known, i.e. the science-based assessment of certainty is relatively good. Due to the tendency of democratic governments to rely on short time legitimization periods (short election periods), politics often lack the motivation to take care of long-term hazards. Therefore, strategies are needed to build up consciousness and to initiate common efforts of institutions for taking responsibility (see Table 8).

Measures of collective commitment (e.g. code of conduct for multinational enterprises) and long-term international institutions (UN or European Risk Assessment Panel) should be conducive to strengthen the long-term responsibility of the international community. Limitations of quantities are also appropriate to reduce these risks. Although the strategies are mainly oriented toward building consciousness, relevant precautionary instruments and measures as, for example, limitations, fund solutions and capacity building are additional in elements of a regulatory regime for this risk type.

If there is a relevant delay between the initial event and the consequences, the first strategy should be to strengthen long-term responsibility and to plan for future generations. The goal is the self-commitment of the states and relevant actors (e.g. multinational enterprises). It is possible that funds could be an effective instrument to mitigate at least the consequences that are likely to occur in the future. On the individual level, potentially affected people can become more conscientious and aware of the problems if they are involved in risk regulations through participation and local empowerment.

Strategies	Regulations and instruments
1. Strengthening the long-term responsibility of key actors	• Self-commitment, code of conduct of international actors • Enhancing of participation, empowerment and institutional security as a means to foster long-term responsibility • Measures against governmental breakdown • Economic fund solutions • International coordination
2. Continuous reduction of risk by introducing substitutes and setting limitations of exposure	• Use of incentive systems (certificates, fees etc.) • Strict liability, if useful • Regulatory limitations of quantities by environmental standards (also international standards) • Improving and developing technical procedures of support • Capacity building (technical know-how, technology transfer, education, training etc.)
3. Contingency management	• Capacity building (recultivation, protection from emergencies) • Technical protection measures, including strategies of containment • Training, education, empowerment

Table 8: Consciousness building strategies and regulations for the risk class *Cassandra*

The second strategy implies the continual reduction of risk potentials, for example the need of developing substitutes. Risk potentials which cannot be substituted should at least be reduced through limitations of quantities or by limiting the field of application (containment strategies). The necessary instruments have already been covered above. The instruments of the third strategy of emergency management correspond to the other risk classes, too.

3.3.2 Application to the Risk Class *Medusa*

The probability of occurrence and the extent of damage of the risk class *Medusa* are rather known, i.e. the science-based assessment of certainty is at least satisfactory. The hazardous nature of the risks is mainly based on the subjective perception that can lead to stress, anxiety and psychosomatic malfunctions. The required strategies focus on building confidence and trustworthiness in regulatory bodies. Together with confidence-building, science-based improvements of knowledge as a means to reduce the remaining uncertainties are also necessary (see Table 9). Clarification of facts, however, 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 decision-making.

The extent of damage and the probability of occurrence of this risk type are not dramatic, the potential of mobilization is high, however. In order to inform the public about the real extent of damage and the probability of occurrence, confidence-building measures are necessary. Independent institutions with high social esteem are important brokers for informing the public about the results of scientific research. Information is not enough, however. The affected people should be given the opportunity to participate in decision-making and licensing procedures. Social scientific research is essential to find out about the motives of people and to provide platforms for conflict resolution.

Strategies	**Regulations and instruments**
1. Building confidence	• Establishment of independent institutions for information and clarification • Increasing the chances of participation with the commitment to set up priorities • Support of social science research concerning the potential of mobilization • Participation of affected people in licensing procedures • International control (e.g. IAEA) • International liability commitment
2. Improving knowledge	• Research to improve the certainty of assessment • Governmental support of research (basic research)
3. Risk communication	• Two-way communication • Involvement of citizens • Informed consent

Table 9: Confidence-building strategies and regulations for the risk class *Medusa*

In addition, the knowledge base about the risk potential needs to be improved. Risks with high mobilization potential are often characterized by high exposure (ubiquity). Precaution is hence necessary, but if science-based data confirm the innocuousness of the respective risk sources, risk reduction measures are not necessary. Research activities produce more certainty and unambiguity is still needed, however, in order to be on the safe side.

3.4 Risk Dynamic

The ultimate goal of all measures taken for reduction is to move risks from the intermediate area to the normal area. In stating this aim, we share the general understanding that it cannot be the aim of any risk policy to reduce all risks down to zero, but rather to move high risks into the normal area, e.g. they reach a scale at which the common methods of risk-benefit assessment can be applied by market participants and by state regulators. Assistance in establishing effectively operating regulatory authorities, functioning insurance markets and effective contingency measures are sufficient. If a transboundary or global risk is identified as belonging to one of the risk classes localized in the intermediate area, then international measures are indeed called for in order to move the risk from the intermediate area to the normal area.

This movement will follow a process passing through several stages. Regardless of the success of individual measures, a risk can move from one class to another without directly entering the normal area. Figure 3 illustrates typical movements from class to class.

In general, we may distinguish between two types of measure: measures aimed at improving knowledge (through research and liability), and regulatory measures impinging upon critical, class-specific quantities (probability, extent of damage, irreversibility, persistence, delay effect and mobilization). As Figure 3 indicates, improved knowledge generally leads to a movement from one class of risk to another, for instance, from *Pandora* to *Pythia*, from *Pythia* to *Cyclops* and from there to *Damocles* or *Medusa*, i.e. the regulating framework moves from precautionary strategies to more science-based strategies. Measures acting upon a specific critical quantity can similarly trigger a cascade movement or can cause a direct move into the normal area.

The following section explains this movement from one class of risk to another using a fictitious example. Imagine a substance that is used internationally, is highly persistent and for which there are reasonable grounds to assume that it causes irreversible effects. This risk belongs in the Pandora class. It is located in the upper third of the intermediate area, since the confidence intervals of the uncertainty bounds extend into the unacceptable area. A risk of this class suggests two primary strategies: Expanding knowledge and limiting the risk potential. Let us first examine the outcome of expanding knowledge: The knowledge pertaining to the risk can be further quantified, in the process of which the assumption of irreversible consequences or of high persistence may be substantiated. If this is the case, a substitution of the substance or even a ban is urgently called for. The risk is thereby unequivocally moved into the prohibited area. If a large period of time elapsed between the triggering event (human or environmental exposure) and its consequence, the prospect of taking direct influence through a ban or restriction would be minute. We then would move towards the risk class *Cassandra*. To handle this risk, long-term responsibility needs to be strengthened and principal actors need to be mobilized so that effective strategies of substitution are introduced or at least containment strategies are implemented.

Let us assume in our illustrative example that the spatial distribution of this substance can indeed be limited such that ubiquitous dispersal is prevented. In this case, the risk is moved to the *Pythia* class, as the probability of occurrence and the extent of damage are still both subject to major uncertainties. The next step in this case would be to determine the extent of damage more clearly. Let us then assume that there are grounds to determine or estimate measurable damage and that this damage seems large enough to preclude locating the risk in the normal area. Under these conditions, movement continues in the direction of the *Cyclops* class. *Cyclops* forms a pivotal node in Figure 3, as risks can undergo transmutation from there to a variety of other classes. If, for instance, we can succeed in determining the probability of occurrence and this is relatively low, then the risk can be categorized as belonging to the *Damocles* class, characterized by high extent of damage and low probability. If, however, probability is found to be high and there is a delay effect, the risk again moves towards the *Cassandra* category. Without this delay effect, a ban or a rapid substitution can be expected (movement to the intolerable area). If technological or other measures can be applied to reduce the extent of damage to a 'normal' level, nothing now stands in the way of movement to the normal area.

On the other hand, if the disaster potential remains very high despite reduction efforts, the risk lands in the *Damocles* class. From here, too, it can be moved to the normal area through a two-pronged strategy of improving knowledge and reducing disaster potential. If all reduction tools fail, then a fundamental decision is due as to whether the benefit associated with this risk is considered to be so substantial that the high potential for damage is tolerated since the probability of occurrence is low. If the outcome of this decision is negative, the risk moves into the intolerable area.

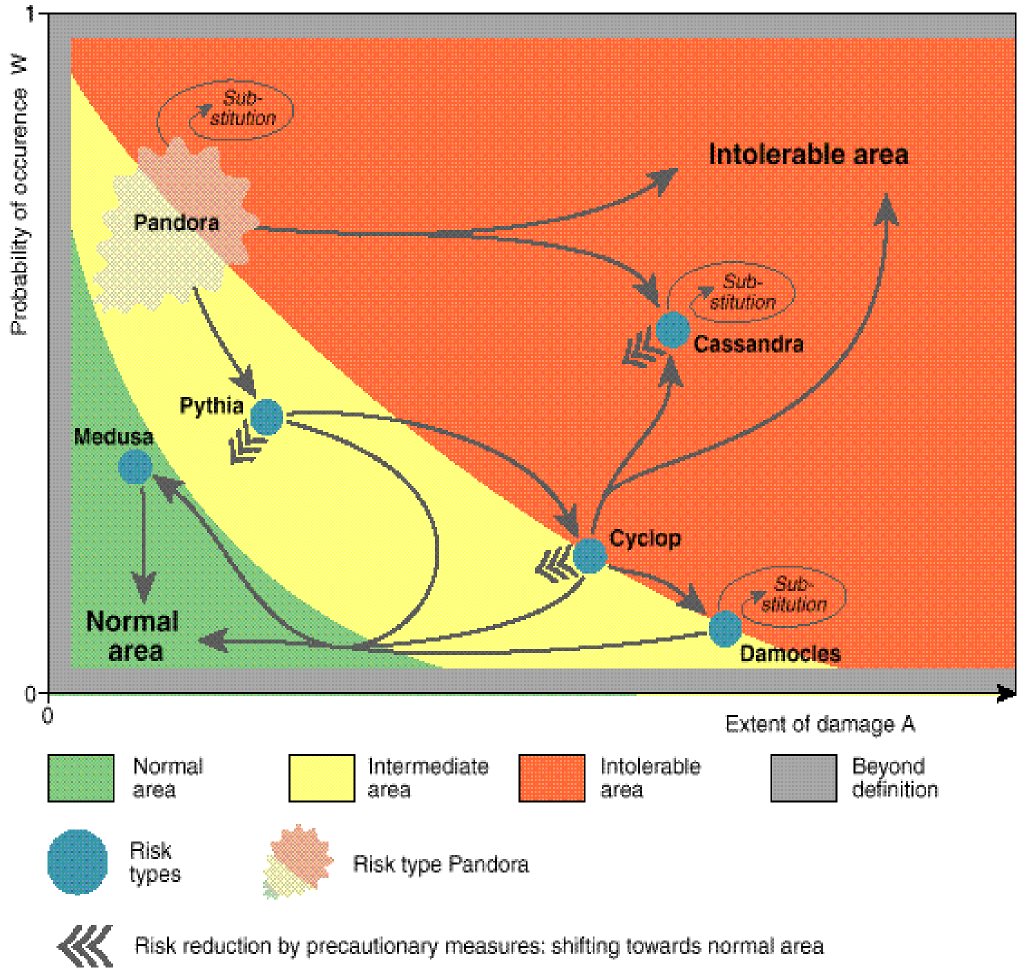

Figure 3: Risk dynamic
Source: WBGU, German Scientific Advisory Council on Global Change (1999)

For all types of risks, the desired movement to the normal area can proceed via the *Medusa* class. Thus, in our fictitious example, the public may have little confidence in the purported reduction of damage potential. By way of illustration, we only need to recall the uproar caused in Germany by the ‘Castor’ nuclear waste transports. Even if the health risk from radiation is assessed as low in terms of both probability and extent of damage – which appears justified considering the isolated cases of radiation dose limits being exceeded – the loss in terms of credibility and reliability is large enough to generate a major political and psychological mobilization effect. Acting on a long history of suffering in public risk debates and their political ramifications, many risk regulators may prefer to opt for a ban, even though both probability and extent of damage indicate a normal risk. In such a case, measures aimed at building confidence and direct participation are necessary in order to make the public aware of the 'normality' of the risk, to give the public more control over regulation activities and, at the same time, to commit technology operators to handle the risk as required by law. In addition, a need always remains to critically review whether the measures instituted have indeed led to the intended risk reduction.

After passing through all these stations, the risk will finally land in the normal area. This cascade movement presupposes intensively tackling the risks to be assessed, and continuously monitoring and scientifically informing the risk reduction measures to be taken. This requires time, institutional provisions and resources. Given the extent of transboundary or global threats, investments in transboundary and international risk management are worthwhile. The analytical framework of risk classes put forward here and the associated dynamic conception of measures offer a logically consistent and politically practicable procedure. This concept can help national governments, the European community and the international community at large to concentrate on those risks that have the potential to emerge as serious threats, while risks in the normal area are adequately addressed by national regulatory structures. Concentrating on essentials is in fact an important message to the public, which, beset by widespread confusion as to the damage potential of risks, expects the policy-makers and the scientific community to deliver orientation and certainty in action. At the same time, the categorization in risk classes and the implementation of class-specific measures can help society and the international community to deal with risks effectively and targettedly, and can instruct risk managers in industry and polity on how to handle risks rationally.

4 Outlook

Today's societies seem to be preoccupied with the notion of risk. The recent examples of BSE, the Brent Spar incident, the anniversary of the infamous Chernobyl accident - just to name a few have gained much attention in the public 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 a lot of confusion about the potential of risk analysis. What is the major lesson to be learned from the review of risk assessment, risk evaluation, and risk management? Risk assessment provides society with a narrow definition of undesirable effects and confines possibilities to numerical probabilities based on relative frequencies. However, this narrowness is a virtue as much as it is a shortcoming. Focused on "real" health effects or ecological damage, risk assessments are based on a societal consensus of undesirability and a (positivistic) methodology that assures equal treatment for all risks under consideration. The price society pays for this methodological rigor is the simplicity of an abstraction that does not take into account differences in culture and social context (Renn 1992).

Looking into the next millennium, it is obvious that risk analysts and managers need to continue their efforts to improve the methodology for risk assessments and to standardize procedures and techniques in order to enhance the spectrum of risk events that they can include in the analysis and to make sure that they are able to understand and use wisely the instruments that have been developed over the last decades. Risk assessments have matured to become a sophisticated and powerful tool in coping with potential harm of human actions or natural events. Its application, however, in risk management is far from reflecting this power and professionalism. In addition to better practical manuals for risk analyses, five major targets for the next decades can be envisioned (cf. Renn 1997):

- widening the scope of effects for using risk assessment, including chronic and psychological diseases (rather than focusing only on fatal diseases such as cancer or heart attack); risks to ecosystem stability (rather than focusing on a single species); and social risks of crime and urbanization;
- addressing risk at a more aggregate and integrated level, such as studying synergistic effects of several agents or constructing a risk profile over a geographic area that encompasses several risk causing facilities;

- studying the variations among different populations, races, and individuals and getting a more adequate picture of the ranges of sensibilities with respect to environmental pollutants, lifestyle factors, stress levels, and impacts of noise;
- integrating risk assessments in a comprehensive technology assessment or problem solving exercise so that the practical values of its information can be phased into the decision making process at the needed time and that its inherent limitations can be compensated through additional methods of data collection and interpretation;
- developing more forgiving technologies that tolerate a large range of human error and provide sufficient time for initiating counteractions.

Talking about risk evaluation and management, the picture becomes more complex. Risk evaluation demands an integration of knowledge and values. The suggestion by the German Scientific Council on Global Change includes a larger set of criteria for evaluating risks than those that have been used before. In addition, the proposal of the Council tries to incorporate the major concerns of people as they have been identified in risk perception studies (Slovic 1987). If all society would care about is to reduce the amount of physical harm done to its members, technical analyses and some form of economic balancing would suffice for effective risk management. The social sciences would only be needed to sell the risk management packages to the ”mis-informed” public via risk communication. However, society is not only concerned about risk minimization. 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 on them or violates their other attitudes and values. Context matters. So does procedure of decision making independent of outcome. ”Real” consequences are always mediated through social interpretation and linked with group values and interests. Responsive risk management needs to take these aspects into account.

The risk evaluation procedure and the deduced risk management strategies that have been proposed by the German Council on Global Environmental Change are the attempt to initiate an analytic-deliberative process (cf. Stern and Fineberg 1996), where rationally defensible criteria of evaluation are used, social values integrated and the results communicated to the public(s). The deliberative process is needed to determine the overall acceptability of the risk and to design the appropriate risk reduction measures. Such a process requires value judgments on at least three levels. The first set of value judgments refer to the list of criteria on which acceptability or tolerability should be judged, the second set of value judgments determine the trade-offs between criteria, and the third set of values should assist in finding resilient strategies for coping with remaining uncertainties. Using informed consent on all three value inputs does not place any doubt on the validity and necessity of applying the best of technical expertise for characterizing and quantifying all risk components, including uncertainties. The magnitude of risks should reflect technical expertise as best as possible, since "real" victims are at stage. Setting priorities within risk management, however, would imply to have 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 compare different options. Public input is hence a crucial contribution for determining the objectives of risk policies and for weighing the various criteria that ought to be applied when evaluating different options (Renn et al. 1993).

For the upcoming years, risk research has still a full agenda. The promises of Prometheus need to be balanced against the potential evils that the opening of Pandora‘s box may entail. This balance is not easy to find as opportunities and risks are emerged in a cloud of uncertainty. The dual nature of risk as a potential for technological progress and as a social threat 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. As much as risk assessment needs to broaden its scope of research targets as well as improve their handling of uncertainty, the social sciences are demanded to inform policy makers about public concerns, develop better methods of mutual communication, and provide models for the type of discourse needed to bring the technical analyses in line with the social and cultural needs of the respective societies. There is no shortage of new problems and challenges in risk research. The remaining gift of Pandora was hope. So we are left with the hope that we will have the professional skills, the demanded creativity and ingenuity, and the energy and ethics necessary to meet the challenges of the risk societies at the beginning of the next millennium.

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