

**ON SCIENCE AND PRECAUTION
IN THE MANAGEMENT OF
TECHNOLOGICAL RISK**

Volume I

A Synthesis Report of case studies

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On Science and Precaution In the Management of Technological Risk

An ESTO Project Report

**Prepared for the
European Commission - JRC
Institute Prospective Technological Studies
Seville**

by

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Prologue

This study co-ordinated by Dr. Stirling shows how greatly our thinking has changed on issues of the management of risks. The use of sophisticated scientific methods in the assessment and then management of risks began with the problems of major industrial hazards, notably those of nuclear power. At first it was believed that quantitative techniques, either of statistics or of modeling, would suffice for the guidance of risk policy and risk management. But as experience accumulated, it became clear that while science is an essential core of the assessment process, it could not be the whole. The supplementary materials have a variety of names, including 'participation' and 'precaution'; and their practical content is still being developed.

Now the hazards we face are more diffuse, and in their own way more threatening. There are concerned publics, capable of acting in a co-ordinated way and directly affecting government policies for the environment and whole industries. We may say that in such issues, facts are uncertain, values in dispute, stakes high and decisions urgent. The traditional peer communities, formerly restricted to qualified experts, are now extended to include citizen participants at many levels.

The management of these new processes present many difficulties. It is to the credit of Dr. Stirling and his colleagues that the problems are analysed to such depth, and that such important and useful practical lessons are drawn. This report can become a valuable contribution to the resolution of an urgent problem.

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EXECUTIVE SUMMARY

Debate over the relative merits of ‘scientific’ and ‘precautionary’ approaches to the management of technological risk can all-too-easily fall into a ‘dichotomy trap’, in which productive and creative ‘solution-oriented’ thinking is hampered by unnecessarily rigid contrasts - with all their associated conflicts. It is true that neither an ‘anything goes’ (totally permissive) approach, nor a ‘stop everything’ (totally restrictive) approach to the regulation of technology offers a valid, feasible or desirable way forward. Fortunately, however, neither the ‘narrow risk-based’ nor the ‘precautionary’ approaches map satisfactorily onto this artificial and sterile dichotomy. To varying extents, existing regulation includes a range of effective checks and balances. It does not necessarily provide for the approval of any technology which may be developed. Likewise, even the most progressive statutory formulations of a Precautionary Principle are circumscribed in their scope and admit a series of incremental instruments. Adoption of a precautionary approach therefore does not mean that no new technological innovation can ever be deployed. Both ‘precautionary’ and ‘scientific’ approaches can be caricatured by stigmatising them in this polarised way. Likewise, both forms of rhetoric are equally vulnerable to manipulation (or even capture) by various parties in order to achieve political or commercial objectives.

Rather than seeing ‘precaution’ as being in tension with ‘science based regulation’, research conducted under this project suggests that key elements of a precautionary approach are entirely consistent with sound scientific practice in responding to intractable problems in risk assessment such as ‘ignorance’ (“we don’t know what we don’t know”) and ‘incommensurability’ (“we have to compare apples and pears”). These intractable problems are well-founded in the fundamental theoretical framework of the sciences underlying risk assessment. With the different assumptions adopted in different risk assessment studies often yielding results that vary by several orders of magnitude, the practical policy implications are equally profound. The acknowledgement of such difficulties under a precautionary approach may thus be seen as a *more* scientifically rigorous way of carrying forward the regulation of technological risk than would be their denial under a purely ‘risk-based’ approach. Recognising the unproductive nature of the science / precaution dichotomy, then, attention can turn to the details of the measured and incremental application of an approach which is both ‘scientific’ and ‘precautionary’ in nature. Here, the Report draws a series of detailed conclusions which fall broadly into three groups.

First, “science should be on tap, not on top”. There can be no simple analytical, instrumental or institutional ‘fixes’ for the complexities encountered in the management of technological risks. Policy making must obviously be based on the available scientific information, but science on its own is not enough. It is documented in this project how scientific risk analysis is unavoidably and inextricably intertwined with subjective framing assumptions, values, trade-offs and expectations of surprise. The appraisal of technological risks should therefore be conducted in an open and pluralistic fashion, allowing for critical discourse as an essential part not only of the regulatory process, but of the appraisal of the technological options themselves. Only in this way can the framing assumptions adopted in risk assessment and the treatment of associated uncertainties and trade-offs be tested and validated against the wider socio-political realities. Here, the developing practice of constructive technology assessment holds a number of useful lessons for the integrating technical and socio-economic factors in the management of risk, as do techniques for accounting for the qualitative strategic properties of different technological options, such as their flexibility, resilience and diversity.

Second, there is a need for flexibility and learning in regulation itself. The management of technological risk is necessarily an incremental and context-specific undertaking. Different technological risks will warrant greater or lesser degrees of precaution at different times and different regulatory instruments will be appropriate in different contexts. Each will hold its own implications for practice, such as conventions over the burden of proof. Attention should be given to the distinguishing of the different crucial (often qualitative) characteristics displayed by different types of risk. This project has gone some way towards mapping some of the key dimensions and the measures which are more or less applicable in different contexts. In addition to the merit of flexibility, a differentiated and incremental approach also offers a way to provide for the open-ended social learning which is an essential quality in the successful management of risk. In addition, systematic attention also needs to be given to institutional and procedural arrangements for ‘early listening’ and ‘technology watch’ .

Third (and as a matter of method rather than process), it is important that we “don’t throw the baby out with the bathwater”. There are a variety of very practical and robust (often quantitative) methods which are entirely consistent with the established procedures of risk assessment and which can be applied under a broader and more pluralistic precautionary approach, taking account of a variety of contending options and their associated benefits as well as their risks. The potential and constraints of these approaches are also examined in this project, including ‘decision’, ‘value tree’, ‘multi-criteria’, ‘scenario’ and ‘sensitivity’ analysis. Likewise, a series of specific discursive

techniques are also available in this regard as a qualitative complement to the established quantitative procedures of risk assessment, including consensus conferences, planning cells, citizen's juries, focus groups and deliberative polls. There is no shortage of practical operational tools for transcending the circumscribed domain of narrow-risk-based regulation and allowing the implementation of an approach to the management of technological risk which is at the same time 'scientific' and 'precautionary'. The Report closes with a review of some 26 quality criteria.

ACKNOWLEDGEMENTS

This synthesis report draws entirely in the first instance on the work of the five participating researchers (Dr Andreas Klinke, Professor Ortwin Renn, Professor Arie Rip, Professor Ahti Salo and Dr Andrew Stirling). The author is grateful for the helpful comments on the draft by his colleagues in the project. The report also owes an enormous and obvious debt to those other researchers whose work is referred to in the bibliography, to participants at the inter-service seminar on this project held at the European Commission and, in particular, to the involvement in oversight of the work by Silvio Funtowicz and Michael Rogers of the European Commission. Other useful comments were made by Topsy Jewell, Gabrielle Kuiper and Paddy Van Zwanenberg. However, the particular scope, emphasis, interpretations and conclusions in this synthesis document are those of the present author as co-ordinator and do not necessarily reflect those of his colleagues or the sponsoring bodies.

PREFACE

The aim of the present research project was to examine, in an open-minded and interdisciplinary fashion, some of the key conceptual issues arising in the application of 'science' and 'precaution' to the management of technological risk and to draw some practical conclusions for policy making. The key guidelines for the work as set out in the Implementation Plan for the project were as follows:

- i) a focus on the operationalisation for policy making of the concepts of 'science based regulation' and 'the precautionary principle';
- ii) an emphasis on innovative and substantive conceptual work rather than descriptive reviews of the *status quo*;
- iii) the illustration of the work with empirical material concerning genetically modified crops, energy technologies and some reference (if appropriate) to chemicals regulation.

Rather than being approached on a sector-by-sector or country-by-country basis, the project was framed explicitly around the exploration of the implications for the chosen topic of understandings developed in four distinctive fields of research, with the aim of constructing a novel interdisciplinary synthesis. The specific selected fields of research and the associated project researchers were as follows:

- a) formal decision analysis and economics (Ahti Salo);
- b) institutional and regulatory policy analysis (Andreas Klinke and Ortwin Renn);
- c) science and technology studies and constructive technology assessment (Arie Rip);
- d) risk assessment and environmental appraisal (Andrew Stirling).

The present Report constitutes a summary and synthesis of the detailed 'Field Studies' conducted by these authors in each of these fields. For the sake of brevity, many points of empirical illustration are omitted from this Report and may be found in the Field Studies and in a Background Report on genetic modification by Renn and Klinke. Likewise, more detailed documentation of the sources is provided in the Field Studies. For convenience, however, the references from all four studies are collected together in the bibliography of this Synthesis Report. A glossary of terms used is also provided at the end of this Report.

It is not possible in a limited project of this sort (amounting to a total of 90 person days among five researchers in four institutes) comprehensively to cover all the pertinent issues, still less to satisfy all perspectives. However, as a complement to the extensive and detailed discussions underway within individual sectors and disciplines it is hoped that the present project may be seen as a useful contribution to the development of practical ways of managing technological risk in a fashion which is at the same time both scientific and precautionary.

1: INTRODUCTION

The New Politics of Risk

According to an influential body of thought in the social sciences, modern industrial civilisation at the end of the Twentieth Century has seen the advent of the 'Risk Society'. Under this view, the abstract concept of risk has become a dominant ordering principle, helping to structure and condition social and institutional relations and, to some extent, replacing monetary wealth and cultural privilege as the focus of distributional tensions and political conflict. Divergent values and interests together with issues of trust, rights and legitimacy in the regulation of risk are beginning to assume at least as much importance as the more traditional scientific and technical connotations.

Despite the theoretical complexities, the practical implications are almost too obvious to spell out: climate change, the ozone hole, urban smog, nuclear waste, pesticides, hormone disrupting chemicals, BSE, Brent Spar, genetically modified food. A host of intractable risks clamour for attention, threading their way in and out of the headlines at a frenetic pace. The issues quickly become polarised. Throughout the industrialised world, public confidence in the competence and intentions of those formally charged with the governance of risk is at a low ebb. Reassurances on the part of government or industry are increasingly coming to be seen as little more than cynical exercises in financial or political damage limitation. There is a danger that public anxieties over each successive 'revelation' of technology-induced threat will compound into a corrosive general attitude of fatalism, disillusion and distrust.

Amidst the social, political and economic tensions, the physical parameters of risk management are truly impressive in their own right. Even if attention is restricted to the energy, chemicals and bio-technologies which form the focus of the present report, the scale of the challenge is formidable. Unless radical reductions are effected in the world-wide dependency on fossil fuels over the next few decades, it is a matter of scientific consensus that we face the potential for changes in global climate of a magnitude not experienced since the end of Ice Age. Yet a wholesale shift to nuclear power would raise daunting challenges of its own, for instance compounding the need for effective management of highly radio-toxic materials for unprecedented spans of time. In the field of chemicals regulation and licensing, the institutions of risk management are faced with some 10 – 15 million substances in commercial use, of which between 50,000 and 100,000 are variously recognised to be of regulatory interest. Testing procedures which are acknowledged to be costly, slow and incomplete are proving inadequate in the face of the hundreds of new chemicals annually entering world markets. And, most recently, the introduction of technologies for the genetic modification of agricultural crops has seen the advent (or intensification) of a variety of concerns ranging from possibilities of irreversible transformations in the genetic composition of established crops, wild plants or microbial life, to the potential fostering of pest resistance, dependence on herbicides, antibiotic resistance and even the creation of new food allergies nutritional effects or toxic reactions. The novelty of the technologies and the diffuse, diverse and dynamic contexts for their application render such concerns extremely difficult to verify or falsify in advance of their manifestation.

With mounting institutional and economic commitments to global technological infrastructures in all these areas, the stakes are high and growing ever higher. Innovation proceeds at an unremitting pace. Once a particular industrial strategy or technological path has been chosen, a host of self-reinforcing mechanisms come into play. The enormous investments of human resources, financial capital and institutional reputation can render technological trajectories – once taken – effectively irreversible. The world-wide experience of nuclear power illustrates the enormous costs to all concerned of (depending on your view) over-ambitious expectations, belated critical questioning or a premature 'loss of nerve' on the part of society as a whole. On the other hand, a failure to seize the initiative and harness the positive creative potential of science and technology can lead to foregone opportunities, economic stagnation and even defeat in the face of the many challenging problems of the modern world.

The question is: what road to take? Whether they result from technological hubris or a post-modern crisis of confidence, mistakes in either direction can be effectively irreversible and extremely costly. There is agreement on all sides of the debate that the more profound and pervasive long term dimensions of technological risk cannot be left to 'the market' alone to resolve. Private enterprise, consumers and public interest groups alike seek consistency, clarity and decisiveness on the part of government (and, increasingly, inter-governmental) regulatory institutions. But how are such qualities to be achieved amidst the messy and intractable complexities and uncertainties of the emerging 'Risk Society'?

It is against this daunting background that the current debate is played out over the respective roles of 'precaution' and 'science' in the regulation of technological risk. Through all the furore, the day to day regulation of technologies

must labour on. The practical business of risk assessment continues to play an essential role in appraisal and one which is not necessarily assisted by the wider social and political overtones of the risk debate. It is the purpose of the present project to explore some of the profound implications for the management of technological risk of contending visions of ‘precaution’ and ‘science’.

2: KEY CONCEPTS

the relationship between science and precaution

The aim of the research reported on here was to examine, in an open-minded and interdisciplinary fashion, some of the key conceptual issues arising in the application of ‘science’ and ‘precaution’ to the practical management of technological risk. As such, the discussion hinges on the relationship between these two crucial concepts.

The nature of ‘science’ has for many years been a relatively familiar and well-explored (though contested) subject. It is the topic of an extensive literature. Particular pertinent aspects of various notions of science are returned to repeatedly throughout this Report, with more detailed background provided in the Field Study by Rip. In short, for the purposes of the present discussion, ‘science’ is conventionally held to imply a series of key properties, including a systematic methodology, scepticism, transparency, quality control by peer-review, professional independence and accountability, and an emphasis on learning. This illustrative set of idealised attributes of science is summarised in Table 1 together with the contrary characteristics.

Table 1: Some Idealised Attributes of Scientific Approaches to the Appraisal of Technological Risk

ATTRIBUTE	DESCRIPTION OF IDEAL	OPPOSITE CHARACTERISTIC
Transparent	All pertinent information and relevant argumentation published.	Opaque
Systematic	Systematic methodologies and repeatable results.	Ad hoc
Sceptical	Intellectual scepticism over knowledge claims.	Credulous
Peer-reviewed	Quality control by extended community of peers.	Doctrinaire
Independent	Independence of methods from personal or parochial interests.	Partisan
Accountable	Institutional procedures for ensuring professional accountability.	Unaccountable
Learning	Understandings open to continuous change in the face of learning.	Impervious to Learning

The formal regulatory concept of ‘precaution’, on the other hand, is a more specific, less familiar and much more recent innovation. The background and particular connotations are reviewed in some detail in the Field Study by Stirling, with a working distinction between the ‘Precautionary Principle’, a ‘precautionary approach’ and ‘precautionary’ set out in the glossary to this Report. General notions of ‘precaution’ have arisen repeatedly in different guises in national and international legislation since the 1972 Stockholm Environment Conference. The concept found its first coherent formal shape in the *Vorsorgeprinzip* enunciated in German environmental policy in the early 1980’s. Since then, the so-called ‘Precautionary Principle’ has been widely adopted in the regulation of marine pollution, climate change, biodiversity loss, dangerous chemicals and the release of genetically modified organisms. One archetypal and globally influential formulation is Principle 15 in the 1992 Rio Declaration on Environment and Development, which holds that:

“Where there are threats of serious irreversible damage, lack of full scientific certainty shall not be used as a reason for postponing cost-effective measures to prevent environmental degradation”.

Discussions over the practical implementation of ‘precaution’ invoke a range of subordinate principles and concepts which are summarised in Table 2. Although disparate in their character and implications, a key common theme in these properties of a ‘precautionary approach’ might be characterised in terms of the ‘breadth of scope’ displayed in the various aspects of appraisal – the range of issues and types of effect taken into account, the accommodation of a

plurality of perspectives and interests, the consideration of a variety of options, the contemplation of a disparate array of alternative possible outcomes and contingencies and the inclusion of benefits within the scope of appraisal.

Table 2: Key Subordinate Principles and Concepts Associated with Precautionary Approaches (after Stirling)

Subordinate Principles	'Prevention'	a duty to prevent rather than to control or treat emissions
	'Polluter Pays'	the placing of burdens on all parties responsible for, or benefiting from, damaging activities
	'No Regrets'	presume in favour of options simultaneously satisfying economic, environmental and wider criteria
	'Clean Production'	adopt only those investment or technology options which are demonstrably of lowest impact
	'Biocentric Ethic'	recognising the intrinsic value of non-human life
Associated Concepts		<ul style="list-style-type: none"> • acknowledge the limitations of science, humility about knowledge and anticipation of surprise • recognise the vulnerability of the natural environment • uphold the rights of those who are adversely affected by technologies • take account of the availability of technical alternatives • consider the complexity of behaviour in real organisations • pay attention to variability of local and other contextual factors • assign equal legitimacy to different value judgements • adopt long-term, holistic and inclusive perspectives in appraisal

As is inevitably the case with any broad principle with such wide-ranging implications in such a heavily contested policy arena, the question of the validity and utility of the Precautionary Principle has become entangled in an intensive and often polarised interplay of divergent socio-political interests and perspectives. This has not always been conducive to measured, focused or constructive discussion. One of the most prominent axes for the emerging debate over the Precautionary Principle concerns a contrast that is often drawn between 'precaution' on the one hand and 'science based regulation' on the other. The implication of this distinction is that the adoption of a 'precautionary' approach might somehow be seen *a priori* as being antithetical to – or at least in tension with – the principles of scientific rigour in the regulation of risk. Under such a view, the implementation of the 'Precautionary Principle' becomes essentially a politically-determined compromise on what are held to be the otherwise clear dictates of the 'sound science' of risk assessment.

It is this perception which offers the starting point for the present project. For it appears at the outset that the debate over the relative merits of science and precaution in the management of technological risk can all-too-easily fall into what Rip describes in his Field Study (in a different context) as a 'dichotomy trap'. While their wider connotations and socio-political implications may well be seen to be in tension, there are strong grounds for holding that the substantive operational content of the concepts of 'science' and 'precaution' are, in fact, entirely consistent and, indeed, (in some senses) mutually reinforcing. At the very least, the imposition of a rigid polarised conception of the relationship between 'science' and 'precaution' risks foreclosing creative and productive thinking.

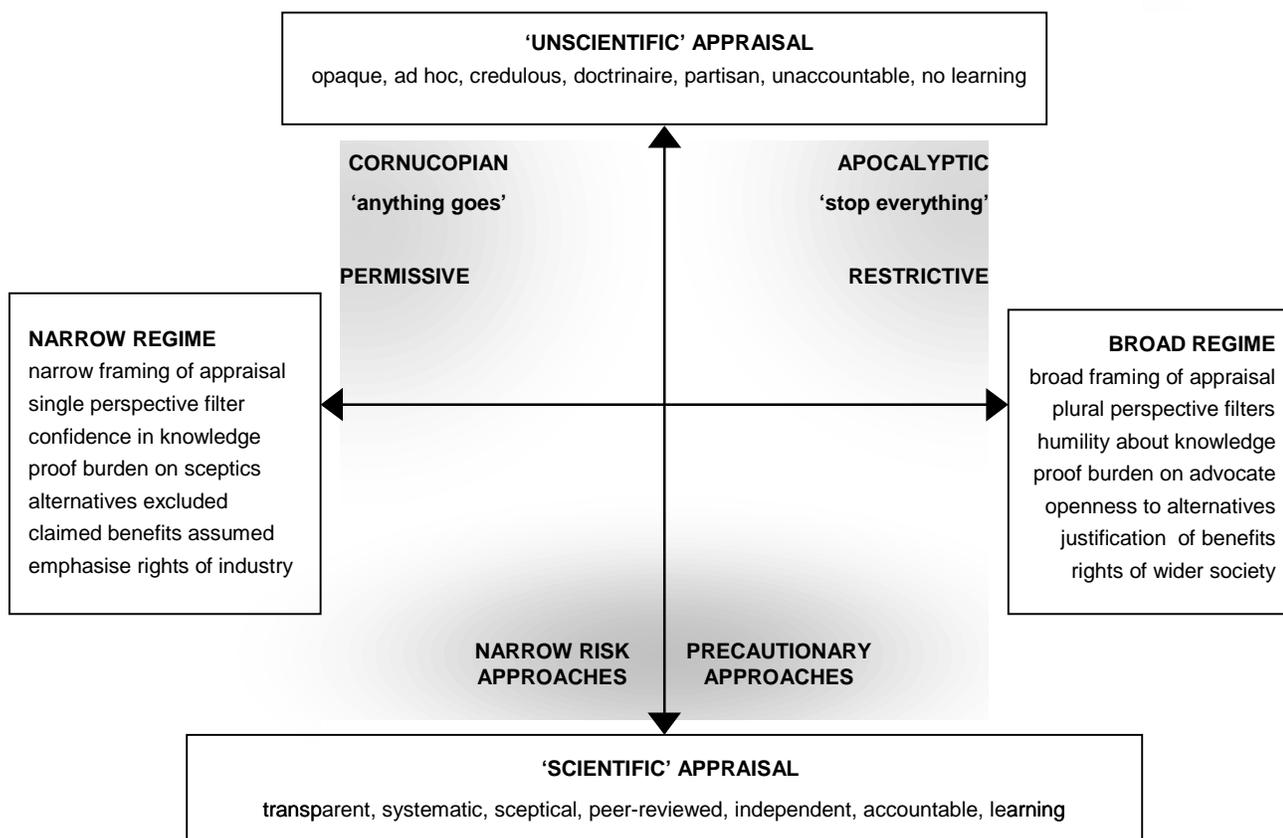
The detailed reasons for scepticism over the polarised opposition of science and precaution form the central theme of this Report. However, based solely on what has thus far been discussed, it seems clear that the simple dichotomy between science and precaution is a false one. In fact, two different distinctions are conventionally rolled together in this idea. On the one hand there is the contrast between relatively '*scientific*' and '*unscientific*' approaches to the understanding of technological risk and to regulatory appraisal itself. On the other hand, there is the choice between adopting relatively '*broad*' or '*narrow*' frameworks for the regulation of technologies on the basis of such understandings and appraisals. To the extent that it is based on the conflation of these two distinct axes, the science / precaution dichotomy might be seen as a straightforward category mistake.

The basic conceptual model underlying this argument is illustrated in Figure 1 below. The properties of 'scientific' approaches and understandings in appraisal displayed in Table 1 are represented on the vertical axis. The contrast between 'broad' and 'narrow' frameworks for acting on scientific understandings and appraisal in the regulation of technology is represented as the horizontal axis in Figure 1, again involving a number of attributes relating to those

summarised in Table 2. Under this dichotomy, a ‘broad’ regime is characterised by a regulatory perspective which takes account of a wide range of different types of impact, including qualitative as well as quantitative issues and including indirect as well as direct effects. Likewise, a ‘broad’ framework upholds a range of different points of view. Taken together, these features increase the number and intensity of the constraints which any technological option must satisfy in order to be approved by the regulatory process, thus making it more difficult to pass through the regulatory ‘filter’. In this sense, the effect may often be one of placing greater restrictions on certain new technologies. Associated with this, there is a culture of humility about the sufficiency and accuracy of existing knowledge which, coupled with the placing of the burden of proof on the proponent of a technology, has the effect of further intensifying the regulatory challenge faced by new technologies. Similarly, there is an openness to considering alternative ways in which the functions of the regulated technology might be fulfilled at lower levels of risk and a requirement for some justification to be made in terms of the benefits associated with the introduction of the technology in question. Finally under a ‘broad’ regime, in deciding on an appropriate balance to strike in the regulation of technological risks, an emphasis is placed on the rights of those who stand potentially to be affected by the technologies in question (referred to in shorthand as ‘victims’). These features may also typically be expected to have the effect of inhibiting the regulatory approval of individual technologies.

Again, the corresponding characteristics of a ‘narrow’ regime for the regulation of technological risk are also displayed on the horizontal axis in Figure 1. Appraisal is tightly framed and embodies only a single perspective. There is a high degree of confidence in the sufficiency of knowledge and the proof burden lies with the sceptic. By excluding consideration of alternatives, it is easier to portray a particular option in a positive light and so gain regulatory approval. Likewise, there is no test of the benefits that are claimed by proponents to be associated with any proposed technology. The emphasis is placed on the rights of an individual industry to innovate and disseminate those technological options which are favoured under its own perspective.

Figure 1: A Model of the Relationships between the Concepts of Risk, Science and Precaution



Of course, both the ‘broad’/‘narrow’ and the ‘scientific’/‘unscientific’ dichotomies drawn here are highly stylised and simplified. However, the shorthand necessarily adopted in making these dual distinctions seems justified in highlighting the deficiencies of the *even more* simplistic one-dimensional distinction between ‘science’ and ‘precaution’. Taken together, the combination of these two dichotomies generates the fourfold array of permutations displayed in Figure 1. The adoption of a ‘narrow’ regime without reference to scientific understandings or disciplines in appraisal might be described as a ‘permissive’ position. Taken to an extreme, this would amount to an entirely uncritical ‘anything goes’ approach to the regulation of technology of the kind associated with caricature ‘cornucopian’ visions of progress. Similarly, a broad-based regime might be similarly unscientific. The resulting ‘restrictive’ position might be associated with a caricature ‘apocalyptic’ vision of progress. In the extreme, it would lead to a situation of paralysis under which no new technological innovation which offends in the slightest respect would ever be approved for deployment. The crucial point is, that neither the ‘permissive’ (cornucopian) nor the ‘restrictive’ (apocalyptic) positions as defined here would be subject to challenge or reversal by the disciplines of scientific discourse associated with the vertical axis.

It is clear that neither the established procedures of risk regulation (based on relatively narrow risk assessment methods) nor the emerging precautionary approach (based on broader perspectives and considerations) actually resemble these stylised ‘permissive’ or ‘restrictive’ caricatures. Existing risk-assessment-based regulation includes a host of effective checks and balances. It certainly does not necessarily provide for the approval of any new technology which may be developed. Likewise, even the most progressive formulations of a ‘Precautionary Principle’ are circumscribed in their scope, admit an incremental series of instruments and allow for regulatory approval under a host of favourable conditions. Both approaches are compatible – at least in principle - with the requirements of systematic methodology, scepticism, transparency, quality control by peer-review, professional independence, accountability, and an emphasis on learning which are held here for the purposes of discussion to be among the key characteristics of science.

On the face of it, then, risk management regimes can be implemented in such a way as to be either relatively ‘narrow’ or ‘broad’ and yet in both instances remain consistent with the attributes of scientific understanding and appraisal as recognised here. This leads to a problem of terminology, in that it would be inaccurate to refer only to the pursuit of a narrowly-based regime under scientific appraisal as being somehow uniquely ‘scientific’. For this reason, the term employed in this Report for this approach to the management of technological risk will, for the purposes of discussion, be the ‘narrow risk-based approach’ or just ‘narrow risk’. This phrase relates to a more detailed discussion of the formal concept of risk which is undertaken later in this Report. For the moment, however, the reference to ‘narrowness’ is supported by the features of narrow framing, reduced perspectives and exclusion of alternatives in appraisal.

Of course, the scheme presented here is based on a highly specific characterisation of some strongly contested concepts. As such, it should be treated simply as a heuristic – a framework for further discussion. For its own part, the present Report will elaborate and substantiate many of the points raised. The purpose here has not been to exclude other understandings of the relationship between science and precaution. Indeed, it is a key theme in the Field Study by Rip (drawing on the sociology of science) that these underlying relationships are the very fabric of negotiation and ‘boundary work’ of the kind which dominates wider discourses over the management of risk. Rip makes the point, for instance, that the notion of ‘science based regulation’ has a particular meaning in the Netherlands – referring simply to a process that *begins* with science. The relationship between scientific and precautionary discourse is also explored further in the Field Study by Renn and Klinke also discussed later in this Report. For the moment, the point is simply that there seems no reason to adopt an *a priori* assumption that science and precaution are somehow opposed, or even – since they lie on a continuum – necessarily in tension. The precise positioning of *particular* ‘narrow risk’ or ‘precautionary’ practices in relation to their scientific status (or otherwise) will depend on the precise characterisation of science. This issue will be returned to later in this Report (Section 6).

It has been the intention in this introductory section to set out the relationships between the key concepts employed in the narrative of this Report. The issues raised here will be further substantiated and elaborated in the ensuing discussion. Drawing on the detailed argumentation advanced in the four Field Studies, attention will now turn to a series of ten organising themes which arise under one or more of the various disciplinary perspectives. These provide a convenient way of combining the different disciplinary perspectives at the same time as developing a coherent argument. For ease of exposition, the ten themes have each been associated with a traditional proverb or saying which expresses the central idea in common sense terms. The themes are as follows:

- i) the multiple dimensions of risk (“it takes all sorts to make a world”)

- ii) narrow notions of risk in a complex world (“accurate and approximate or precise and wrong?”)
- iii) the scientific limits to probability (“knowing your ignorance is the best part of knowledge”)
- iv) subjectivity and interests in the framing of risk science (“science should be on tap, not on top”)
- v) learning, discourse and dissent (“look before you leap” and “learn as you go”)
- vi) constructive approaches to technology assessment (“a stitch in time saves nine”)
- vii) the dynamics of technology (“don’t burn your bridges” or “put your eggs in one basket”)
- viii) systematic procedures and quantitative methods (“don't throw out babies with bathwater”)
- ix) the diversity of technological risk (“horses for courses”)
- x) incremental approaches to precaution (“walk before you run”)

Each of these themes will be taken in turn in the sections that follow.

3: IT TAKES ALL SORTS TO MAKE A WORLD

the multiple dimensions of risk

Technological risk is not a single monolithic quantity. Even under the most reductive of analytical approaches, it is conceded that risk is a function of two variables – the *probability* of an impact and its *magnitude*. However, it is only very rarely the case that an individual technology is seen to present only one form of hazard. Normally, the characterisation of risks associated with any individual technology requires the aggregation of a series of different magnitudes, each corresponding with a particular form of impact. To take the example of GM crops cited in the Field Study by Stirling – and discussed in more detail in a Background Paper by Renn and Klinke – it is clear that the regulatory debate in this area typically encompasses a wide range of disparate issues, including the environment, human health, agricultural practice, economics, social impacts and questions of fundamental ethics. Some of the particular classes of effect which are variously held to be of relevance in the appraisal of the risks of GM technologies in agriculture are set out in Table 3 below.

The conventional analytical response to this breadth and diversity of issues in risk assessment is to adopt a single major yardstick of performance and seek to measure all the various aspects of risk using this as a metric. The chosen unit of measurement in conventional risk assessment is almost always human mortality, although more complex regulatory appraisals sometimes also employ a variety of measures of human morbidity effects. In some areas, the techniques of cost-benefit analysis are employed to varying degrees in order to subject a wider range of impacts to measurement under a common monetary metric. In this way, it is hoped that the multiplicity of magnitudes typically confronted in technological risk may usefully be reduced to a single key factor, thus significantly simplifying the process of appraisal.

Of course, one crucial consequence of this artificial narrowing and conflation of the full diversity of technological risk is effectively to exclude from consideration many classes of effect. For instance, it is clear that only a minority of the types of impact set out in Table 3 above are meaningfully addressed by a mortality or morbidity metric. However, the difficulty with reductions of this sort, seductive as they are, is unfortunately more serious than this. For even with respect to the single issue of human health, the manifestations of different types of technological risk are inherently multi-dimensional in nature. Drawing on one of the longest-established and most elaborate fields for the comparative appraisal of technological risks – that concerned with energy technologies – the Field Study by Stirling identifies a large number of discrete dimensions of risk. These cross-cut the different classes of individual effect (such as those listed – in a different context – in Table 3 above). They apply even in the case where risks are held to be adequately represented exclusively in terms of a single metric such as human mortality or monetary value. These different dimensions of technological risk are set out in Table 4.

Table 3: The Different Aspects of Technological Risk (the example of genetically modified crops)
(after Stirling)

BROAD ISSUE	CLASS OF EFFECT	EXAMPLE
Environment	Biodiversity	<i>eg: field boundary ecology, other environmental risks</i>
	Chemical use	<i>eg: reduction in use of existing herbicide sprays, benefits of contact herbicides versus soil acting residuals, longer term pollution of air and water</i>
	Genetic pollution	<i>eg: gene flow to other crops and native flora</i>
	Wildlife effects	<i>eg: Impact of enhanced weed control efficiency on wildlife, other practices affecting wildlife value of agricultural systems</i>
	Unexpected effects	<i>eg: potential for effects not foresee under this scheme</i>
	Visual	<i>eg: amenity impacts]</i>
	Aesthetics	<i>eg: feelings about environment</i>
Health	Allergenicity	<i>eg: from food consumption</i>
	Toxicity	<i>eg: human or animal health</i>
	Nutrition	<i>eg: to consumers</i>
	Unexpected effects	<i>eg: unexpected interactions between ingredients, stability of genetic insert</i>
	Ability to manage	<i>eg: traceability and ease of recall</i>
Agriculture	Weed control	<i>eg: invasive volunteers and weedy relatives</i>
	Food supply stability	<i>eg: sustainability, tendency to monocultures, global food security</i>
	Agricultural practice	<i>eg: farmers' rights, choice and quality of life, land requirements</i>
Economy	Consumer benefit	<i>eg: retail price</i>
	Producer benefit	<i>eg: shorter term costs, yield or longer term value added</i>
	Benefit to processor	<i>eg: profitability</i>
	Socio-economic impact	<i>eg: welfare of small farmers, substitutions for developing countries</i>
Society	Individual impacts	<i>eg: consumer choice, transparency, accessibility, participation, pluralism</i>
	Institutional impacts	<i>eg: concentration of power, institutional trust, regulatory complexity</i>
	Social needs	<i>eg: opportunities, opportunity costs, misuse of science, employment, quality of life</i>
Ethics	Fundamental principles	<i>eg: animal welfare, taking care of nature</i>
	Knowledge base	<i>eg: hubris about scientific knowledge</i>

The crucial point with regard to many of these dimensions is that, as with many of the different classes of impact (as illustrated in Table 3), they are irreducibly qualitative in nature. Even where some effort at quantification under an individual dimension is felt possible, the resulting values will be *incommensurable* in the sense that they cannot readily or unambiguously be reduced to a single measure of performance. The relative priority attached to the different dimensions of risk is intrinsically a matter of subjective value judgement. These properties of multidimensionality and incommensurability are crucial and intractable features of technological risk.

Table 4: The Multiple Dimensions of Technological Risk (with examples from energy technologies)
(after Stirling)

DIMENSION	ILLUSTRATIVE QUESTION AND PRACTICAL EXAMPLE
Severity	Do the options differ in the ratios of risks of death to risks of injury or disease which they pose? How much illness or how many serious injuries equate in severity with one death? (<i>Eg: offshore wind vs biomass</i>).
Immediacy	Are the effects associated with different options equally immediate in their manifestation or do they differ in the degree of latency between the initial commitment of a burden and the eventual realisation of an effect? For instance, are some risks manifest as injuries and others as disease? (<i>Eg: rooftop solar arrays vs nuclear power</i>).
Gravity	Are the risks associated with some options dominated by low probabilities of large impacts, while those of other options are characterised predominantly as high probabilities of relatively low impacts? To what extent are impacts the result of single or repeated events? (<i>Eg: nuclear vs coal</i>).
Reversibility	Are the effects associated with different options all equally reversible after they have been committed? (<i>Eg: nuclear and fossil fuels vs wind</i>).
Spatial Distribution	Are the effects associated with different options identical in their spatial extents? Is it better that impacts of a given magnitude be geographically concentrated or dispersed? (<i>Eg: wind vs fossil fuels</i>).
Balance of Benefits and Burdens	To what extent is the social distribution of the environmental burdens caused by each option balanced by the distribution of associated benefits? (<i>Eg: distributed vs centralised</i>).
Fairness	To what extent do the distributions of burdens imposed by the different options act to alleviate or compound pre-existing patterns of privilege or social disadvantage? To what extent should exposure to other (unrelated) risk-inducing agents be taken into account in assessing the acceptability of incremental burdens? (<i>Eg: urban waste-to-energy vs domestic PV</i>).
Public or Worker Exposure	To what extent do different options impose different distributions of risks across workers and the general public? (<i>Eg: offshore wind vs oil</i>).
Intergenerational Equity	Do the effects associated with certain options present risks to future generations to a degree not associated with others? What is the appropriate discount rate, if any? (<i>Eg: nuclear and fossil vs renewables</i>).
Human or Non-human	Do the options differ in the degree to which their impacts affect the well-being of humans and non-human organisms? (<i>Eg: biomass vs gas</i>).
Voluntariness	Do the environmental effects of different options vary in the degree to which exposure may be considered to be 'voluntary' prior to the commitment of an impact? (<i>Eg: do-it-yourself home insulation vs centralised coal</i>).
Controllability	Once committed, are the impacts associated with different options all equally controllable from the point of view of the individuals or communities who stand to be affected? Do certain effects require efforts at control which are perceived to pose a threat to democratic institutions or processes? (<i>Eg: nuclear vs wind</i>).
Familiarity	Do the effects associated with different options differ in terms of the degree to which they are familiar to individuals, communities and established social institutions? Do responses to the different effects involve equally disruptive changes to normal routines and attitudes? (<i>Eg: nuclear vs biomass</i>).
Trust	Do options differ in terms of the degree of trust enjoyed in the wider society by the institutions and communities charged with evaluating and managing their associated risks? Does the appraisal of certain options tend to be more a specialised undertaking than that of others? (<i>Eg: nuclear vs biomass</i>).

Some concrete examples might be helpful in elaborating this point. One issue lies in the selection of factors which are to be included in the regulatory appraisal of risk. Should appraisal take account of social, economic, cultural and ethical issues, as well as environmental and health factors? With respect to the more narrowly defined physical factors, to what extent should appraisal seek to address the potential additive, cumulative, synergistic and indirect effects associated with particular technological risks? With how wide an array of potential substitutes should each individual technological or policy option be compared in appraisal? Should attention be confined simply to the *operation* of the options concerned, or should it extend to manufacture, decommissioning and disposal, as well as to the various inputs and associated risks at each stage? Should the relative *benefits* of different options be taken into account in appraisal so that they can be offset against the associated risks?

In an ideal world, the appropriate response to factors such as these is easy to determine. All else being equal, the appraisal of technological risk be as *complete* and as *comprehensive* as possible (in the senses set out in the Field Studies by Salo and Stirling in the present project). Regulatory decision making on technological risk should ideally

be based on consideration of the full range of issues which may reasonably be held to be pertinent and on all aspects of the life cycles and resource chains associated with the various technologies. Appraisal should take account of all relevant additive, cumulative, synergistic and indirect effects as well as the more simple causal relationships. Judgements over the acceptability or justifiability of different risks should be accompanied and informed by consideration of the magnitude of the associated benefits. In the end, decisions over which technology or policy to pursue should be arrived at only after comparing the risks and benefits associated with a range of alternative options, rather than a single option considered in isolation.

However, aspirations to completeness and comprehensiveness concerning the different types of option and classes and dimensions of risk and benefit provide only a rather loose operational guidance in the practical regulation of risk. The crucial decisions will often lie in the interpretation, rather than the adoption, of such principles. In any case, in the real world constraints on budgets, skills, staff, information, computational resources and response times can all-too-often militate against the full realisation of such laudable objectives. In such cases, the reasonable limits to regulatory appraisal are drawn not so much by any abstract prescriptions of scientific rigour or precaution as by the practical realities and constraints of broader policy making.

This may seem serious enough, but the Field Study by Stirling raises one further problem which is even less tractable than the necessarily bounded nature of risk assessment. This concerns the way in which the different aspects of technological risk which *are* included in appraisal are framed and prioritised in analysis. For instance, to what extent should analysis be based on well-documented past empirical data relating to possibly outdated options, superseded practices or irrelevant circumstances or to what extent should it make use of theoretical models of performance based on extrapolations, projections and untested assumptions? How should individual unquantifiable aspects of risk be taken into account? Referring again to Table 4, the Field Study by Stirling highlights the importance of generic risk characteristics which cross-cut the individual effects, including issues such as irreversibility, persistence, gravity, familiarity and trust. Even where they are quantifiable, there is the question of the relative priority that should be attached to the different factors in the aggregation of effects such as toxicity, carcinogenicity, allergenicity, occupational safety, biodiversity or ecological integrity? What relative weight should properly be placed on impacts to different groups, such as workers, children, pregnant and breastfeeding mothers, future generations, disadvantaged communities, foreigners, those who do not benefit from the technology in question or even to animals and plants as beings in their own right?

Even if they were practically feasible, objectives such as completeness or comprehensiveness do not assist in addressing issues of framing and prioritisation of this kind. No one set of assumptions or priorities may be claimed to be uniquely rational, complete or comprehensive. It is here that we come to a classic and well-explored dilemma in the field of social choice theory. In reviewing an extensive literature in this regard, the Field Study by Stirling introduces a particularly important point which is frequently forgotten in considering the role of science in risk assessment. For it remains the case that the disciplines of risk assessment, economics and decision analysis have developed no single definitive way of addressing the problems of multidimensionality and incommensurability discussed here. Even the most optimistic of proponents of rational choice theory acknowledge that there is no effective way to compare (or aggregate) utility across individuals or different groups in society. Indeed, even where social choices are addressed simply in ordinal (or relative) terms, the economist Arrow went a long way towards earning his Nobel Prize for demonstrating formally that it is *impossible* definitively to aggregate preferences in a plural society.

The implications of these problems for notions of ‘sound science’ and ‘science based regulation’ in the management of technological risk are picked up in a later section of this report. For the moment, the point is simply that “it takes all sorts to make a world”. Different cultural groups, political constituencies or economic interests typically attach different degrees of importance to the different aspects of technological risk. Within the bounds defined by the domain of plural social discourse, no one set of values can definitively be ruled more ‘rational’ or ‘well informed’ than any other. Even were there to be complete certainty in the quantification of all the various classes and dimensions of risk, it is entirely reasonable that fundamentally different conclusions over technological risk might be drawn under different – but equally legitimate – perspectives. *There can be no analytical fix for the problems encountered in the social appraisal of risk.* Whether seen in terms of ‘science’ or ‘precaution’, this is a fundamental feature of the management of technological risk which must be explicitly addressed in appraisal procedures and regulatory policy alike.

4: ACCURATE AND APPROXIMATE OR PRECISE AND WRONG?

narrow notions of risk in a complex world

The typical practical response to these problems of multi-dimensionality and incommensurability of technological risk on the part of regulatory authorities is (as with the different classes of impact) to reduce and simplify – focussing on those aspects which are held to be most tractable. Drawing on a wide literature documenting regulatory practice in a number of industrialised countries, such as Germany, the Netherlands, Switzerland and the USA, the Field Study by Renn and Klinken shows how the multiplicity of qualitative dimensions in the appraisal of technological risk is typically reduced to a set of eight major ‘criteria’ as set out in Table 5. In reviewing an impressive range of different technological risks, Renn and Klinken argue that many of these different criteria can in practice often be seen to be quite strongly correlated, in many cases allowing the practical further reduction in the perceived dimensionality of risk to the first three criteria: probability, magnitude and ‘uncertainty’. The resulting approach and associated insights are discussed in more detail later in this report (Section 11).

Table 5: Some Criteria Typically Used in the Regulatory Appraisal of Risk (after Renn and Klinken)

CRITERION	DESCRIPTION
Probability of occurrence	ranging from zero (impossible) to one (certain)
Magnitude of damage	ranging from zero to infinite damage
Certainty of assessment	ranging from small to large confidence intervals on probabilities and magnitudes
Ubiquity	ranging from localised to global extent
Persistence	ranging from short to long term duration
Reversibility	ranging from low to high potential for restoration of damage
Delay effect	ranging from low to high latency between initial event and occurrence of damage
Mobilization potential	ranging from zero to high political sensitivity

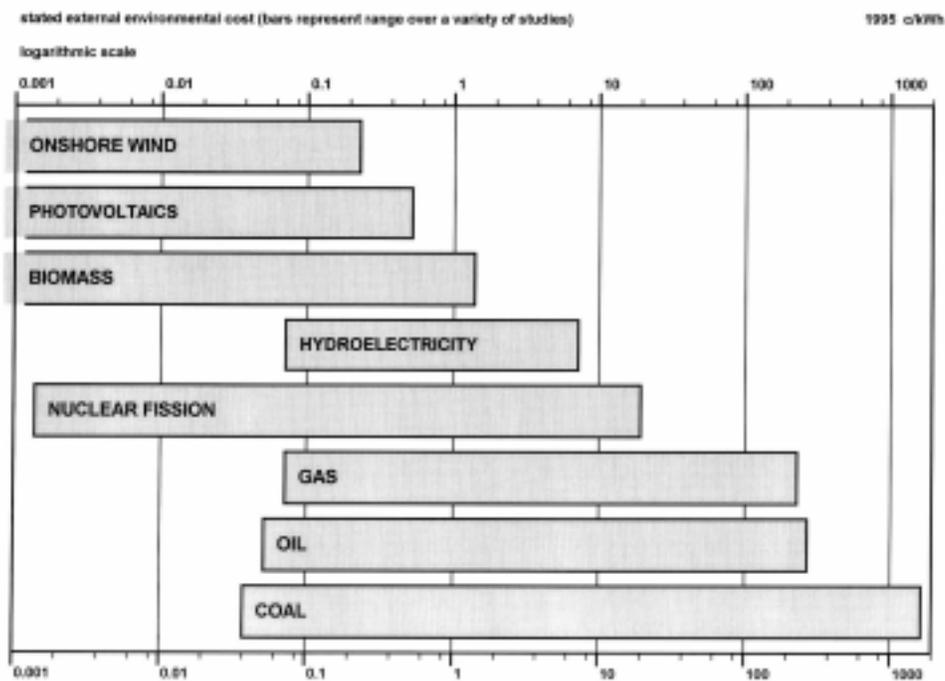
For the moment, however, it must be acknowledged that even an eightfold scheme of criteria such as that displayed in Table 5 above effectively omits or conflates many of the fourteen or so dimensions of technological risk addressed in Table 4 in the previous section of this report. When taken together with the realisation that different cultural groups, political constituencies or economic interests will typically attach different importance to the different forms and dimensions of risk, the result might be expected to be the introduction of a certain degree of volatility into the business of risk assessment. The apparent riskiness of different options might be expected to vary quite radically, depending on the priorities attached to the ‘hidden variables’ during the process of appraisal.

Looking in some detail at the particular case of energy technologies – one of the most mature and sophisticated fields of application for the techniques of comparative risk assessment – the Field Study by Stirling documents exactly this kind of volatility. Although individual studies are typically highly precise in their derivation of risk values for individual technologies and draw strongly prescriptive conclusions concerning the relative ordering of the different options, the picture yielded by the literature as a whole is seen to display a rather extreme degree of variability and ambiguity. Figure 2 displays the values obtained over a number of years by industry and government-sponsored studies in industrialised countries of the risks and environmental impacts associated with modern coal-fired electricity generating technologies (expressed as monetary ‘external costs’ in constant US currency terms).

than four hundredths of a cent per kilowatt-hour. The difference is more than four orders of magnitude – a factor of more than fifty thousand!

When attention turns to a comparison of the results obtained for a range of different electricity supply options, the Field Study by Stirling finds that the picture is similarly ambiguous. Figure 3 displays the risks associated with eight key energy technologies, again expressed as monetary ‘externality’ values drawn from the same thirty two studies represented in Figure 2. The lowest values obtained for the worst ranking option (coal) are lower than the highest values obtained for the apparently best ranking options (wind). Since individual studies show results at the high end of the overall range for some options but lower in the distributions for others, the overall picture yielded by the literature as a whole would accommodate virtually any conceivable ranking order for these eight options!

Figure 3: Ambiguity of Ordering in Technological Risk Assessments (an example from energy technologies)
(after Stirling)



Stirling argues that this picture of variability and ambiguity arising in the appraisal of energy technologies is broadly reproduced in other areas of technological risk (such as toxic chemicals and GM crops) and under metrics other than monetary value (such as mortality or morbidity measures). Closer examination of the literature to find the reasons for this kind of discrepancy reveals that the problem does not tend to be driven by any single factor in analysis, nor is it a simple matter of some studies being more ‘accurate’ or ‘reasonable’ than others in any definitive sense. The manifest variability in results and ambiguity in rankings is rather a simple reflection of the issue raised in the previous section – the adoption of different (but equally scientifically valid) assumptions and priorities concerning the multitude of different dimensions of risk. In addition to the dimensions already set out in Table 4, the key methodological variables which lie behind the evident inconsistencies between risk assessment studies are summarised in Table 6.

Taken together with the foregoing acknowledgement that “it takes all sorts to make a world”, the evident disjuncture between precision and accuracy in risk assessment paints a rather negative picture of the practical utility of quantitative, uni-dimensional, analytical approaches to regulatory appraisal, such as risk assessment. One of the first and most basic tasks in the management of technological risks is to construct some robust overall notion of the relative merits of the different options under consideration from the point of view of society as a whole. Where this cannot be achieved in any absolute sense, then the value of appraisal lies in exposing the relationships between

different assumptions in analysis and the associated pictures of the relative importance of different options. Since many of the incommensurable dimensions of variability discussed here (and shown in Tables 4 and 6) typically remain implicit in risk assessment, serious questions must be raised over whether the associated results – no matter how precisely expressed – are of any practical policy use at all.

Table 6: A Set of Methodological Variables Influencing Variability and Ambiguity in Risk Assessment
(after Stirling)

VARIABLE	ILLUSTRATIVE QUESTION AND PRACTICAL EXAMPLE
Quantifiability	Are the effects associated with different options all equally quantifiable? How has appraisal avoided a disproportionate emphasis on the more quantifiable aspects - and thus an overemphasis of the impacts of the associated options? (<i>Eg: acid emissions vs aesthetic landscape impacts</i>).
Coherence	How coherent is the classificatory scheme adopted in any particular study with respect to the full range of environmental effects? Are there gaps or overlaps between the different classes of effect which are recognised for the purposes of analysis? (<i>Eg: emissions, burdens, or effects</i>).
Trajectories	How long a historic data series is appropriate as a basis for the appraisal of current options? How robust are assumptions concerning the likely future behaviour of those at risk? Are different options on different 'learning curves' in terms of the potential for future improvements in performance? (<i>Eg: radioactive waste, photovoltaics</i>).
System Boundaries	How systematically does analysis address the resource chains and facility life cycles associated with the different options? How far back into the wider economy should analysis regress in assessing energy and material inputs? (<i>Eg: material and energy inputs to renewable capital equipment, overseas uranium mining for nuclear</i>).
Articulation	How are the results of analysis to be articulated with wider considerations and the subsequent decision making process. At what point does the domain of analysis end and that of politics begin? (<i>Eg: claims to 'real', 'true' or 'full' status?</i>).

The practical conclusions both for 'scientific' and 'precautionary' approaches seem clear. The theoretical impossibility of the 'analytical fix' is borne out in practice. The appraisal of technological risk is evidently as much about systematic qualitative exploration of the consequences of divergent social values as it is about precise numerical characterisations of the physical impacts of the technologies themselves. It is better to be *roughly accurate* in this task of mapping the social and methodological context-dependencies, than it is to be *precisely wrong* in spurious aspirations to a one-dimensional quantitative expression of technological risk.

5: KNOWING YOUR IGNORANCE IS THE BEST PART OF KNOWLEDGE

the limits to probability

Before turning to more positive themes, there is one further fundamental difficulty in the 'narrow risk' approach to the management of technology which has been explored in detail in this project and which should be considered in this Report. It has already been shown how risk is conventionally regarded to comprise the two basic elements of probabilities and magnitudes. The problems of multidimensionality and incommensurability discussed so far reside with the 'magnitude' component of risk. It is with the concept of 'probability', on the other hand, that we invoke the problems of uncertainty and ignorance. These themes are discussed in some detail in the Field Studies by Salo and Stirling.

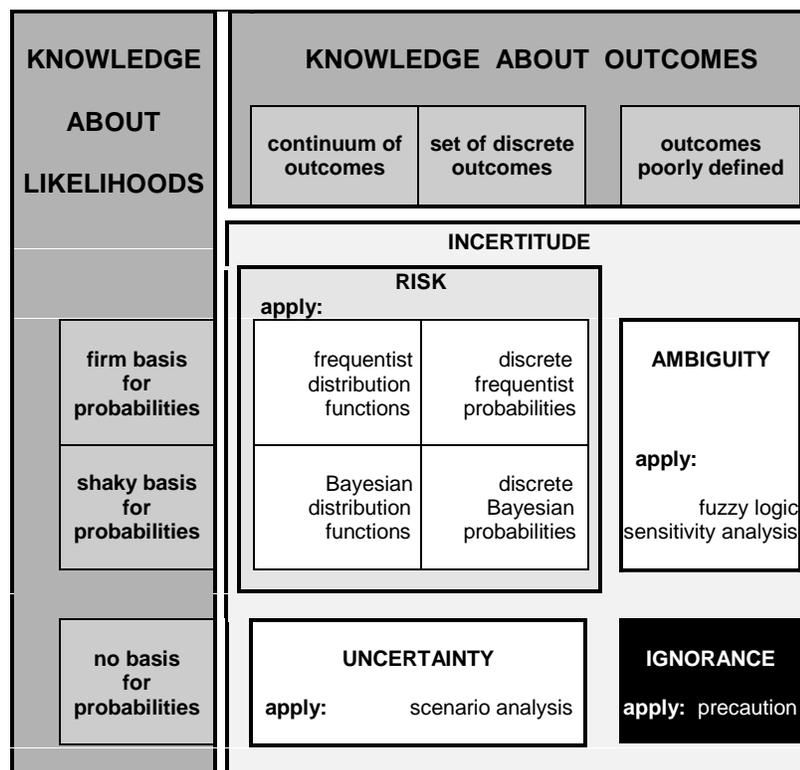
In economics and decision analysis, the well-established formal definition of *risk* is that it is a condition under which it is possible both to define a comprehensive set of all possible outcomes *and* to resolve a discrete set of probabilities (or a density function) across this array of outcomes. This is the domain under which the various probabilistic techniques of risk assessment are applicable, permitting (in theory) the full characterisation and ordering of the different options under appraisal. There are a host of details relating to this picture (such as those hinging on the

distinction between ‘frequentist’ and ‘Bayesian’ understandings of probability), which are discussed further in the Stirling Field Study but these are irrelevant for present purposes.

The strict sense of the term *uncertainty*, by contrast, applies to a condition under which there is confidence in the completeness of the defined set of outcomes, but where there is acknowledged to exist no valid theoretical or empirical basis for the assigning of probabilities to these outcomes. Here, the analytical armoury is less well-developed, with the various sorts of scenario analysis being the best that can usually be managed.. Whilst the different options under appraisal may still be broadly characterised, they cannot be ranked even in relative terms without some knowledge of the relative likelihoods of the different outcomes.

Finally, there is the condition of *ignorance*. This applies in circumstances where there not only exists no basis for the assigning of probabilities (as under uncertainty), but where the definition of a complete set of outcomes is also problematic. In short, it is an acknowledgement of the possibility of surprises. Here, it is not only impossible to rank the options but even their full characterisation is difficult. Under a state of ignorance (in this strict sense), it is always possible that there are effects (outcomes) which have been entirely excluded from consideration. These formal definitions for the concepts of risk, uncertainty and ignorance are illustrated schematically in Figure 4.

Figure 4: The Concepts of ‘Incertitude’, ‘Risk’, ‘Uncertainty’ and ‘Ignorance’ (after Stirling)



In order to avoid confusion between the strict definition of the term uncertainty as used here, and the looser colloquial usage, the Field Study by Stirling introduces the term ‘incertitude’ to apply in a broad overarching sense to the conditions of risk, uncertainty and ignorance (as well as a fourth category of ‘ambiguity’ which is not so relevant here, but whose definition is also illustrated in Figure 4). Drawing on a wide literature, the Field Study by Salo, resolves three broad dimensions cross-cutting all these forms of incertitude which are confronted in the management of technological risk.. These concern:

- i) the scientific knowledge on which risk assessment/analysis depends,
- ii) the stakeholders’ value judgements about the impacts engendered by new technology, and
- iii) the scope and efficacy of the policy measures which may be adopted to control and monitor technology.

Under each of these dimensions, a series of different sources of uncertainty and ignorance are documented by Salo and summarised (with some additions) in Table 7 below.

Table 7: Some Sources of Uncertainty and Ignorance in the Appraisal of Technological Risk (after Salo)

Physical Causation	Causes	<ul style="list-style-type: none"> • What particular characteristics of the technology are potentially harmful?
	Consequences	<ul style="list-style-type: none"> • What harmful effects is can the introduction of technology have?
	Causation	<ul style="list-style-type: none"> • What causal relationships govern the emergence of harmful consequences?
	Conditions	<ul style="list-style-type: none"> • Under what specific external circumstances may harmful consequences arise?
	Detection	<ul style="list-style-type: none"> • What means are available for detecting and monitoring the harms?
	Time of manifestation	<ul style="list-style-type: none"> • When might the harm come about?
Value Concerns	Stakeholders	<ul style="list-style-type: none"> • Who are the stakeholders that may be affected by the harm?
	Communication	<ul style="list-style-type: none"> • Do the stakeholders have sufficient, impartial and intelligible information about the technology? Can they interact with each other?
	Preferences	<ul style="list-style-type: none"> • Do the stakeholders have stable preferences that they can explicate?
	Representation	<ul style="list-style-type: none"> • What deficiencies are associated with the mechanisms of representation through which the stakeholders' views are brought into the regulatory discourse?
Policy Response	Practice	<ul style="list-style-type: none"> • Can we be confident that the operation of technology conforms with assumed practice?
	Measures	<ul style="list-style-type: none"> • What policy measures could be instituted to counter any harm?
	Effectiveness	<ul style="list-style-type: none"> • How effective are these measures?
	Cost	<ul style="list-style-type: none"> • What budgetary, social and general opportunity costs are incurred by regulation?

By reference to the regulation of energy technologies, toxic chemicals and genetically modified organisms, the Field Study by Stirling reviews a variety of practical examples of situations in the regulatory appraisal of technology which are dominated by the conditions of uncertainty and ignorance rather than risk. Indeed, the imponderables associated with global climate models, the sheer number of chemicals and the unpredictability of their behaviour in the environment and the unprecedented nature of genetic modification technology are all such as to render ignorance and uncertainty (in their formal senses) the dominant conditions in the management of each of these types of risk. Other examples from the field of technological risk are too numerous to mention.

The curious thing is, that these and other sources of intractable uncertainty and ignorance are routinely treated in the regulatory appraisal of technology by using the probabilistic techniques of risk assessment. Given the manifest inapplicability of probabilistic techniques under uncertainty and ignorance, this is a quite remarkable phenomenon. On the basis of a review of a wide literature on decision-making under incertitude, the Field Study by Stirling observes that the seductive appeal of the elegance and facility of probabilistic calculus can easily overwhelm measured judgements as to its efficacy. For all this, the continued treatment of ignorance and uncertainty as if they were mere risk provides an example of the kind of “pretence at knowledge” lamented by the economist Hayek in his Nobel acceptance speech. Either way, it is the highly circumscribed practical applicability of probabilistic techniques which forms part of the basis for the use of the term ‘narrow risk’ introduced in Section 2 of this Study.

The literature on the sociology of science has repeatedly documented a similar phenomenon to this ‘pretence at knowledge’ in considerable detail in a number of fields other than risk assessment and goes some way towards a general explanation. Here (drawing on the work of MacKenzie), the Field Study by Rip introduces the concept of the ‘trough of uncertainty’. This refers to the observed tendency for the acknowledgement of ignorance and uncertainty to diminish in the intermediate domain between the forefront of research activity and its broader public dissemination. And it is precisely in this region of intermediate proximity to the knowledge production process itself, that a body of knowledge tends to be most intensively employed as a basis for action. This is certainly the case in the use of sciences such as climatology, toxicology, genetics or ecology in the regulatory appraisal of technology. In other words, it is precisely where the stakes are highest that the uncertainties (and ignorance) tend to most strongly understated.

As is noted in three of the Field Studies, similar observations underlie a series of other important themes in the study of scientific uncertainty, including Funtowicz and Ravetz’s recent influential notion of ‘post-normal science’ and the seminal preceding concept of ‘trans-science’ introduced thirty years ago by Weinberg. All these bodies of work

share a common insight. It is in the recognition, characterisation and articulation of incertitude that the interplay of science, interests and values becomes most intense. The dilemma is, of course, that those who through their expertise are most in a position to document and explicate the sources of ignorance associated with a particular body of knowledge are often those who are subject to the most pronounced interests in the use of this knowledge as a basis for action. Nowhere is this more true than in the appraisal of technological risk. Though they may be explicable in sociological terms, the systematic understating of incertitude and the ‘pretence at knowledge’ associated with Rip’s ‘trough of uncertainty’ are of quite profound importance in considering the practical relationships between science and precaution in the management of technological risk.

For the purposes of the present study, however, the implications are clear. Stirling points out in his Field Study that judgements concerning the extent to which “we don’t know what we don’t know”, no matter how well informed, are ultimately unavoidably subjective and value laden. This would continue to be true, even in cases where the multiple aspects and dimensions were held to be compressible into a single metric. In a fashion similar to incommensurability, then, it seems that here again with the problem of ignorance, we encounter a rationale for a more inclusive approach to the appraisal of technological risk. It is by harnessing the imagination and intuition about different possibilities engendered by the inclusion of disparate perspectives, for instance, that the condition of ignorance can systematically be converted into uncertainty. This cannot be achieved by a process which systematically understates the property of ignorance. It is here that the wisdom of the Chinese philosopher Lao Tzu becomes highly pertinent. When he wrote that “knowing one’s ignorance is the greater part of knowledge” he crafted an injunction which, as well as being both ‘scientific’ and ‘precautionary’ in sentiment, carries a profoundly important message for the management of technological risk.

6: SCIENCE SHOULD BE ON TAP, NOT ON TOP

subjectivity and interests in the framing of science

The account presented in this Report thus far may seem somewhat pessimistic – even despairing – in relation to the role of science in the management of technological risk. The Conservative British Prime Minister Winston Churchill, by contrast, was famous for his bullish attitudes. He was hardly the paradigm example of what have later in some quarters come to be seen as post-modern anxieties over risk. And yet it is to a remark of Churchill’s that a central theme of this study can be linked: “science should be on tap not on top”. For – in different ways – this is a key conclusion of each of the Field Studies on which this report is based.

On the face of it, this sentiment seems to run directly counter to the widespread advocacy of ‘sound science’ as a basis for the regulation of risk. However, it is a central finding of this project that, whether viewed from the point of view of policy analysis, science and technology studies, decision analysis or risk assessment, notions of a unitary definitive concept of ‘sound science’ are highly problematic. In situations where different bodies of scientific evidence, alternative theoretical paradigms or different disciplinary perspectives appear to be in tension, it is often far from clear what criteria are to be employed in determining the practical substance of ‘sound science’. As is discussed in particular in the Field Study by Rip, institutional procedures for verification, validation and learning have long been the object of close scrutiny in the history, philosophy and social studies of science. What emerges throughout the field as a whole – encompassing areas far removed from the sciences of risk assessment – is that the quality of ‘soundness’ in science is highly ambiguous, context dependent and value laden. Indeed, where appeals to ‘sound science’ remain unsubstantiated by explicit criteria for what precisely is meant by ‘soundness’, they often amount to little more than rhetorical strategies. In short, there exist so many alternative ways of conceiving of ‘sound science’ and of the appropriate ways by which to achieve it in any given context, that it becomes extremely difficult to render the concept operational in any practical fashion.

Given the polarisation and strength of feeling so often encountered in discussions over the role of science in the regulation of risk, it is important to be clear from the outset about what is *not* being argued here. The argument is *not* that “nothing is more true than anything else”. Put simply, the implication is rather that “a number of things may be equally true” in the appraisal of risk. It is, of course, uncontentious that policy making, regulation and the day-to-day management of technological risk must be informed by all the available empirical evidence and should be consistent with prevailing scientific understandings. However, this does not mean that science on its own should be assumed to *determine* particular regulatory or policy responses. In fact, in the terms discussed in the Field Study by Rip, the key

finding arising in the field of science and technology studies is that science in itself manifestly *under-determines* social action. It is only rarely the case that a single particular prescription emerges naturally and uncontroversially from even the most robust and specific of scientific understandings. Interpretations of scientific knowledge and applications of scientific information are subject to a multitude of exogenous, subjective and often conflicting influences. In this way, not only the notion of ‘sound science’, but also the concept of ‘science-based regulation’ become quite ambiguous. Science can only ever provide one part of the basis for the regulation of technological risk. Science is a necessary, but not sufficient, condition for effective risk management.

The argument to this point tends to be quite widely acknowledged as an *external* critique of some of the narrower ‘scientific’ notions of technological risk. What is less well-recognised, however, is the irony that (even were the concepts of ‘sound science’ and ‘science based regulation’ to be unproblematic and uncontroversial) they are in their own terms quite profoundly mutually contradictory. The preceding sections of this Report have documented the multidimensionality of risk, the formal impossibility of definitive aggregations of diverse perspectives in a plural society and the limits to the applicability of probability in the face of the conditions of strict uncertainty and ignorance. Each of these points relates to matters of fundamental theory which underlie the science of risk assessment. They are intrinsic features of the utilitarian and probabilistic paradigms on which all conventional notions of ‘sound science’ in risk assessment tend to be based. In the formal theoretical terms of the sciences most central to risk assessment, then, the insufficiency of science emerges as a result of the science itself!

The implications are clear. Decisions over the framing and scope of appraisal, the relative priority to assign to different factors, the comparative likelihoods of many different possibilities and the weighting to place on ignorance and surprise are all matters on which the sciences of risk assessment are *intrinsically* unable to provide definitive answers. It is in these terms that it might be seen as a matter of ‘sound science’ (as well as ‘common sense’) that regulation cannot exclusively be based on science – hence the contradiction between the notions of ‘sound science’ and ‘science based regulation’ mentioned above. The conclusion is thus reinforced that science can only ever provide one (albeit crucial) element in the management of technological risk. There can be no ‘analytical fix’ for the complexities, ambiguities and contradictions encountered in the social appraisal of risk.

It is in this light that Churchill’s adage that “science should be on tap, not on top” might be seen, not as a nihilistic counsel of despair, but as an endorsement of the importance of paying greater attention to the role of subjective values, plural rationalities and divergent interests in the framing of the science of risk assessment. In the remainder of this report, much more will be said about the ways in which this might be achieved. The Field Study by Klinke and Renn and that by Rip, in particular, focus on matters of social learning and social discourse on risk. The studies by Stirling and Salo point to a variety of specific techniques. For the moment, the crucial point is that the under-determining and insufficient nature of science in risk assessment together provide a robust rationale for developing inclusive procedures for participatory deliberation over the management of technological risk.

Arguments for greater public involvement in risk regulation are frequently heard from the point of view of democratic ethics, institutional legitimacy, due process and even practical expediency in the achieving of public acceptance and trust. The emerging argument for greater inclusiveness in appraisal is rather different. In acknowledging that the problems of scope, incommensurability and ignorance in risk assessment are otherwise intractable, active stakeholder engagement in the appraisal process becomes a matter of *analytical rigour*. For without systematic reference to the values, priorities and scope displayed in wider discourse, how can the crucial framing assumptions adopted in appraisal be validated?

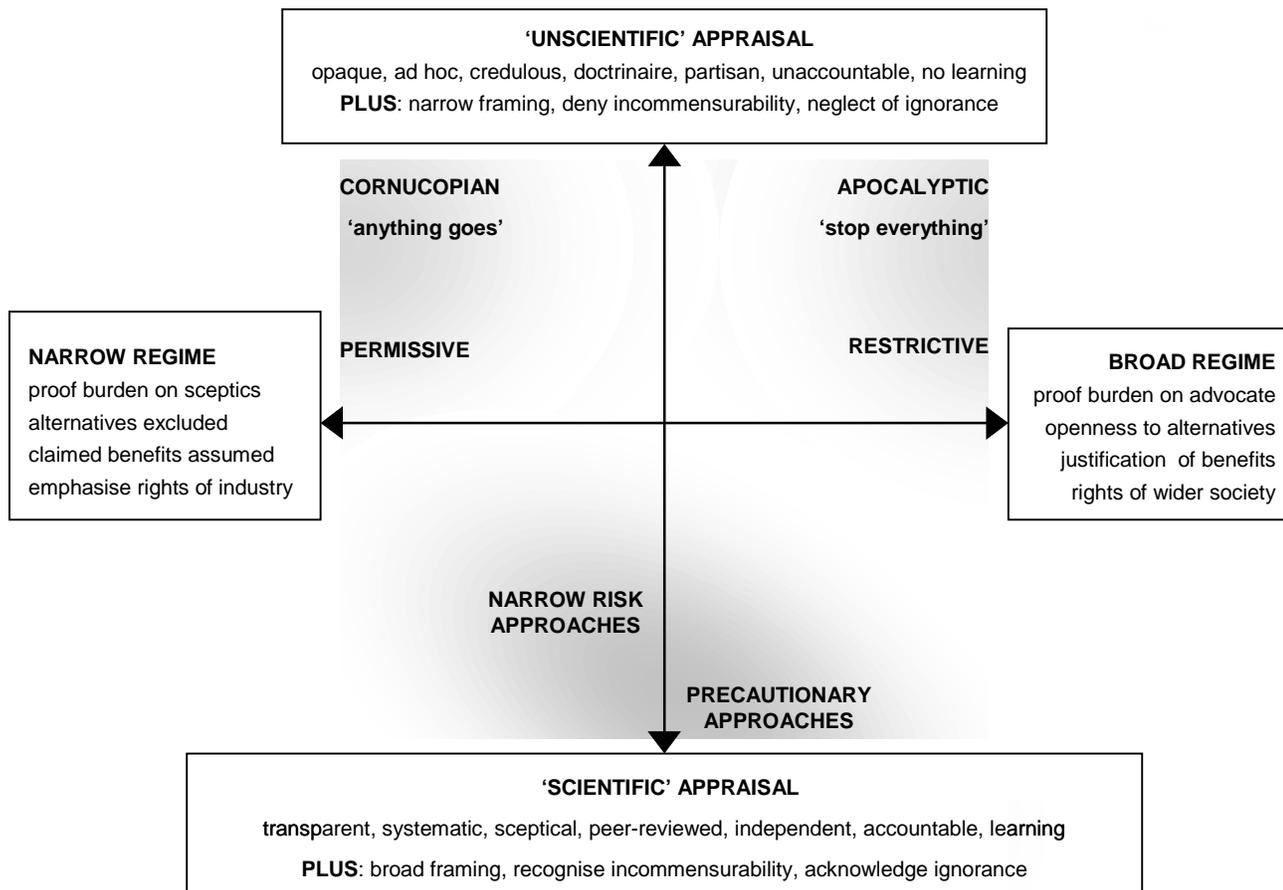
At this point, it might be useful to return to the model of the relationship between ‘narrow risk’ and ‘precautionary’ approaches to risk management introduced at the beginning of this Report (Figure 1). In defining the concept of ‘science’ for the purposes of that discussion, it was made clear that a deliberately minimal set of properties were selected from a much wider set of possibilities extant in the literature. The particular features of science identified there for the purposes of initial discussion were systematic methodology, scepticism, transparency, quality control by peer-review, professional independence and accountability, and an emphasis on learning. Questions over the scope of appraisal, the plurality of perspectives taken into account and the degree of confidence placed in the available knowledge were all addressed in that discussion as features, not of science, but of the ‘breadth’ of the regulatory regime taken as a whole.

In the light of the preceding discussion, however, this picture might usefully be reviewed. It has been argued that recognition of the fundamental status of multidimensionality, incommensurability, impossibility and ignorance in risk assessment contributes to a ‘scientific’ rationale for greater pluralism, breadth of framing and humility about knowledge. If this is accepted, then these three properties might more appropriately be seen as aspects of the application of *science* to the management of technological risk, than as features of the wider regulatory regime.

Accordingly, Figure 5 provides a reinterpretation of Figure 1, with the axes reconfigured to take account of this alternative conception of three of the key characteristics of science in the management of technological risk. The implications are clear. Whereas under the narrow conception of science in Figure 1, the ‘scientific’ status of ‘narrow risk’ and ‘precautionary’ approaches were seen to be broadly similar, under the extended notion of risk science in Figure 5 an asymmetry is introduced. The effect of changing ‘breadth of framing’, ‘recognition of incommensurability’ and ‘acknowledgement of ignorance’ from being features of a broad regime to features of scientific understanding is effectively to rotate the vertical axis in Figure 1 towards the domain of the precautionary approach. As a result, it becomes evident that – under the broader view of risk science articulated here – a precautionary approach displaying these three features might arguably be seen to be *more* scientific than the traditional ‘narrow risk’ approach.

None of this changes the conclusions drawn above concerning the overall insufficiency and under-determining nature of science in risk assessment. Many crucial factors (such those addressed on the horizontal axis in Figure 5) remain external to science even in this broader sense and yet crucial to the business of technology management. As has been emphasised repeatedly, the particular characteristics identified in risk science will remain – like the results of risk assessment itself – conditioned by exogenous subjective framing assumptions. Consequently, a determination of the extent to which a precautionary approach might indeed be seen to be ‘more scientific’ than a narrow risk approach will depend on such wider judgements. The conclusion here is simply that, when ignorance and incommensurability are acknowledged to be firmly grounded in the science of risk assessment, then it follows that a more broadly-based, pluralistic and epistemologically humble precautionary approach is more scientific than traditional narrow risk assessment. Either way, it remains the case that, though science in itself may be insufficient (however it is precisely conceived), it is certainly an indispensable element in the effective management of technological risk.

Figure 5: An Alternative Model of Relationships Between the Concepts of Risk, Science and Precaution



7: LOOK BEFORE YOU LEAP AND LEARN AS YOU GO

learning, discourse and dissent

In seeking to extend the breadth of scope and depth of focus of regulatory appraisal and risk management in the face of the many problems raised in the Field Studies reported on here, a wide array of procedures and institutional arrangements have been developed and implemented in different countries. These are typically highly specific to individual specialist areas of regulation such as the release of GM organisms, the use of toxic chemicals, or nuclear or food safety. However, a general need for provision for 'early listening' and 'technology watch' is variously addressed by bodies such as the EC's Institute for Prospective Technology Studies (IPTS), the European Parliament's Science and Technology Options Assessment office and various official technology assessment and reporting bodies in countries such as the UK (POST), Germany (WBGU), Netherlands (Rathenau Institute) and Denmark (Teknologiradet). Although the paradigm example - the US Congress Office of Technology Assessment - has now been dissolved, responsible bodies in the US (such as the National Research Council) continue to emphasise the general importance in all fields of effective *ex ante* 'risk characterisation' in the management of technological risk. It is through institutions such as these, that the regulatory process may hope to maintain a broad, detailed and up-to-date picture of the status of different technological options and operational practices as well as any emerging indications of associated risks. With the increasingly concrete formulations of concepts such as 'best available technology' (BAT) in national and international legislation, the responsibility of such bodies for active comparative review of technological options is becoming increasingly formalised. An example touched on in the Stirling Field Study, for instance, is the role of the IPTS in Seville in co-ordinating the drafting of BAT Reference Documents under the 1996 Directive on Integrated Pollution Prevention and Control.

A host of specific measures and procedures are employed by these and more specialist regulatory institutions. These are discussed further in the Field Study by Rip and that by Renn and Klinke. The well-established traditional approach has been a reliance on committees of scientific experts, periodically augmented by more wide-ranging Parliamentary Inquiries, Government Commissions or 'Delphi' exercises eliciting even broader ranges of expertise (such as Japanese and UK 'Foresight' Programmes). More recently, Rip mentions that attention is also turning to electronic and other techniques for the more systematic and exhaustive scrutiny of the scientific literature - especially with regard to recent issues such as BSE. Expert deliberation by means of Inquiries, Commissions or Delphi exercises, as well as techniques such as systematic literature audits, all present effective ways to address those sources of uncertainty and ignorance which are identified in Salo's Field Study to reside with the 'physical causations' and (to a less complete extent) 'policy responses' associated with different technological risks (see Table 7). They are essential aspects of the culture of 'open-ended learning' highlighted in the Field Study by Rip.

In all their various forms, these and other institutions of technology assessment offer a way of ensuring a general social provision for "looking before leaping" in the management of technological risk. This theme is necessarily central to all regulation of technology. Despite the differences of context, the essential anticipatory and learning functions of such institutions clearly relate both to 'narrow risk' and 'precautionary' approaches. However, taken on its own, such a conclusion falls short of addressing in full some of the key findings which have already been outlined in this Report. What of the insufficient and under-determining nature of science in risk assessment? What of the imperative of analytical rigour for the empirical validation of the social provenance of framing assumptions and priorities adopted in the regulatory appraisal of technological risk? It seems clear that the implications of a culture of 'open-ended learning' go far beyond the institutions and procedures of expert deliberation alone, extending out into wider social discourses on risk.

There is an enormous literature concerning the broad subject of social discourses over technological risks. The Field Study by Renn and Klinke briefly reviews some of the main themes in the study of risk perception and communication and goes on to survey the literature on risk and deliberative democracy. Here, they distinguish four broad forms of social discourse on risk: 'reflective', 'design' (or 'planning'), 'cognitive' and 'educational' discourse. Of these, it is the latter two which embody the essentially hierarchical nature of the traditional relationship between expert institutions and wider public values and understandings concerning technological risk. The 'cognitive' discourse refers to the expert deliberations which have already been described in relation to the established institutions of risk management. Learning takes place here on all sides, largely as a result of interactions between technical specialists from different fields, with the aim of arriving at a consensual interdisciplinary understanding of empirical 'facts' and theoretical models or, where necessary, a clear demarcation of any disagreement.

Learning can also be a two-way process in an ‘educational’ discourse, but here the process is highly asymmetric. In one direction, it is the objective to ‘educate’ different public constituencies about the ‘facts’ of technological risk as determined in the ‘cognitive’ discourse. In the other direction, it is necessary that the ‘educators’ learn about the nature and context of any information ‘deficits’ and ‘misperceptions’ which it is the goal of the process to address. Although it has been shown in this report that the science of risk is under-determining and strongly shaped by subjective values and contingent assumptions, it has been emphasised that this does *not* mean that ‘anything goes’. As has already been discussed, under a view where more than one thing can be ‘right’, it is, of course, still entirely possible to be ‘wrong’ in a conventional positivistic sense. To this extent, then, even under a ‘constructivist perspective’, it is entirely clear that there exists an essential role for Renn and Klinke’s ‘cognitive’ and ‘educational’ discourses over risk. These form an important part of the process of open-ended social learning identified by Rip to be intrinsic both to scientific and precautionary approaches to the management of technological risk.

What is perhaps less well recognised, however, is the equally essential role of the other two forms of discourse identified by Renn and Klinke as part of the process of social learning on risk. The ‘reflective’ discourse deals with the crucial issue of the framing and interpretation of risk science. As was argued in the last section, it is only by means of deliberate efforts to foster learning of this sort, that appraisal can hope to validate and justify the particular assumptions and priorities embodied in regulatory decision making over technological risk. It is this form of discourse which allows risk management effectively to address the sources of uncertainty identified in the Salo Field Study concerning ‘social values’ (Table 7). In addition, it is by means of inclusive reflective discourse that the regulatory process may elicit creative ideas concerning new technological or policy options, unconstrained by institutional or disciplinary blinkers or preconceptions. Likewise, it is only by means of the unbounded garnering of the insights and possibilities which emerge under different perspectives, that the formal condition of ignorance defined in an earlier section of this Report can progressively be reduced to the more tractable state of uncertainty. These and other means to the ‘reduction of intractability’ represent an important part of the open-ended social learning which is highlighted in the Field Study by Rip. The continued treatment of this sort of social learning entirely as a matter of ‘cognitive’ or ‘educational’ discourse (emphasising specialist expertise in the technical and physical aspects of risk) remains an entirely misguided and potentially highly counterproductive feature of much regulatory thinking on risk.

Finally, Renn and Klinke’s ‘design’ (or ‘planning’) discourse – focused on the evaluation of policy and regulatory options – is essentially political in nature. Again, this necessarily involves a symmetrical interaction between specialist and lay communities. It is here that mechanisms of accountability, conditions for legitimacy and rules and procedures for representation, mediation and direct citizen participation are all established and sustained. It is through this form of discourse that the risk management process can complement and broaden expert understandings on the sources of uncertainty identified in the Salo Field Study concerning ‘policy responses’ (see Table 7). The experience and outcomes of these negotiations represent an element in the wider process of open-ended social learning on risk which is just as crucial as the fostering of ‘cognitive’ and ‘educational’ discourse. Indeed, there is a sense in which it is the ‘design’ discourse which supports and oversees the conduct of the other three, thus maintaining the overall architecture of the processes of social learning on risk. In the Field Study by Rip, for instance, it is argued that the ‘Precautionary Principle’ itself (along with other principles, such as those associated with various notions of ‘sound science’) represents a ‘design principle’ of the kind which – either intentionally or implicitly – is negotiated and affirmed as part of such a discourse. Recognition of the importance of Rip’s ‘open-ended social learning’ and, in particular, of Renn and Klinke’s ‘reflective’ and ‘design’ discourses on risk, therefore do not represent an exclusively ‘precautionary’ perspective. The need for explicit attention to such matters is also entirely consistent – indeed (as Stirling argues), a prerequisite – for other aspects of the scientifically informed management of technological risk

The Field Study by Rip specifically discusses the positioning of a ‘precautionary approach’ on the basis of a set of concepts which closely parallels the distinction between three of the discourses constructed by Renn and Klinke. Rip notes that a ‘Precautionary Principle’ (like virtually any other policy principle) can be formulated and implemented in terms of three different sorts of ‘rules’ operating at a number of levels: ‘decisions’, ‘culture’ and ‘constitutions’. As a ‘decision rule’ of whatever form, ‘precaution’ is acting at the explicit level of rationalistic process. This is the domain of Renn and Klinke’s ‘cognitive discourse’. As a ‘culture-embedded’ rule, by contrast, such a principle acts (often in an invisible fashion) as an ‘archetype’ to shape the form of institutions and procedures. Here Rip is noting something at the level of Renn and Klinke’s reflective discourse. Finally, as a ‘constitutional rule’ (‘process rule’, ‘rule of standing’), the ‘Precautionary Principle’ helps to govern the modes of interaction themselves. This is a matter of design discourse. Again, the point is that ‘precaution’ – along with other general approaches to the management of technologies – serves simultaneously as a framework for learning at several levels of discourse. It is

neither feasible nor helpful to seek to confine notions of ‘precaution’ (or, for that matter, ‘science’) to a single discursive domain.

Before turning to other issues, there is one further crucial aspect of open-ended social learning on risk which is also identified in the Field Study by Rip but which has not so far been discussed in this report. This concerns the role – and indeed value – of active social contention and dissent over risk. It is something of a received wisdom in the field of risk communication and management to regard divergent attitudes and understandings (and the associated social discord) as a generally negative phenomenon. Under such a view, the objective of social learning should be to reduce, minimise, or even eliminate, such contention and substitute it with as near a state to informed consensus as can be achieved. Drawing on insights arising in the social sciences, however, Rip develops a more positive view of dissent.

First, it should be emphasised that Rip’s Field Study acknowledges that many aspects of social conflict over risk, while perhaps unavoidable, are likely sometimes to be counterproductive. This is especially the case where such conflict militates against effective communication (and thence learning) between groupings. Examples of these negative aspects include the tendencies for the rhetoric of risk discourse to be polarised by what Rip describes as the competing ‘labels’ and ‘naming myths’ produced in the different ‘risk repertoires’ associated with different socio-political constituencies. This polarisation can sometimes be exacerbated by the specialisation and associated fragmentation of interests among risk management institutions and, to some extent, also by the professionalisation of interest groups, advocacy and lobbying organisations. The tensions are further amplified by the media imperative always to construct a simplified ‘storyline’, often emphasising the conflict between ‘winners’ and ‘losers’. For all these reasons, Rip concurs with the orthodoxy in risk management in identifying a need better to ‘modulate’ social discourses over risk in order to foster more effective open-ended learning.

However, Rip also points out that (if left to their own devices), the different institutions charged with risk management would naturally seek to avoid agonistic interactions of the kind which challenge their own embodied perceptions and interests. The result would be a self-reinforcing process of selective inclusion and exclusion, leading to a polarisation of proponents and opponents in relation to particular technological options. Seen in this light, it is the very existence of active social contention and dissent over technological risk which provides the kind of incentive (or ‘forceful focus’) for learning on the part of all the different actors involved. This permits a process of what Rip terms the ‘antagonistic coordination’ of social discourse over technological risk. In other words, it is the existence – even nurturing – of healthy dissent which provides a means to engagement and quality control in social discourse over risk. Indeed, where it is possible to achieve recognition by all actors of the value of this process, then some degree of active antagonism in the risk debate might be seen as a parallel for the organised scepticism which forms such an important part of scientific culture. In this way, a reflexive and appropriately modulated process of active scepticism and dissent might be seen as an important element in, and indicator of, a high quality process of social learning over technological risk.

8: A STITCH IN TIME SAVES NINE

constructive approaches to technology assessment

The crucial question, of course, is what practical form such constructive social ‘modulation’ of risk discourses and ‘antagonistic coordination’ might take. A series of specific methods and procedures are discussed later in this Report (Section 10). Before turning to these, there are a couple of further issues to consider. The first concerns the time dimension to the social management of technology.

Among the forms of discourse identified in different ways in the Field Study by Renn and Klinke and that by Rip as arenas for the practical implementation of risk management approaches (like ‘precaution’) are those concerning ‘design principles’. Although these relate to institutions of all sorts, they apply particularly strongly in the case of technologies and their associated systems. There is an extensive literature in the field of the economics of technology and innovation touched on in the Field Study by Rip which documents the ‘path dependent’ character of technological change. Technological innovation is an inherently hierarchical process, with features embodied at an infrastructural or ‘architectural’ level often strongly influencing the form of the technologies which might subsequently be adopted. The implementation of precautionary considerations at an early or formative stage in the development of what may later come to be a large scale technological system (such as a renewable energy

infrastructure, the chlorinated hydrocarbon industry or a biotechnology-based agricultural sector) can exert a profound effect in shaping and selecting further technological choices.

It follows from this, that the implementation of ‘precaution’ (or indeed any other regulatory principle) simply at the level of the regulation of an individual technology or the licensing of investments may well come too late and at too low a level to impact in any significant way on the established developmental trajectory of the technological system as a whole. Sunk investments, standard-setting, corporate strategies and tacit knowledge typically conspire to make decisions over the form of technological systems extremely difficult and expensive to reverse once committed. A potentially far more cost-effective strategy would be to anticipate the possible regulatory difficulties at an early stage of innovation and filter the selection process accordingly. This offers benefits both in terms of avoiding unnecessary expense on the part of prospective developers and of enhanced ‘early warning’ on the part of society at large - as discussed in the last section. If it is to be effective in these terms, then, the management of technological risk needs to take place at the level of the ‘design principles’ for the networks and infrastructures into which individual technological options are to be embedded. In this way, as in others, the wisdom of the old adage that “a stitch in time saves nine” seems especially apt.

It is recognition of this fundamental feature of the dynamics of technology choice which has helped to inspire the development over the past two decades, especially in the Netherlands, of the new approach of *constructive technology assessment*. This is discussed in some detail in the Field Study by Rip. Although the phrase ‘constructive’ refers to insights arising in the academic study of the ‘social shaping’ of technology, constructive technology assessment remains an essentially positive ‘modernist’ endeavour - seeking to improve the quality of the technological choices made by society. Indeed, it sets out to increase the ‘robustness’ of new technological developments in the face of social and environmental considerations in much the same way that an engineer seeks to optimise the ‘robustness’ of a design in terms of more physical pressures. The term ‘constructive’ refers to two features. First, the focus on the innovation and demonstration stages in technological development, rather than the final market dissemination. Second, to the greater degree of pluralism in the range of perspectives that are typically taken into account compared with orthodox technology assessment.

A further three key characteristics of constructive technology assessment are highlighted in the Field Study by Rip. First, it has the objective of transcending the institutional separation between activities and procedures oriented towards ‘promotion’ of a technology and those directed at its ‘control’. A central theme is that the anticipation of the future effects of technology, as well as subsequent learning, should be integrated into the essentially promotional processes of technology development and dissemination. This means that those involved in the activities of technology regulation and control should directly participate in the design and development of new technologies. Conversely, it also means an increased emphasis on the role of industry and other non-governmental bodies in the management of technological risk. Although constructive technology assessment still provides for an important role for government and its agencies as initiators and regulators of the modulation processes, this role is not exclusive to government and can be taken up by other social actors.

A second major characteristic of constructive technology assessment is the aim of opening up the social and institutional networks typically associated with innovation and technology development. Under normal circumstances, decisions over the development of new technologies are usually undertaken within relatively closed circles. Constructive technology assessment seeks to achieve the inclusion of a wider range of social actors at an earlier stage in this process, thus allowing consideration to extend to a more diverse array of possible impacts at the earliest stages of development and introduction of a new technology. This is a practice which many industry organisations are themselves increasingly undertaking in different ways in different countries. Constructive technology assessment seeks to establish and ‘modulate’ these processes in a more coherent and explicit fashion.

The third important characteristic of constructive technology assessment identified in the Field Study by Rip is the explicit focus on the ‘modulation’ of risk discourses and social learning introduced in the last section. Because of the irreducible forms of uncertainty already discussed in this Report, it is recognised that the anticipation of impacts should be an ongoing activity during the development and implementation of new technologies. All the actors involved in the resulting discourse should be enabled to learn about the possible new linkages between the design options, their associated emerging impacts and the demands and preferences of the envisaged users. This process of social learning should go beyond simple questions of individual impacts and their respective responses and extend to address wider questions of the political and social connotations of a technology and its acceptability in terms of broader cultural values in society. And finally - as befits a discipline influenced by the social studies of technology - there is an emphasis on the need for all actors to be ‘reflexive’ about their own role and that of others in the processes of co-evolution of technology and society and of technology and its social impacts.

Taken together then, all these characteristics combine to make constructive technology assessment - at least as currently developed and practiced in the Netherlands - a rather broader, more strategic and more pervasive activity than conventional technology assessment in the model of the former US OTA. Rather than focussing essentially on awareness-raising, constructive technology assessment offers a new design practice under which the assessment of impacts is fed back into the development of technology in an iterative and reflexive way and which retains an explicit focus on social learning. It provides a concrete process within which questions such as the justification of new technologies and their associated benefits (the so-called ‘fourth hurdle’) can be articulated with the more familiar issues of impacts.

Although still at a relatively early stage, a number of specific technology management strategies have been examined and developed under the broad framework of constructive technology assessment. Of these, two are particularly relevant in the context of the present discussion of precaution. A strategy of ‘technology forcing’, for instance, is concerned with procedures for the rapid development of new technologies in circumstances where this is held to be required by some wider social or environmental imperative. The introduction of electric cars to mitigate urban smog problems might be an example. Here, the strategy of ‘technology forcing’ begins with the firm specification of a particular quality or target which has to be achieved. This is formulated on the basis of a broad pluralistic discourse, but then raises the question of the form of deliberate authority required to ensure implementation across a range of divergent and cross-cutting interests.

A second generic technology management strategy formulated under the framework of constructive technology assessment is called ‘strategic niche management’. This involves the establishing of a series of ‘experimental settings’ - perhaps insulated from the full force of market competition or other selection mechanisms - within which the development of particular new technological forms can be undertaken and their qualities tested. Such an approach also requires the orchestration of a diverse array of actors, but here the process focuses not on the achievement of an externally imposed target, but on the systematic exploration of the potentialities and implications of the new technology. The incremental process of strategic niche management allows those associated with the development of a new technology gradually to learn and appreciate the implications for other actors of their innovation. These third parties, in their turn, have the opportunity to engage in an informed discourse over the implementation of a new technology in a contained fashion, without exposure at this initial stage to the polarising effect of ‘all or nothing’ mass market dynamics.

The procedures of constructive technology assessment have been developed for some years in the context of the regulatory regime in the Netherlands. To varying extents, they seek directly to address several of the key features identified in this report to be associated with the implementation both of ‘scientific’ and ‘precautionary’ approaches to the management of technological risk, including: broad-based appraisal, comparison of options, consideration of benefits and justification, pluralistic discourse, stakeholder participation and social learning. There is more that can be said about the practicalities of these issues (and these will be addressed again in Section 10). For the moment, though, it can be concluded that, though constructive technology assessment falls far short of offering a panacea, it does exemplify one coherent way in which the policy of “a stitch in time” has begun to be implemented in practice. This should bear more detailed examination in any ‘scientific precautionary’ approach to the management of technological risk.

9: DON’T BURN YOUR BRIDGES OR PUT YOUR EGGS IN ONE BASKET

strategic factors in technology choice

Before turning to some of these more detailed practical issues, there is a second theme which should be briefly discussed concerning the relationships between science and precaution (on the one hand) and the wider dynamics of technology choice (on the other). This involves consideration of what might be termed ‘qualitative strategic factors’ in the development of technology. These are strategic properties of a technological system (such as flexibility and diversity) which should be taken into account alongside consideration of the associated impacts in arriving at any final judgement over the balance to strike in regulation. After all, the commonsense conception of precaution in everyday life lies not so much in aspirations to synoptic appraisal or efforts at omnipotent control, but rather in rules of thumb, such as “not burning the bridges” (flexibility) and “not putting all the eggs in one basket” (diversity). These issues are addressed in the Field Study by Salo and that by Stirling.

The particular strategic properties discussed by Salo are: flexibility, resilience, adaptability and robustness. Stirling adds a more detailed discussion of diversity. These factors differ from the qualitative dimensions of risk discussed in the Field Study by Stirling and that by Renn and Klinke (such as persistence, reversibility and gravity, cf: Tables 4 and 5) because they are properties of the technological systems themselves rather than of their effects. Some working characterisations of these concepts based on those provided by Salo and Stirling are illustrated in Table 8.

Table 8: ‘Precautionary’ Strategic Factors in the Dynamics of Technology (after Salo and Stirling)

PROPERTY	DESCRIPTION	
diversity	the retention in parallel of a series of different strategies for realising the same objective, involving the inclusion of options which appear to perform less well as an insurance against changes in performance in other options.	
flexibility	the capacity to retain as many options for as long as possible in advance of commitment and (when commitments are made) to retain an ability to withdraw without great penalty if prohibitive conditions arise	
resilience	the capacity to sustain performance under external perturbations, perhaps through preservation of the internal structure (<i>robustness</i>), perhaps through adapting structures to changing conditions (<i>adaptability</i>).	
	robustness	the capacity to sustain performance under external perturbations by maintaining an established internal structure
	adaptability	the capacity to sustain performance under external perturbations by changing internal structures.

With respect to diversity, there exists a fairly well-developed literature which is briefly reviewed in the Field Study by Stirling. Stirling notes that much of the activity in the regulatory appraisal of technological risks is aimed at establishing the ‘tolerability’ or ‘acceptability’ of *individual* proposed investment, technology or policy against some absolute metric (such as mortality, morbidity or monetary value). However, even on those occasions where analysis extends to the comparative appraisal of a *range* of contending options, orthodox approaches to risk and environmental impact assessment still typically tend to be aimed at the identification of the *individual* option whose performance is rated highest under the metric in question. This is held to correspond with the identification of the single relatively ‘best’ choice from the point of view of society as a whole. In this sense, current comparative appraisal might generally be seen as a ‘first past the post’ approach – the ‘picking of winners’ in the regulation of technological choices.

An important conclusion drawn earlier in this Report is that the notion of an objective ‘best’ choice from the point of view of society as a whole is, in the most fundamental of scientific terms, highly problematic. Nevertheless, in contemplating the intractabilities of ignorance and Arrow’s Impossibility, it is remarkable that the strategy of not “putting all the eggs in one basket” offers a quite straightforward and robust response. Instead of aspiring (let alone claiming) vainly to identify individual ‘optimal’ or ‘best’ choices from the point of view of society as a whole, the management of technology might instead aim at the construction of *portfolios* of choices. The pursuit in parallel of a diverse portfolio of what are judged to be the better-performing options may at the same time accommodate divergent value judgements *and* help to hedge against ignorance in appraisal. Although not reflecting deliberate regulatory policy, such a state of affairs prevails for reasons of historical or geographical contingency in a variety of sectors, including energy, agriculture and transport. However, Stirling points to a literature under which a variety of quite well-established formal characterisations of diversity have been developed in various fields, and yet which remain curiously neglected both in the study and in the practical management of technological risk.

The remaining properties of flexibility, resilience, adaptability and robustness reviewed in the Field Study by Salo (and defined in Table 8 above) are even less widely discussed in the literature. However, Salo is able to advance some useful general observations. Although all these strategies offer means to hedge against intractable uncertainty and ignorance concerning the future performance of technologies, they are not without their own difficulties. The building in of a property of robustness, for instance, implies the effective anticipation of the form of future conditions, if not their relative likelihoods. As such, though it offers a potentially effective response to uncertainty, it does not address the essential attribute of ignorance (as defined in Section 5 of this Report) to the effect that certain possible future conditions may be entirely unforeseen (and even unforeseeable). Likewise, the realisation of the full value of the property of flexibility requires the sustained acquisition and assimilation of all pertinent performance information. As with diversity, none of these strategies are without cost implications, at least in the short term.

In identifying the broad form of these potential strategic responses to the problems of technological risk, this Report is addressing a series of issues which remain relatively poorly explored in the wider literature. It seems likely that these issues would be seen to warrant more substantive and extensive attention, especially in the context of the value of constructive approaches to technology assessment discussed in the last section. This is especially the case, given the disproportionate weight of attention that is routinely devoted to addressing *problems* in the appraisal of technological risk as distinct from the strategic *responses* in technology policy. However, for the moment, it is simply the conclusion here that the relative academic neglect of these issues should not be taken as a reflection of their intrinsic lack of importance.

10: DON'T THROW OUT BABIES WITH BATHWATER

systematic procedures and quantitative methods

In the discussion in previous sections of this Report concerning the 'modulation' of different forms of 'risk discourse' and 'social learning', the concepts employed have been rather general and abstract in nature. It now remains to provide a more concrete illustration of some of the practical measures which are available to implement these strategies for achieving a framework for the management of technological risk which is at the same time both 'scientific and 'precautionary' in nature (in the terms defined at the beginning of this Report).

In contemplating this challenge, it is important not to be unduly discouraged by the formidable scope and intractable nature of the difficulties which have been documented here with respect to narrow risk-based approaches. Although the conditions of ignorance, multidimensionality and incommensurability all serve to constrain and undermine the applicability of orthodox risk assessment techniques, this should not be taken to imply that they rule out the use of *all* systematic or quantitative methodologies. Similarly, it should not be assumed that quantitative techniques offer the *only* effective means by which systematic and robust conclusions can be drawn in appraisal in order to inform the management of technological risk. While the criticisms of risk-based approaches advanced here are severe, under-recognised and well-grounded, they should not prompt a nihilistic reflex in which the "baby is thrown out with the bathwater". Many existing and newly emerging methods and procedures show a great deal of promise and potential for further development.

The first group of practical measures surveyed in this project are the techniques of decision and value trees and multi-criteria, scenario and sensitivity analysis discussed in detail in the Field Study by Salo and (to a lesser extent) that by Stirling. Some of the key attributes of a selection of these methods are summarised in Table 9. Many of these techniques are conventionally employed in a fashion which runs counter to some of the findings of this Report. For instance, there is tendency to employ these approaches in association with exclusively probabilistic characterisations of uncertainty, thus neglecting the conditions of strict uncertainty and ignorance discussed in Section 5. Likewise, there is often an attempt to aggregate different perspectives in a fashion which fails to address the problems of multidimensionality, incommensurability and Arrow's Impossibility discussed in Sections 3 and 4. Nevertheless, all the methods summarised in Table 9 can be employed in such a way as to avoid (or at least minimise) these problems and yet retain their value as systematic means to explore and communicate the consequences of different possible approaches to regulatory decision-making over risk. In short, both individually and in combination, such methods – if employed carefully – offer a host of different ways of providing an 'audit trail' which links particular prescriptive results obtained in analysis with the crucial determining assumptions associated with particular points of view.

Despite their merits in comparison with conventional narrow risk assessment, however, none of these methods can solve the fundamental problem of appraisal. There can be no 'analytical fix' for the intrinsic subjectivity and open-endedness of the 'framing assumptions' which underlie and determine the results of appraisal. In the end, the justification for the adoption of any particular framing assumption in appraisal must lie in the degree to which this is defensible in wider social, political and ethical discourse. What is needed, is a means to audit and verify this aspect of appraisal.

Table 9: Some Systematic Approaches to Analysis which can be both ‘Scientific’ and ‘Precautionary’
(after Salo and Stirling)

ANALYTICAL APPROACH	SOME KEY CHARACTERISTICS
Decision Trees	Focuses on relationships between sequences of decisions, their consequences and contingencies Often used exclusively with probabilistic approaches, but can also be a more qualitative tool. Tends often to be used in association with some of the other techniques mentioned below.
Value Trees	Develops a single structure encompassing all values, criteria and priorities entertained by a group. Each value, criterion or priority is weighted to reflect its relative importance under each perspective. Can be used to derive single overall weighting scheme, or to ‘map’ contrasts between different views.
Multi-criteria Analysis	Combines weighted criteria with ratings of option performance under each criterion to derive rankings Sometimes used to identify single course of action which optimises utility under all perspectives Possible use in association with sensitivity analysis to ‘map’ relationships between inputs and results.
Sensitivity Analysis	Systematic presentation of relationships between input assumptions and their consequent results. Can be used to vary one parameter at a time, or to explore all permutations of parameter variations. Offers a basis for presentation of appraisal results as systematic ‘maps’ rather than discrete values.
Scenario Analysis	Systematic examination of different possible outcomes and contingencies which bear on a decision. Can take a quantitative or a qualitative form as a flexible tool for exploring possibilities. Need not provide a basis for <i>analytical</i> derivation of the ‘best’ scenario, option or course of action.

This is where the second group of practical measures touched on in this project come in. For many years now, a range of systematic deliberative procedures have been under development in many countries. These include (but are not confined to) the consensus conferences, citizen’s juries, scenario workshops, focus groups and deliberative polls whose key characteristics are summarised in Table 10. Founded in various forms of social theory and increasingly well-tested in practice in many different sectors, such procedures are concerned with the systematic elicitation, construction, exploration and (sometimes) development under learning of the divergent values and priorities associated with different public constituencies and interest groups. As such, they provide a means precisely to ‘fill the gap’ in the use of analytical methods to address broad plural perspectives. It is only by inclusive deliberative approaches such as these, that the regulatory process can hope to validate the *particular* sets of values, priorities, framing assumptions and trade-offs which are explored and eventually adopted in the appraisal and subsequent management of technological risks. For their part, on the other hand, the analytical techniques provide a means to confer transparency and auditability within deliberative approaches which might otherwise be lacking in these essential qualities.

In short then, when taken together, the analytical methods and procedures for inclusive deliberation summarised here (and discussed in more detail in the Field Studies) offer ways simultaneously to help achieve the qualities associated (in Tables 1 and 2) with both ‘scientific’ and ‘precautionary’ approaches. They are systematic in nature, readily subject to peer review and provide an effective framework for learning, whilst also addressing criteria of transparency, scepticism, independence, accountability and openness to learning which were held to be key characteristics of a ‘scientific’ approach to the appraisal of technological risk. At the same time, the analytical methods and deliberative procedures summarised here are also entirely consistent with the objectives of broadening the scope of appraisal, maintaining a focus on alternative options, including a plurality of social perspectives, acknowledging ignorance and considering benefits as well as risks which are held to be crucial elements of ‘precautionary’ approaches.

Table 10: Some Systematic Procedures for Inclusive Deliberative Appraisal

(after Renn & Klinke, Rip, Salo and Stirling)

APPRAISAL PROCESS	SOME KEY CHARACTERISTICS
Consensus Conferences	<p>Typically involves less than twenty individuals, usually selected on the basis of a random process, stratified to account for basic demographic factors.</p> <p>Involves a series of meetings over a protracted period of time, to which representations are made by different interests groups and specialist witnesses called to a final public conference, with participation by the audience and attendance by the media.</p> <p>Consensus is regarded as a desirable outcome, but (depending upon the context) is often not a requirement – the expression of dissenting views being possible in the final report.</p>
Citizen's Juries	<p>Typically involves less than twenty individuals, usually selected on the basis of a random process, stratified to account for basic demographic factors.</p> <p>Involves a series of meetings over a protracted period of time, which are generally more private than those of a consensus conference, with specialist witnesses being called, but no final public conference or media involvement.</p> <p>Generally less focused on achievement of a consensus than a consensus conference – dissenting minority reports may be written.</p>
Scenario Workshops	<p>Similar model to citizen's juries, but making use of scenario techniques to envisage favoured and adverse outcomes under different perspectives and circumstances with an emphasis on the construction of a consensual vision of a desirable outcome or course of action.</p>
Focus Groups	<p>Typically involves less than twenty individuals, usually deliberately selected on the basis of finely-formulated demographic or other criteria.</p> <p>Structured discussion of a bounded topic by a small group of selected individuals under the moderation of a trained facilitator with full transcripts recorded and analysed and conclusions drawn by specialists.</p>
Deliberative Polls	<p>Typically involves more than twenty individuals, usually selected on the basis of a random process, stratified to account for basic demographic factors.</p> <p>The eliciting of opinions by systematic questionnaire protocols augmented by some form of interactive process, with sampling often performed both before and after deliberation.</p>
Strategic Niche Management	<p>Involves a variable number of different social actors with a manifest interest in the configuration of an emerging technology or technological system.</p> <p>Iterative and reflexive interactions, appropriately 'modulated', take place in a variety of ways and over the protracted period of development of the technology in question in a protected niche market.</p>

There is undoubtedly considerable scope for further work in exploring the best means to exploit and combine these and other procedures and techniques and to articulate them with orthodox risk assessment where appropriate. The details of the application of such approaches will vary from case to case and jurisdiction to jurisdiction. Rather than being a matter on which firm *ex ante* prescriptions can be made, the precise configuration of an appraisal regime based on these approaches must properly be determined by the kind of open and inclusive 'design discourses' discussed in the Field Study by Rip and that by Renn and Klinke and summarised earlier. In particular, the approach of strategic niche management provides one specific context for the articulation of these procedures with the more conventional techniques of constructive technology assessment. In the end, of course, though they may inform, enrich and render the appraisal process more robust, the final justification of regulatory decisions can lie neither in the 'objectivity' of analysis nor the 'authority' of associated deliberative procedures but must rest (in democratic societies) with institutional legitimacy and political accountability. For the moment, however, it seems clear that, even at this general level, there already exist many concrete ways of acting on the rather abstract imperatives for improved 'modulation' and 'social learning' in the management of technological risk.

11: HORSES FOR COURSES

the diversity of technological risks

Thus far, the discussion in this report has focused on the role of science and precaution in the management of risk only at a fairly general level. The points made so far concerning the pluralistic character of technological risk, the limitations of ‘narrow risk’ approaches and the need for more inclusive approaches to appraisal and regulation all apply (to varying degrees) across the full spectrum of technological risks. However, in seeking to apply these general findings in the practical context of real regulatory decision making, there must be some discussion of the (sometimes radical) differences between the characters and contexts of the many diverse effects which are conventionally lumped together as ‘risk’. Although the basic principles may be the same, it is highly likely that some regulatory instruments and measures will be more appropriate than others in different contexts. In short, it must be recognised that there are “horses for courses”.

The Field Study by Renn and Klinke takes the lead role in the present project in systematically distinguishing the different forms of risk. Drawing principally on wide-ranging research undertaken by these authors for the German Government’s Advisory Council on Global Change (WBGU), their approach is based on the eightfold scheme of criteria discussed in an earlier section of this report (and displayed in Table 5). Despite the reduced form of this scheme in comparison with the full range of qualitative dimensions often recognised in the characterisation of risk (see Table 4), Renn and Klinke argue that for practical purposes it captures the key aspects of the different dimensions of technological risk. Indeed, they conclude that, in practice, the properties of ‘ubiquity’ (geographical extent), ‘reversibility’ (potential for restoration), ‘delay’ (latency of manifestation), ‘persistence’ (duration of harm) and ‘mobilization potential’ (political sensitivity) all tend to be quite closely correlated with the other three criteria.

In this way, it emerges from Renn and Klinke’s analysis that – whilst acknowledging the difficulties with simplistic reductions – the straightforward criteria of ‘magnitude’ (scale of harm), ‘probability’ (likelihood of harm) and ‘uncertainty’ (in magnitudes or probabilities) do in themselves provide a potentially useful starting point in distinguishing between different types and contexts of technological risk. In the spirit of the accompanying analysis in this report, then, the resulting taxonomy of risks is presented here as a heuristic (a framework for discussion) rather than as an assertion of a definitive final characterisation of the different forms of technological risk.

The basic way in which the registering of ‘low’ or ‘high’ values to each of the criteria ‘magnitude’, ‘probability’ and ‘uncertainty’ yields the six main categories of risk is summarised (together with key correlations with other criteria and examples) in Table 11 below. For ease of exposition, Renn and Klinke name each category after a character in Greek mythology, the attributes of whose myth their own characteristics most closely evoke. In this fashion, they identify Medusa-, Damocles-, Cassandra-, Cyclops-, Pythia- and Pandora-style risks.

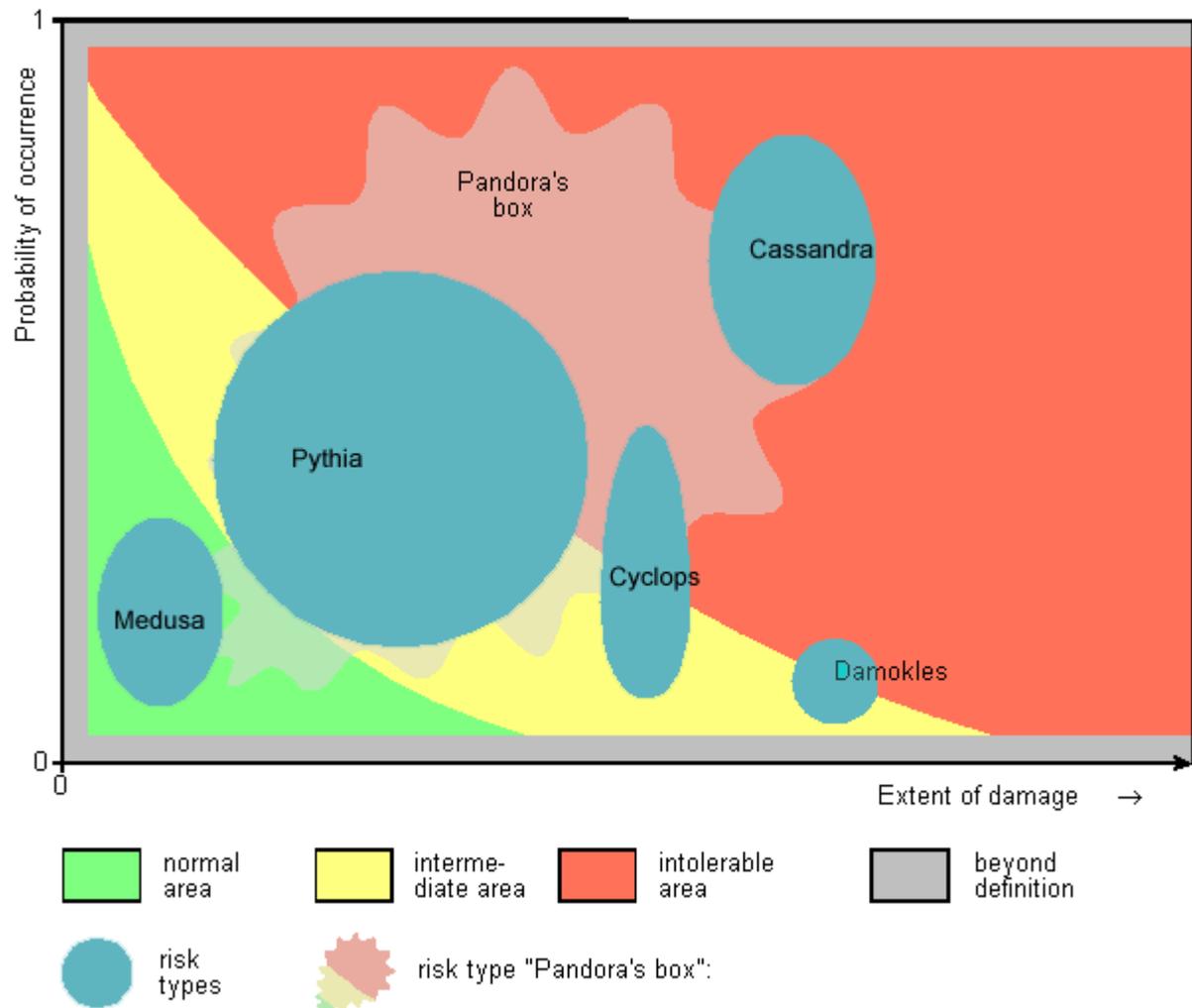
Table 11: A Heuristic Taxonomy of Different Classes of Technological Risk (after Renn and Klinke)

NAME	PROBABILITY	MAGNITUDE	OTHER	EXAMPLES
Medusa	low	low	(high mobilisation)	Electromagnetic fields
Damocles	low	high		dams, nuclear power, large chemical plants
Cassandra	high	high	(high delay)	global ecology, currently committed global warming
Cyclops	uncertain	high		Weapons of mass destruction, AIDS
Pythia	uncertain	uncertain		BSE, GM crops, continued growth in global warming
Pandora	uncertain	uncertain	(high persistence)	POPs, endocrine disrupters

When seen as a heuristic, one of the merits of Renn and Klinke’s scheme is that the central threefold distinction between ‘magnitude’, ‘probability’ and ‘uncertainty’ admits a fairly ready graphical conceptualisation. Under a regulatory paradigm which is now well-established throughout Europe, the tolerability of risk is conventionally represented as a convex curve on a plot of ‘magnitude’ against ‘probability’. The different risk classes resolved by Renn and Klinke can be plotted in broad comparative terms on such a chart, with ‘uncertainty’ represented by the

relative spread of each risk domain on the two axes. Such a diagram is reproduced as Figure 6 below. In this view, the aim of risk regulation is to move the various types of risk progressively further down into the regions of tolerability and negligibility near the origin.

Figure 3: A Graphic Representation of the Heuristic Risk Taxonomy (after Renn and Klinke)



Renn and Klinke employ their taxonomy as a means to structure a fairly detailed discussion of the different domains of applicability of various risk regulation instruments for reducing the potential for harm, improving knowledge and preparedness and managing the consequences when they arise. Discussion of such instruments is picked up in the final section of this report. For the moment, the key point is that Renn and Klinke use their scheme to draw general conclusions about the broad style of risk management that might be appropriate in different contexts.

For instance, Renn and Klinke identify Pythia-, Pandora- and (to a lesser extent) Cyclops-style risks as conditions under which a more strongly precautionary strategy might be seen to be justified by the relatively high uncertainty. Examples of this kind of risk include weapons of mass destruction, AIDS, BSE, POPs, endocrine disrupters, GM crops and continued growth in global warming. In the terms introduced in an earlier section of this report (also drawing on the Field Study by Renn and Klinke), this might be an area where broad social 'reflective' discourse and essentially political 'design' discourse might be expected to predominate in the wider debate over the management of risk.

Examples of Damocles-style risks identified by Renn and Klinke include hydroelectric dams, nuclear power stations and large chemical plants. Here, the relatively low uncertainty but high potential harm which they recognise to be displayed by these risks are seen to warrant more traditional ‘narrow risk’ approaches to risk management. Accordingly, they might expect to find a corresponding emphasis on an expert-centered ‘cognitive’ discourse in the regulation of such risks.

Under Cassandra- and Medusa-style risks, there is a degree of convergence, but for very different reasons. With Cassandra-style risks (such as global ecological disruption and the consequences of currently committed levels of global warming) the jointly high magnitudes and probabilities of harm tend to be ignored due to the associated delay effects. With Medusa-style risks (such as electromagnetic fields), on the other hand, what Renn and Klinke hold to be essentially ‘harmless’ consequences are nevertheless the object of considerable political sensitivity. In both cases, the authors emphasise the application of ‘educational discourses’ for awareness raising and social learning of the kind discussed in an earlier section of this report.

Renn and Klinke’s Field Study goes into considerable further detail in elaborating on these themes. For present purposes, however, the implications are clear. Even on the basis of a rather restricted set of criteria, it is possible to construct a potentially useful heuristic taxonomy of recognisably different types of risk. Such a scheme may then serve the very useful function of going beyond broad generalisations and providing a framework for discussion of the applicability of individual approaches in specific instances. Renn and Klinke readily concede that there might be scope for dispute over the assignment of individual risks under their scheme. An example might be nuclear power which, under many viewpoints, is regarded to incur the type of uncertainties that would justify its classification in the Cyclops category, thus warranting attention more by ‘reflective’ than by ‘cognitive’ discourse.

Renn and Klinke also acknowledge that the *particular* taxonomy which they have constructed might be subject to development or change by further empirical research into social values and continuing ‘reflective discourse’. In particular, for instance, it might be that inclusion of the ‘trust’ factor (omitted from their defining criteria but prominent among the dimensions of risk reviewed in Table 4) would lead to a somewhat different partitioning of the various technological risks. Even so, the essential point arising from Renn and Klinke’s work remains clear. Different risks are all distinguishable at some level one from another. Stylised taxonomies and heuristic schemes greatly assist in clarifying the all-important processes of deliberation and communication on these themes. In the end, however, whether under a ‘precautionary’ or a ‘narrow risk’ approach, there is a sense in which each individual risk must be addressed irreducibly and in its full context. There remains an important need – and an enormous potential – for systematic efforts to map the different forms of technological risk.

A final important point with regard to the practical operationalising of a risk taxonomy heuristic such as that developed by Renn and Klinke, is that both the development of the basic framework and the assigning of individual risks within the resulting scheme will remain a matter for ‘design discourse’ and ‘social learning’ of a kind described earlier in this report. In other words, the requirements to recognise a plurality of rationalities, to acknowledge the limitations of ‘narrow risk’ approaches and to provide for more inclusive engagement in the debate over regulatory policy all apply as much in the design of the overall approach as they do in its implementation. This said, the conclusion which arises most strongly from the work of Renn and Klinke is that the practical appraisal of technological risk can (and should) pay as much careful attention to qualitative issues of social values and priorities as they do to the quantification of probabilities and physical magnitudes.

12: WALK BEFORE YOU RUN

incremental approaches to precaution

It has already been noted that individual technological risks should – in the end – be addressed in the light of their own specific contextual circumstances. Similarly, a theme which emerges in all the Field Studies is the need to recognise that, rather than being partitioned into simple dichotomous groups according to their ‘precautionary’ or ‘narrow risk’ nature, all regulatory instruments lie on a continuum. The degree to which the regulation of technological risk imposes a restrictive or a permissive environment for the pursuit of particular technologies need no more be constant over time than it is across technologies. As is emphasised in the Field Study by Rip, the precautionary character of a risk management regime can be varied incrementally. This can be achieved in a ‘tightening’ fashion (starting with the least stringent regime and becoming progressively more restrictive), or in a

'loosening' fashion (starting with the most restrictive regime and gradually relaxing over time). In this way, there exists a further 'meta-level' for the implementation of precautionary approaches to the management of technological risk – applying not only in the choice of individual instruments but also in the direction in which the character of the regulatory framework responds to the unfolding process of social learning. In this sense, a precautionary approach might be associated with the adoption of the motto “walk before you run” in the development and implementation of new technologies.

Table 12: Incremental Measures for the Implementation of Precaution (after Stirling)

AREA	MEASURES
Appraisal Disciplines	<ul style="list-style-type: none"> • Maintain independence from sponsors and other conflicts of interest. • Address all 'life cycle' stages and all effects, including long term, indirect, cumulative and synergistic factors. • Take account of a full range of relevant options (including complete inaction). • Allowance of a 'margin of error' (in favour of the environment) • Conduct 'ignorance audits' and apply 'minimax' criteria • Emphasise deterministic 'sensitivity envelopes' rather than elaborate stochastic modeling. • Freedom of information, transparency, inclusiveness and extended peer review in the working of scientific panels. • Subject to inclusive procedures for prior consultation and open negotiation involving all interested parties. • Validation of framing assumptions by consensus conferences, scenario workshops and citizens juries • Express results not as discrete numbers but in terms of sensitivities to uncertainty and divergent assumptions.
Capacity Building	<ul style="list-style-type: none"> • Ensure dissemination of best practice with regard to hazard containment and technical protection measures. • Implement training and education in commercial, regulatory, policy-making bodies as well as in wider society. • Develop detailed emergency planning provisions for all relevant sites and contingencies. • Maintain long term monitoring programmes to ensure compliance and provide baseline data. • Pursue active research and development to reduce risks and develop alternative less risky options
Commercial Strategies	<ul style="list-style-type: none"> • Pursue a policy of 'total quality management' throughout business. • Implement programmes for monitored 'continuous performance improvement'. • Continuous educational and training programmes within business. • Conduct 'waste prevention audits' in all areas of business. • Adopt a policy of 'duty of care' with regard to all products. • Commit to long term surveillance and monitoring, with feedbacks to regulatory and management practices. • Undertake full provision of consumer information by means of audited labeling schemes.
Financial Instruments	<ul style="list-style-type: none"> • Introduce 'incentive-based' economic instruments such as 'green taxes' and 'tradable permits'. • Establish and enforce mandatory insurance provision including minimum capacities and all products. • Ensure efficient, timely and equitable compensation of those suffering damage. • Shift away from fault-based liability towards a 'strict' or 'absolute' regime. • Allow exoneration under a 'strict' regime only on demonstration of 'due diligence'. • Uphold responsibility of beneficiaries by channeling liability to investors, financiers, suppliers or contractors. • Introduce product 'take back' schemes. • Adopt flexible financial measures like 'restoration requirements', 'deposit-refund schemes' and 'assurance bonds'. • Segregate funding for decommissioning and restoration or 'worst case' compensation and remedial action.
Legal Provisions	<ul style="list-style-type: none"> • Adopt 'safe minimum standards' (back-stop safeguards based on strictest health or environmental models). • Recognise principle that "lack of evidence of harm is not the same as evidence of lack of harm". • Impose a 'reverse onus' of proof in favour of human health and the environment. • Require prior informed consent to all potentially hazardous activities by individual states. • Establish personal legal responsibility of individual decision makers. • Base regulation on 'reverse listing' (under which only specified activities are permitted). • Use 'evidentiary presumptions' (eg: persistence, toxicity and bioaccumulation as proxies for unacceptable impact) • Standardise international action by imposing on all treaty parties the measures of the most precautionary party. • Adoption of mandatory time-tabled 'forcing targets' (derived by 'back-casting' bans or phase-out schedules).

Drawing on the literature reviewed in the Field Study by Stirling, Table 12 summarises a series of regulatory measures which are identified as representing varying degrees of precaution in the management of technological risk. The specific measures are grouped into the broad areas of appraisal disciplines, capacity building, commercial strategies, financial instruments and other legal provisions. As well as some less well-known measures, they include a wide range of permutations on the relatively prominent themes of consultation, freedom of information, planning, research, monitoring, corporate responsibility, compensation, tax incentives, insurance, liability, criteria of best practice, minimum standards, phase-outs and the burden of proof.

The crucial issue, of course, is to establish the applicability of these and other different measures under different contexts and with respect to different types of risk such as the six broad categories discussed in the previous section. How to decide which instruments are most appropriate in each case? What are the precise implications of their implementation? How might they interact? To what degree might the different measures actually be seen as more or less ‘precautionary’ in different contexts? Such questions are, of course, the subject of an enormous literature in their own right (some of which is referred to in the Field Study by Renn and Klinke and that by Stirling). The answers lie well beyond the scope of the present small conceptual project. However, the research reviewed in this report does lead to a number of concrete conclusions concerning the type of quality criteria which might be applied to this process of deliberation over the appraisal of technological risks and the determination of regulatory responses. These are outlined in the final section which follows.

For the moment, the key point which arises in this overview of the spectrum of ‘precautionary’ and ‘narrow risk’ approaches is the sheer diversity of regulatory options. The variety matches (and even exceeds) the manifest diversity of different types of risk. Taken together with the discussion in this report so far, two significant conclusions flow from this observation.

First, the importance of factors such as divergent contexts and interests, plural values and rationalities, intractable uncertainties and ignorance, the imperatives of social learning and the under-determining character of science – each documented in some detail in this report – all militate against the definition of a single monolithic scheme for thinking about the regulatory options for the management of technological risk. No matter how broad and exhaustive the research and consultation, the task of determining the specific applicability and implications and the relative degree of precaution associated with each of the available measures (such as those listed in Table 9) is not a matter on which there can be a single definitive or even uniquely authoritative conclusion. This business, as with the appraisal of technological risk itself, must be a matter for Renn and Klinke’s socio-political ‘design discourses’, Rip’s ‘antagonistic co-ordination’ and ‘open-ended learning’ and Stirling’s ‘inclusive deliberation’.

Second, while the implementation of such procedures might aim to be systematic, consistent and robust, the result is likely to be a certain *diversity* – yielding a variegated patchwork of outcomes across different risk types, socio-political contexts, nation states and other polities. There is nothing in such a vision which precludes the establishing of certain uniform – even universal – ‘architectural provisions’ (what Rip terms ‘constitutional rules’) in the regulation of technological risk. Examples might include minimum standards, labeling provisions or compensation levels. However, it seems unavoidable that, if adopted on a wide scale, a more deliberative and inclusive approach to the management of technological risk would lead to a more diverse mosaic of practices than that which is usually associated with current drives towards harmonisation and globalisation. It is here that we face the profound implication. For it seems that a necessary consequence of recognition of plural interests and values and multiple possibilities in the management of technological risk is the acceptance (indeed, celebration) of a certain minimum level of interpolity pluralism on the European and global political stage. A sensitivity to the prevalence of different sets of values, interests and priorities in different political, cultural and geographical contexts will lead inevitably to the manifestation of different regulatory outcomes under different jurisdictions. This is not the place to explore this implication in any detail, but it must be noted as a potentially crucial issue in discussions over approaches to technological risk which aim at the same time to be ‘scientific’ and ‘precautionary’.

13: QUALITY CRITERIA

for a scientific precautionary approach to the management of technological risk

The purpose of the present report was to examine, in an open-minded and interdisciplinary fashion, some of the key conceptual issues arising in the application of 'science' and 'precaution' to the management of technological risk and to draw some practical conclusions for policy making. It is clear from the attention given in the foregoing discussion to the importance of context, pluralism and discourse that there can be no single monolithic body of methodological or procedural prescriptions. However, a number of quite specific and coherent operational principles emerge from this analysis which, taken together, offer a concrete basis for practical policy recommendations.

The resulting 'quality criteria' provide a first step towards a common framework for the evaluation both of the 'scientific' and the 'precautionary' elements in the regulatory appraisal of technological risk. They offer a series of benchmarks against which the quality of individual instances of regulatory appraisal - or the associated methodologies, procedures and institutions - might themselves be appraised. The implementation of such criteria in progressively more concrete operational terms should assist in the task of developing approaches to the regulatory appraisal of risk which are at the same time both 'scientific' and 'precautionary'.

Accordingly - organised according to their relevance to the 'regulatory process', 'appraisal methodologies' or 'regulatory instruments' - the twenty six bullet points listed below provide a snapshot summary of some of the key operational themes raised in this report and the research on which it draws. Further details of the implications and rationale for each item may be found in the text of this Report.

REGULATORY PROCESS

- **Humility:** Maintain a culture of humility in the face of the many sources of uncertainty and ignorance in appraisal as well as to subjectivity in framing assumptions. Avoid claims to complete or otherwise definitive knowledge.
- **Candour:** Acknowledge the necessarily subjective character of assumptions adopted in the framing and interpretation of risk - avoid claims to definitive 'objectivity', 'rigour' or uniquely 'scientifically sound' status.
- **Inclusiveness:** Complement and inform analysis with procedures for inclusive participatory deliberation by stakeholders, such as consensus conferences citizen's juries, focus groups and deliberative polls.
- **Learning:** Make explicit provisions for social learning at all stages and levels of the regulatory process, not just in educational discourse, but in expert and stakeholder consultations as well as in deliberation over institutions and regulatory process.
- **Tolerance:** Recognise the value of contention and dissent as a means to quality control in wider discourse over risk, much as organised scepticism serves as a quality control mechanism in science. Avoid aspirations to the appearance of consensus.
- **Constructiveness:** Insofar as possible address appraisal processes at the earliest stages of innovation in order to influence the 'architectural' principles of technological systems and networks as well as the specific details of individual designs.
- **Niches:** Where markets impede dissemination, consider the techniques of constructive technology assessment as a way to experiment with the probationary deployment of different forms of favoured technologies under contained and controlled conditions.
- **Coherence:** Ensure that, where adopted, overarching 'design principles' (such as 'precaution') pervade all aspects and levels of the regulatory process, including those relating to specific decisions, institutional culture and the constitution of the process itself.
- **Accountability:** Uphold the primacy of institutional legitimacy and political accountability (rather than the 'objectivity' of analysis or in the 'authority' of due process) in the final justification of regulatory decisions.

- **Diversity:** Accept that one likely consequence of the quality criteria listed here is the emergence of a degree of global diversity in the character of (equally 'scientific' or 'precautionary') regulatory regimes adopted by different polities.

APPRAISAL METHODOLOGIES

- **Completeness:** Broaden the scope of the regulatory appraisal of technological risk to address cumulative, additive, complex, synergistic and indirect effects as well as more direct causal processes.
- **Benefits:** Include in appraisal some systematic consideration of the benefits claimed for a technology as well as any associated adverse effects, in order to allow determination of 'net' benefits under different contexts..
- **Comparison:** Conduct appraisal on a comparative rather than a case-by-case basis, including account of a variety of technological and policy options and the cumulative effects across different cases.
- **Precision:** Avoid the expression of numerical data with levels of precision which obscure the limits to the accuracy of the underlying analytical methods or the sensitivity of their results to divergent framing assumptions.
- **Mapping:** Express appraisal results not as single discrete numerical values, but using sensitivity analysis systematically to 'map' the consequences of different value judgements and framing assumptions using methods like multi-criteria analysis.
- **Auditability** In combining account of scientific and social information use techniques which allow the detailed auditing of derived results in relation to the inputs (eg: decision analytic methods like value trees, multi-criteria models and scenario techniques).
- **Transparency:** Prioritise the qualities of transparency and simplicity in selecting appraisal methods. Avoid models and procedures with large numbers of hidden variables and factors.
- **Extended Peer Review:** Extend peer review of technical methodologies and scientific information and models to a wide community of specialists associated with the full range of stakeholder perspectives.
- **Active Search:** Undertake systematic measures to document nature and extent of uncertainty by means such as 'ignorance audits' and broad ranging scientific literature review to inform the use of methodological tools like 'error margins' and 'minimax criteria'.

REGULATORY INSTRUMENTS

- **Proportionality:** The costs and other adverse effects incurred by regulation or the implementation of precautionary strategies should be affirmed by inclusive deliberation to be proportional to the wider social and environmental benefits thereby realised.
- **Expediency:** The scale of the effort and resources expended in the appraisal and regulatory process itself should be affirmed by inclusive deliberation to be commensurate with the magnitude of the associated benefits thereby realised or the harms avoided.
- **Flexibility:** Distinguish on the basis of inclusive deliberative procedures between various types and magnitudes of risk and establish this as a basis for differentiated, incremental and adaptable application of different instruments in different regulatory contexts.
- **Predictability:** Establish a process which is as stable and predictable as possible for technology developers with respect to specific forms of technological risk (making use of explicit schemes for differentiation between forms of risk).

- **Strategic Vision:** Instruments should be focussed on the dynamics of portfolios of technologies rather than on individual static options. Account should be taken of dynamic factors in technological strategies, like flexibility, resilience, robustness and adaptability.
- **Portfolios** Focus regulation on the management of portfolios of technologies which collectively achieve the desired performance levels while retaining sufficient diversity to permit accommodation of different perspectives and hedge ignorance.
- **Monitoring:** Make adequate provision for the monitoring of compliance and ensure monitoring results are an integral part of subsequent deliberation over comparable risks and regulatory instruments.
- **Open-endedness:** Allow iteration, reflexivity and open-endedness in the interactions between sustained scientific monitoring, continued analysis and inclusive deliberation in appraisal. The process is never definitively complete.

14: CONCLUSION

This project was formulated on the basis of a distinction between ‘precaution’ and ‘science-based regulation’. However, it has been shown that this constitutes a false and misleading dichotomy. A more valid and useful distinction might be made between the relatively ‘narrow’ basis for regulation provided by risk assessment and the relatively broad framework associated with ‘precaution’. While they are distinguishable under a variety of criteria and social values, these approaches might be seen to be equally ‘scientific’ in nature (under a minimal characterisation of the connotations of ‘science’). However, where the characterisation of ‘science’ is extended to include an acknowledgement of the multidimensional scope of risk, the incommensurability of different classes and aspects of risk and the formal conditions of strict uncertainty and ignorance (rather than just the narrow formal concept of risk), then it is the ‘precautionary’ approach which is revealed as being the more ‘scientific’.

This theoretical discussion is backed up in an empirically-based review of the degree of variability and ambiguity displayed by the results of orthodox narrow risk assessment methods. While risk assessment may appear to yield precise prescriptive results in the context of an individual tightly-framed appraisal, this apparent coherence breaks down rapidly when consideration focuses on the scope for divergent methodological conventions, analytical boundaries or subjective priorities adopted in the risk assessment process. It emerges that far greater and more systematic attention needs to be paid to the formulation of these exogenous and intrinsically subjective ‘framing assumptions’ and to their validity in the context of the values and priorities upheld under different perspectives in a pluralistic society.

There flows from these findings a series of important operational implications for the practical business of managing technological risks. Science is found to be under-determining of regulatory decisions – providing a necessary but not sufficient condition for the effective management of technological risk. An essential complement to the science lies in the development of institutions and procedures for the fostering of social learning in different forms of discourse over risk and, in particular, for the provision of vital contextual information on values and priorities to inform the framing of the science itself. As part of these discursive processes, it is clear that there exists a positive role for dissent as well as for the recognition of consensus where this arises. Likewise, it appears that there already exist a series of potentially useful management strategies, such as those developed in the emerging field of constructive technology assessment. However, regulatory techniques for dealing with crucial properties of technology strategies like diversity, flexibility and resilience remain at a rudimentary level and warrant further attention.

In conclusion, it is possible to identify a range of specific techniques and quantitative methods which offer practical ways to address the deficiencies of narrow risk approaches (including decision analytic and scenario methods as well as a crucial role for sensitivity analysis). A variety of discursive procedures are also available (such as consensus conferences, citizen’s juries, focus groups and deliberative polls) which offer systematic ways of providing the vital information on values and priorities required to complement and frame the science of risk assessment. Using techniques such as these alongside the established insights of risk assessment, much can be done to establish better understandings of the different forms and dimensions of technological risks as a basis for the implementation of incremental regulatory instruments embodying varying degrees of ‘precaution’. Although the specific outcomes of such a regime have yet to unfold, it seems that the broad shape of a regulatory approach to the

management of technological risk which is at the same time 'scientific' and 'precautionary' can already be discerned with some confidence.

GLOSSARY

additive effect	an environmental or health effect arising from the addition of one incremental burden to a different pre-existing burden.
antagonistic co-ordination	the way in which a healthy level of social contention and dissent on risk issues can serve as a focus for learning and productive policy discourse
cognitive discourse	a form of social discourse over risk concerned with the establishing of the scientific and technical aspects of risk, based on specialist understandings.
constructive technology assessment	a strategic form of technology assessment developed mainly in the Netherlands under which an emphasis is placed on the inclusion of plural perspectives and on influencing the early process of innovation
cumulative effect	an environmental or health effect arising from the accumulation of successive burdens of a particular type over protracted periods.
design (planning) discourse	a form of social discourse over risk concerned with the legitimating and constitution of risk management institutions and procedures.
educational discourse	a form of social discourse over risk concerned with the transfer of information from one constituency to another, either in relation to scientific and technical details, or with respect to values and interests.
framing assumptions	a collective term for the various exogenous determinants of the results of analysis, such as the scope and boundaries, the emphasis placed on different factors, the adoption of different methodological conventions and the treatment of uncertainty and ignorance'
ignorance	a precise technical concept which is as well-founded in probability theory as the concept of risk and which refers to a situation under which it is possible neither to assign probabilities nor even to define all possible outcomes.
incertitude	a term introduced in this Report (after Stirling) to encompass the formal concepts of 'risk', 'uncertainty' and 'ignorance'.
incommensurability	a property displayed where multi-dimensional attributes cannot be characteristics under a single criterion or metric.
indirect effect	an environmental or health effect arising from interactions between one or more agents of harm associated with a particular burden and other contingent environmental or health factors.
modulation	the deliberate process of harnessing through careful policy intervention the potential benefits of antagonistic coordination and promoting open ended social learning
narrow risk approach	an approach to the management of technological risk based entirely on risk assessment, without addressing factors (raised in this Report) like multi-dimensionality, incommensurability and ignorance.
precautionary approach	an approach to the management of technological risk which directly addresses the problems of multi-dimensionality, incommensurability and ignorance, displaying properties such as a broad framing, inclusion of multiple perspectives, humility about knowledge, an openness to alternatives, consideration of benefits as well as placing the proof burden on advocates of a technology (rather than the sceptics) and emphasising the rights of wider society rather (than those of industry).
precautionary measures	specific methods, techniques, instruments or measures which, when viewed in context, qualify as a means to the implementation of a wider precautionary approach.
precautionary principle	the adoption of a precautionary approach as an explicit formal element in the design of conventions, treaties, legislation, institutions or other statutory instruments associated with the management of technological risk.
reflective discourse	a form of social discourse over risk concerned with the framing and interpretation of appraisal by reference to different social values and interests
(decision) risk	a precise technical usage of the term 'risk' to mean a situation under which it is possible to define all possible outcomes and confidently assign a probability to reflect the likelihood of each outcome.
(technological) risk	broad colloquial usage of the term 'risk' to mean the general property of threatening adverse impacts or effects
risk repertoires	the way in which different public constituencies and interest groups construct different risk rhetorics, for instance labeling risks using different 'naming myths'.
science based regulation	the notion (contested in this Report) that the regulation of risk can be exclusively based on 'science' (by which is usually meant the techniques of narrow risk assessment)
sound science	a notion (refuted in this Report) that there is a single definitive model for the conception and practice of science (especially in relation to risk management) and that there can consequently only ever be a single monolithic 'scientific' picture of any individual risk.

strategic niche management	a strategy formulated under constructive technology assessment for the probationary development of particular favoured technologies in well-defined 'niches', protected from wider market pressures.
synergistic effect	an environmental or health effect arising from the interactions between different agents of harm associated with a particular technological risk.
(strict) uncertainty	a precise technical usage of the term 'uncertainty' to mean a situation under which it is possible to define all possible outcomes but where there is no basis for the confident assigning of probabilities.

REFERENCES

This Report draws in the first instance entirely on the four Field Studies conducted by the five participating authors. These are listed below. The references cited in these Field Studies have been compiled into a comprehensive bibliography which is also appended to this Report.

O. Renn, A. Klinke, 'Risk Evaluation and Risk Management for Institutional and Regulatory Policy', a study conducted under the auspices of an ESTO project on technological risk and the management of uncertainty, Centre for Technology Assessment in Baden-Wurttemberg, Stuttgart, April 1999

A. Rip, '*Contributions from Social Studies of Science and Constructive Technology Assessment*', a study conducted under the auspices of an ESTO project on technological risk and the management of uncertainty, Centre for Science Studies, University of Twente, April, 1999

A. Salo, '*Technological Risk and the Management of Uncertainty: the Role of Decision Analytic Modeling*', a study conducted under the auspices of an ESTO project on technological risk and the management of uncertainty, Helsinki University of Technology, April 1999

A. Stirling, '*On Precautionary and Science-Based Approaches to Risk Assessment and Environmental Appraisal*', a study conducted under the auspices of an ESTO project on technological risk and the management of uncertainty, SPRU – science and technology policy research, University of Sussex, April 1999

BIBLIOGRAPHY

Allen, 1994	P. Allen, Coherence, Chaos and Evolution in the Social Context, <i>Futures</i> , 26 , 6, 598-609
Andrews, 1995	C. Andrews, Evaluating Risk Management Strategies in Resource Planning, <i>IEEE PES Transactions</i> , 10 , 1, 420-6
Arrow and Raynaud, 1986	K. Arrow, H. Raynaud, Social Choice and Multicriterion Decision-Making, , MIT Press, Cambridge MASS, 1986
Arrow, 1963	K. Arrow, <i>Social Choice and Individual Values</i> , Yale University Press, New Haven
Arrow, 1974	K. Arrow, <i>The Limits of Organisation</i> , W.W. Norton, New York
Aurand and Hazard, 1992	K. Aurand, B Hazard, Die Rolle und Bedeutung von Information für die Umweltmedizin. In: Aurand, K.; Hazard, B.P. and Tretter, F. (eds.): Umweltbelastungen und Ängste. Opladen: Westdeutscher Verlag, 15-27.
Bacow and Wheeler, 1984	Bacow, L.S. und Wheeler, M. (1984): Environmental Dispute Resolution. New York: Plenum.
Bailar, 1988	J. Bailar, ' <i>Scientific Inferences and Environmental Problems: the uses of statistical thinking</i> ', Institute for Environmental Studies, University of North Carolina
Bal & Halffman. 1998	R. Bal & W. Halffman (eds.), The Politics of Chemical Risk: Scenarios for a Regulatory Future, Dordrecht: Kluwer Academic Publishers, 1998.
Bal, 1999	Roland Bal, Grenzenwerk. Over het organiseren van normstelling voor de arbeidsplek, Academisch proefschrift, Universiteit Twente, 22 januari 1999.
Bana e Costa, 1990	C. A. Bana e Costa, <i>Readings in Multiple Criteria Decision Aid</i> , Springer, Berlin, 1990

- Banse, 1986 Banse, G. (1996): Herkunft und Anspruch der Risikoforschung. In: Banse, G. (ed.): Risikoforschung zwischen Disziplinarität und Interdisziplinarität. Berlin: Edition Sigma, 15-72:
- Barnes and Edge, 1982 B. Barnes, D. Edge, *Science in Context: readings in the sociology of science*, Open University Press, Milton Keynes 1982
- Bechman, 1990 Bechmann, G. (1990): Großtechnische Systeme, Risiko und gesellschaftliche Unsicherheit. In: Halfmann, J. and Japp, K.P. (eds.): Riskante Entscheidungen und Katastrophenpotentiale. Elemente einer soziologischen Risikoforschung. Opladen: Westdeutscher Verlag, 129-149.
- Beck, 1986 Beck, U. (1986): Risikogesellschaft. Auf dem Weg in eine andere Moderne. Frankfurt/M.: Suhrkamp.
- Beck, 1987 M. Beck, Water Quality Modeling: a review of the analysis of uncertainty, *Water Resources Research*, **23**, 8
- Beck, 1992 U. Beck, *Risk Society: Towards a New Modernity*, SAGE, London
- Beck, 1992 Ulrich Beck, *Risk Society. Towards a New Modernity*, London: Sage Publications, 1992.
- Beck, Giddens and Lash, 1994 U. Beck, A. Giddens, S. Lash, *Reflexive Modernisation: politics, tradition and Aesthetics in the Modern Social Order*, Polity, London
- Bell et al, 1977 D. E. Bell, R. L. Keeney, H. Raiffa, *Conflicting Objectives in Decisions*, John Wiley and Sons, Chichester, 1977
- Beringer, 1998 J. Beringer, Testmony under Cross-Questioning by House of Lords Select Committee, in HoL, 1998
- Bernstein, 1996 P. Bernstein, 'Against the Gods: the remarkable story of risk', Wiley, New York
- Beroggi et al, 1997 Beroggi, G.E.G.; Abbas, T.C.; Stoop, J.A. and Aebi, M. (1997): Risk Assessment in the Netherlands. Arbeitsbericht Nr. 91 der Akademie für Technikfolgenabschätzung. Stuttgart: Akademie für Technikfolgenabschätzung.
- Bezembinder, 1989 T. Bezembinder, Social Choice Theory and Practice, in Vlek and Cvetkovitch, 1989
- Bijker and Law, 1992b J. Law, W. Bijker (eds), '*Shaping Technology / Building Society: studies in sociotechnical change*', MIT Press, Cambridge MASS
- Biodiversity, 1992 UN Convention on Biodiversity, Rio de Janeiro, 1992
- Bodansky, 1991 D. Bodansky, Scientific Uncertainty and the Precautionary Principle, *Environment*, **33**, 7, 4-44
- Boehmer-Christiansen, 1994 S. Boehmer-Christiansen, The Precautionary Principle in Germany - enabling Government in O'Riordan and Cameron, 1994
- Bogetoft and Pruzan, 1991 P. Bogetoft, P. Pruzan, *Planning with Multiple Criteria: investigation, communication, choice*, North Holland, Amsterdam, 1991
- Bohmann, 1996 J. Bohmann, *Public Deliberation: pluralism, complexity and democracy*, MIT Press, Cambridge
- Bonner, 1986 J. Bonner, *Politics, Economics and Welfare: an elementary introduction to social choice*, Harvester Press, Brighton
- Bonß, 1996 W. (1996): Die Rückkehr der Unsicherheit. Zur gesellschaftstheoretischen Bedeutung des Risikobegriffes. In: Banse, G. (ed.): Risikoforschung zwischen Disziplinarität und Interdisziplinarität. Berlin: Edition Sigma, 166-185.
- Borcherding et al, 1990 K. Borcherding, O. I. Larichev, D. Messick, Contemporary Issues in Decision Making, North Holland, Netherlands, 1990
- Brealey and Myers, 1988 R. Brealey, S. Myers, *Principles of Corporate Finance*, Third Edition, McGraw Hill, New York
- Brehmer 1997 Brehmer, B. (1987): The Psychology of Risk. In: Singleton, W.T. and Howden, J. (eds.): Risk and Decisions. New York: Wiley, 25-39.
- Brooks 1973 H. Brooks, The State of the Art: technology assessment as a process, *the Social Assessment of Technology, International Social Science Journal*, **25**, 3, 253
- Brooks, 1986 H. Brooks, *The Typology of Surprises in Technology, Institutions and Development*, in Clark and Munn, 1986
- Brown, 1996 George E. Brown, Jr., Environmental Science Under Siege. A Report by Repr. George E. Brown, Jr., US Congress, Oct. 23, 1996.
- Bruhèze, 1992 A.A. Albert de la Bruhèze, 'Closing the Ranks: Definition and Stabilization of Radioactive Wastes in the US Atomic Energy Commission, 1945-1960,' in W.E. Bijker and J. Las (eds.), *Shaping technology/building society: studies in sociotechnical change*, Cambridge, Mass.: MIT Press, 1992, pp. 140-174.
- Bunn and Salo, 1993 D. Bunn, A. Salo, Forecasting with Scenarios. *European Journal of Operational Research* **69**, 291-303.

- Bunn, 1984 D. Bunn, *Applied Decision Analysis*. New York: McGraw-Hill.
- CA, 1998 'Confronting Risk: report of a workshop run by Consumers Association, Unilever and Sainsbury's', London, 1998
- Callon and Rip, 1992 Michel Callon, Arie Rip, 'Humains, non-humains: morale d'une coexistence, in: Jacques Theys & Bernard Kalaora (dir.), *La Terre outragée. Les experts sont formel!* (Paris: Ed. Autrement, 1992. Série Sciences en société no. 1. ISBN , 140-156.
- Cambrosio, Limoges and Hoffman, 1992 Alberto Cambrosio, Camille Limoges and Eric Hoffman, 'Expertise as a Network: A Case Study of the Controversies over the Environmental Release of Genetically Engineered Organisms,' in Nico Stehr and Richard V. Ericson (eds.), *The Culture and Power of Knowledge* (Berlin and New York: De Gruyter, 1992), 341-361.
- Cameron and Abouchar, 1991 J. Cameron, J. Abouchar, *The Precautionary Principle: A Fundamental Principle of Law and Policy for the Protection of the Global Environment*, Boston College International Comp. Law Review, **14** 1-27
- Cameron and Edge, 1979 I. Cameron, D. Edge, *Scientific Images and their Social Uses: an introduction to the concept of scientism*, Butterworth SISCO, London.
- Campbell, 1979 Donald T. Campbell, 'A Tribal Model of the Social System Vehicle Carrying Scientific Knowledge,' *Knowledge* 1(2) (December 1979) 181-201.
- CEC, 1989 California Energy Commission, "*Energy Technology Status Report*", June 1989
- CEPA, 1994 California Environmental Protection Agency (1994): *Toward the 21st Century. Planning for Protection of California's Environment. Final Report*. Sacramento, Cal.: EPA.
- Chankong and Haimes, 1983 V. Chankong, Y. Haimes, *Multi-objective Decision Making: theory and methodology*, North Holland Series in System Science and Engineering, Volume 8, North Holland, New York, 1983
- Chapman, 1997 P. Chapman, *The Precautionary Principle and Ecological Quality Standards/objectives*, *Marine Pollution Bulletin*, **34**, 227-8
- Chernick & Caverhill, 1989 P. Chernick, E. Caverhill, '*The Valuation of Externalities from Energy Production, Delivery and Use, Fall 1989 Update*', Chernick and Caverhill Inc., Boston, 1989
- Clark and Munn, 1996 W.Clark, W.Munn, *Sustainable Development of the Biosphere*, IIASA / CUP, Cambridge
- Clark, 1985 Kim B. Clark, 'The interaction of design hierarchies and market concepts in technological evolution,' *Research Policy* 14 (1985) 235-251.
- Clemen, 1991 R.T. Clemen, *Making Hard Decisions: an introduction to decision analysis*, North Holland Series in System Science and Engineering, Volume 8, PWS Kent Publishing, Boston, 1991
- Cline, 1992 W. Cline '*The Economics of Global Warming*', Institute for International Economics, Washington DC, 1992
- Cohen & Pritchard, 1980 A.V. Cohen, D.K. Pritchard, '*Comparative Risks of Electricity Production: a critical survey of the literature*', UK Health and Safety Executive Research Paper 11, HMSO, 1980
- Collingridge, 1980 David Collingridge, *The Social Control of Technology*, London: Frances Pinter (Publishers), 1980.
- Collingridge, 1980 D. Collingridge, *The Social Control of Technology*, Open University Press, M. Keynes
- Collingridge, 1982 D. Collingridge, *Critical Decision Making: a new theory of social choice*, Pinter, London
- Collins, 1985 H.M. Collins, *Changing Order. Replication and induction in scientific practice*,. London etc: Sage Publications, 1985.
- Comar & Sagan, 1976 CL Comar, LA Sagan, "Health Effects of Energy Production and Conversion", *Annual Review of Energy*, 1976
- Corner and Kirkwood, 1991 J. Corner, C. Kirkwood, *Decision Analysis Applications in the Operations Research Literature, 1970-1989. Operations Research* **39**, 206-219.
- Costanza and Cornwell, 1992 R. Costanza, L. Cornwell, *The 4P Approach to Dealing with Scientific Uncertainty, Environment*, **34**, 9, 12-42
- Costanza, 1991 R. Costanza, *Ecological Economics*, Columbia University Press, New York
- Costanza, R. and Cornwell, L. (1992). *The 4P Approach to Dealing with Scientific Uncertainty. Environment* 34(9), 12-20, 42.
- Covello, 1983 Covello, V.T. (1983): *The Perception of Technological Risks: A Literature Review. Technological Forecasting and Social Change* 23 (4), 285-297.
- Covello, et al, 1985 V. Covello, J. Mumpower, P. Stallen, V. Uppuluri, *Environmental Impact Assessment, Technology Assessment and Risk Analysis: contributions from the psychological and decision sciences*, Springer / NATO, Berlin

- Craig, 1994 N. Craig, *An Industrialists Perspective*, in Earll, 1994
- Cropper and Oates, 1991 M. Cropper, W. Oates, *Environmental Economics: a survey*, Discussion Paper QE90-12-REV, Resources for the Future, Washington
- Cyranski, 1986 J. Cyranski, *The Probability of a Probability*, in Justice
- Danish Board of Technology, 1996 Bro-Rasmussen et al, 'The Non-assessed Chemicals in the EU', report and recommendations from an interdisciplinary group of Danish experts, Danish Board of Technology,
- De Finetti, 1974 N. de Finetti, *Theory of Probability*, Wiley, New York
- De Marchi and Ravetz, 1998 B. de Marchi, J. Ravetz, *Risk Management and Governance*, Forward Studies Unit, ISIG, Gorizia, 1998
- Deuten, Rip and Jelsma, 1997 J. Jasper Deuten, Arie Rip and Jaap Jelsma, 'Societal Embedment and Product Creation Management,' *Technology Analysis & Strategic Management*, 9(2) (1997), 219-236.
- Deville, A. and Harding, R. (1997). *Applying the Precautionary Principle*. Sydney: The Federation Press.
- Dosi and Egidi, 1987 G. Dosi, M. Egidi, Substantive and Procedural Uncertainty, an Exploration of Economic Behaviours in Complex and Changing Environments, SPRU DRC Discussion Paper No.46, 1987, SPRU, Sussex
- Douglas and Wildavsky, 1982 Mary Douglas and Aaron Wildavsky, *Risk and Culture. An Essay on the Selection of Technological and Environmental Dangers*, Berkeley: University of California Press, 1982.
- Douglas, 1982 Mary Douglas (ed.), *Essays in the Sociology of Perception*, London: Routledge & Kegan Paul, 1982.
- Dovers and Handmer, 1992 S. Dovers, J. Handmer, Uncertainty, Sustainability and Change, *Global Environmental Change*, 12/92,
- Dovers and Handmer, 1995 S. Dovers, J. Handmer, Ignorance, the Precautionary Principle and Sustainability, *Ambio*, 24, 2, 92-7
- Drottz-Sjöberg , 1991 Drottz-Sjöberg, B.-M. (1991): *Perception of Risk. Studies of Risk Attitudes, Perceptions, and Definitions*. Stockholm: Center for Risk Research.
- DTI, 1992 D. Pearce, C. Bann, S. Georgiou, "*The Social Cost of the Fuel Cycles*", report to the UK Department of Trade and Industry by the Centre for Social and Economic Research on the Global Environment, HMSO, September 1992
- Dubois, et al, 1988 D. Dubois, H. Prade, H. Farreny, et al, *Possibility Theory: an approach to computerised processing of uncertainty*, Plenum, New York
- Earll, 1994 R. Earll, *The Precautionary Principle: making it work in practice: workshop report*, Environment Council, London
- EC, 1990 European Commission, Council Directive on the Deliberate Release into the Environment of Genetically Modified Organisms, Directive 90/220/EEC, Brussels, 8 May 1990
- EC, 1992 Treaty of European Union, Maastricht, 1992
- EC, 1998 European Commission, Proposal for a Directive Amending the Council Directive on the Deliberate Release into the Environment of Genetically Modified Organisms, Brussels, 26 February 1998
- ECO Northwest, 1987 ECO Northwest et al, '*Generic Coal Study: Quantification and Valuation of Environmental Impacts*', report commissioned by Bonneville Power Administration, January 1987
- Ecocycle, 1997a Ecocycle Commission, *A Strategy for Recyclable Materials and Products*, Swedish Ministry of Environment, Stockholm
- Ecocycle, 1997b. Ecocycle Commission, *Producer Responsibility for Goods*, Swedish Ministry of Environment, Stockholm, 1997
- Edwards and Newman, 1982 W. Edwards, J.R. Newman, *Multiattribute Evaluation, quantitative applications in the social sciences*, Sage, London, 1982
- EPRI, 1987 Results cited but not referenced in Hohmeyer, 1990
- Esbjerg, 1995 Ministerial Declaration of the Fourth International Conference on the Protection of the North Sea, 8-9 June 1995, Esbjerg, Denmark
- Esbjerg, 1995 Ministerial Declaration of the Fourth International Conference on the Protection of the North Sea, 8-9 June 1995, Esbjerg, Denmark
- Evans, 1986 N. Evans, *Assessing the Risks of Nuclear Energy*, in Harrison and Gretton, 1986
- Everts, 1998 Everts, Saskia, *Gender & Technology. Empowering Women, Engendering Development* (London & New York: Zed Books, 1998).
- Ewald, 1993 Ewald, F. (1993): *Der Vorsorgestaat*. Frankfurt/M.: Sirkamp.

- Externe, 1993 UK Energy Technology Support Unit, CEC, DG XII, et al, "Assessment of the External Costs of the Coal Fuel Cycle", draft position paper prepared for the CEC/US Joint Study on Fuel Cycle Costs, Harwell, February 1993
- Externe, 1995 European Commission 'Externe: externalities of energy' Volumes 1 - 6, EUR 16520 - 16525 EN, Brussels, 1995
- Eyre and Holland, 1993 N. Eyre, M. Holland, External Costs of Electricity Generation Using Coal, in OECD, 1993
- Eyre, 1995 N. Eyre, 'The External Costs of Wind Energy and What They Mean for Energy Policy', paper to the Third International Conference on External Costs, Ladenburg, May 1995
- Faber and Proops, 1994 M. Faber, J. Proops, *Evolution, Time, Production and the Environment*, Springer, Berlin
- Fankhauser, 1993 S. Fankhauser, 'Global Warming Damage Costs: some monetary estimates', CSERGE GEC Working Paper 92-29, University of East Anglia, Norwich, 1992
- Farber, 1995 S. Farber, Economic Resilience and Economic Policy, *Ecological Economics*, **15**, pp105-7
- FCCC, 1992 UN Framework Convention on Climate Change, Rio de Janeiro, June 1992
- Ferguson, 1992 R. Ferguson, results cited in Hohmeyer, 1990 and HoC, 1992 and confirmed by personal communication, November 1991
- Fiorino, 1989 D. Fiorino, Environmental Risk and Democratic Process: a critical review, *Columbia Journal of Environmental Law*, **14**,501
- Fiorino, 1989 Fiorino, D.J. (1989): Technical and Democratic Values in Risk Analysis. *Risk Analysis* 9 (3), 293-299.
- Fiorino, 1990 D. Fiorino, Citizen Participation and Environmental Risk: a survey of institutional mechanisms, *Science, Technology and Human Values*, **15**, 2, 226-243
- Fischhoff et al, 1978 Fischhoff, B.; Slovic, P.; Lichtenstein, S.; Read, S., and Combs, B. (1978): How Safe Is Safe Enough? A Psychometric Study of Attitudes Toward Technological Risks and Benefits. *Policy Sciences* 9 (1), 127-152.
- Fischhoff, Slovic and Lichtenstein 1980 B. Fischhoff, P. Slovic, S. Lichtenstein, *Labile Values: a Challenge for Risk Assessment*, Academic Press, London
- Fleming, D. (1996). The Economics of Taking Care: An Evaluation of the Precautionary Principle. In: D. Freestone and E. Hey (Eds.), *The Precautionary Principle and International Law*, The Hague: Kluwer Law International, 147-167.
- Fonk, 1994 Gertjan Fonk Een constructieve rol van de consument in technologie-ontwikkeling. Constructief Technologisch Aspectenonderzoek vanuit consumentenoptiek, ISBN 90 6573 188-1, 438 pp.(SWOKA, The Hague; Ph.D. thesis, University of Twente, 1994
- Ford, 1983 J. Ford, *Choice, Expectation and Uncertainty: an appraisal of G.L.S. Shackles Theory*, Barnes and Noble, Totowa, NJ
- Freestone, 1994 D. Freestone, *A Legal Perspective*, in Earll, 1994
- French, 1986 S. French, *Decision Theory: An Introduction to the Mathematics of Rationality*. Chichester: Ellis Horwood Ltd.
- Friedrich et al, 1990 R. Friedrich, U. Kallenbach, "External Costs of Electricity Generation" in Hohmeyer & Ottinger, 1990
- Friedrich et al, 1993 R. Friedrich, A. Voss, "External Costs of Electricity Generation", *Energy Policy*, February 1993
- Friend and Jessop, 1977 J.K. Friend, W.N. Jessop, *Local Government and Strategic Choice: an operational research approach to the processes of public planning*, Pergamon, London, 1977
- Fritzsche, 1989 A.F. Fritzsche, "The Health Risks of Energy Production", *Risk Analysis*, Vol.9, No.4, 1989
- Fritzsche, 1986 Fritzsche, A.F. (1986): *Wie sicher leben wir? Risikobeurteilung und -bewältigung in unserer Gesellschaft*. Köln: TÜV Rheinland.
- Funtowicz and Ravetz, 1989a S. Funtowicz, J. Ravetz, *Managing the Uncertainties of Statistical Information*, in Brown
- Funtowicz and Ravetz, 1989b S. Funtowicz, J. Ravetz, *Scientific Uncertainty and Quality Evaluation in Technology Scenarios and R&D Programmes*, in OECD, 1989
- Funtowicz and Ravetz, 1990 S. Funtowicz, J. Ravetz, *Uncertainty and Quality in Science for Policy*, Kluwer, Amsterdam
- Funtowicz and Ravetz, 1991 S. Funtowicz, J. Ravetz, *A New Scientific Methodology for Global Environmental Issues*, in Costanza, 1991
- Funtowicz and Ravetz, 1992 S. Funtowicz, J. Ravetz, *Three Types of Risk Assessment and the Emergence of Post-Normal Science*, in Krinsky and Golding, 1992
- Funtowicz and Ravetz, 1993 S. Funtowicz, J. Ravetz, 'Science for the post-normal age,' *Futures* 25(7) (1993) 735-755

- Furstenberg, 1990 G. Furstenberg, *Acting under Uncertainty*, Kluwer, Dordrecht
- Galison, 1987 P. Galison, *How Experiments End*, Chicago and London: University of Chicago Press, 1987
- Genus, 1995a A. Genus, *Flexible Strategic Management*, Chapman and Hall, London
- Genus, 1995b A. Genus, Walls and Bridges: towards a multidisciplinary approach to the concept of flexibility, *Knowledge in Society*, 1, 2, pp6-22
- Giddens, 1991 A. Giddens, *Modernity and self-identity: self and society in the late modern age*, Polity, London
- Giddens, 1994 Giddens, A. (1994): *Beyond Left and Right. The Future of Radical Politics*. Stanford: Stanford University Press.
- Goodman, 1986 J. Goodman, On Criteria of Insignificant Difference between Two Risks, *Risk Analysis*, 6, 2, 1986, Soc. Risk Anal., USA
- Gould et al, 1988 Gould, L.C.; Gardner, G.Y.; DeLuca, D.R.; Tieman, A.; Doob, L.W. and Stolwijk, J.A.J. (1988): *Perceptions of Technological Risk and Benefits*. New York: Russell Sage Foundation.
- Gray and Bewers, 1996 J. Gray, J. Bewers, 'Towards a Scientific Definition of the Precautionary Principle', *Marine Pollution Bulletin*, 32(11), 768-771.
- Gray and Brewers, 1996 J. Gray, J. Bewers, Towards a Scientific Definition of the Precautionary Principle. *Marine Pollution Bulletin* 32(11), 768-771.
- Gray, 1994 J. Gray, *A Scientists Perspective*, in Earll, 1994
- Gray, 1996 J. Gray, Integrating Precautionary Scientific Methods into Decision-Making. In: D. Freestone and E. Hey (Eds.), *The Precautionary Principle and International Law*, The Hague: Kluwer Law International, 133-146.
- Gross et al, 1994 P. Gross, N. Levitt, *Higher Superstition: The Academic Left and Its Quarrels with Science*, Johns Hopkins University Press, Baltimore, MD, 1994.
- Grove-White al, 1997 R.Grove-White, P.MacNaghten, S.Mayer, B.Wynne, B., (1997) '*Uncertain World: genetically modified organisms, food and public attitudes in Britain*', Lancaster
- Hacking, 1975 I. Hacking, *The Emergence of Probability: a philosophical study of early ideas about probability induction and statistical inference*, Cambridge University Press, Cambridge
- Hagen et al, 1991 D. Hagen, S. Kanef, "*Application of Solar Thermal Technology in Reducing Greenhouse Gas Emissions - Opportunities and Benefits for Australian Industry*", ANUTECH Pty, 1991
- Hämäläinen et al, 1992 R. Hämäläinen, A. Salo, K. Pöysti, Observations about Consensus Seeking in a Multiple Criteria Environment. Proceedings of the 25th Hawaii International Conference on System Sciences, Vol. IV, January 1992, 190-198.
- Hamstra, 1995 A.Hamstra, 'Consumer Acceptance Model for Food Biotechnology', final report, SWOKA, Institute for Consumer Research, Netherlands
- Harrison and Gretton, 1986 L. Harrison, N. Gretton (eds), *Energy UK 1986*, Policy Journals, Newbury
- Hattis and Minkowitz 1997 Hattis, D. and Minkowitz, W.S. (1997): *Risk Evaluation: Legal Requirements, Conceptual Foundations, and Practical Experiences in the United States*. Arbeitsbericht Nr. 93 der Akademie für Technikfolgenabschätzung. Stuttgart: Akademie für Technikfolgenabschätzung.
- Hauptmanns et al, 1987 Hauptmanns, U.; Hertrich, M. and Werner, W. (1987): *Technische Risiken: Ermittlung und Beurteilung*. Berlin: Springer.
- Hauptmanns, 1997 Hauptmanns, U. (1997): *Risk Assessment in the Federal Republic of Germany*. Arbeitsbericht Nr. 94 der Akademie für Technikfolgenabschätzung. Stuttgart: Akademie für Technikfolgenabschätzung.
- Hayek, 1978 F. von Hayek, *New Studies in Philosophy, Politics, Economics and the History of Ideas*, Chicago University Press
- Hazen, 1986 G. Hazen, Partial Information, Dominance, and Potential Optimality in Multiattribute Utility Theory. *Operations Research* 34, 296-310.
- Hey, 1991 E. Hey, The Precautionary Approach: implications of the revision of the Oslo and Paris conventions, *Marine Policy*, 15, 4,244-54
- Hey, 1992 E. Hey, *The Precautionary Principle and the LDC*, Erasmus University
- Hischemöller and Hoppe, 1996 M. Hischemöller, R. Hoppe, 'Coping with intractable controversies: the case of problem structuring in policy design and analysis, *Knowledge and Policy* 8(4) (1996) 40-60.
- HMSO (1993). Report of the Committee on the Ethics of Genetic Modification and Food Use. London: Ministry of Agriculture, Fisheries and Food.
- Hogwood and Gunn, 1984 B. Hogwood, L. Gunn, *Policy Analysis for the Real World*, Oxford University Press, Oxford

- Hohmeyer & Ottinger, 1990 O. Hohmeyer, R. Ottinger (eds), "External Environmental Costs of Electric Power Production and Utility Acquisition Analysis and Internalization: Proceedings of a German-American Workshop", Fraunhofer ISI, 1990
- Hohmeyer, 1988 O. Hohmeyer, "Social Costs of Energy Consumption: external effects of electricity generation in the Federal Republic of Germany", prepared for DG XII of the European Commission by the Fraunhofer Institut fuer Systemtechnik und Innovationforschung, Springer Verlag, Berlin, 1988
- Hohmeyer, 1990 Hohmeyer, "Latest Results of the International Discussion on the Social Costs of Energy - How Does Wind Compare Today?", presented at the *1990 European Wind Energy Conference*, Madrid, October 1990
- Hohmeyer, 1992 O Hohmeyer, "Renewables and the Full Costs of Energy", *Energy Policy*, April 1992
- HoL, 1998 UK House of Lords Select Committee on the European Communities, Report of the Inquiry into EC Regulation of Genetic Modification in Agriculture', HL-11-1, HMSO, London, 1998
- Holdren et al, 1980 J. Holdren, G Morris, I Mintzer, "Environmental Aspects of Renewable Energy Sources", *Annual Review of Energy*, Vol5, 1980
- Holdren, 1982 J. Holdren, Energy Hazards: what to measure, what to compare, *Technology Review*, MIT, Boston
- Holling, 1994 C. Holling, Simplifying the Complex: the paradigms of ecological function and structure, *Futures*, **26**, 6, 598-609
- Hoppe and Peterse, 1998 R. Hoppe, A. Peterse (ed.), *Bouwstenen voor Argumentatieve Beleidsanalyse*, 's-Gravenhage: Elsevier Bedrijfsinformatie, 1998.
- HSE, 1998 UK Health and Safety Executive, Risk Assessment and Risk Management: improving policy and practice within government departments, second report of ILGRA,
- IAEA et al, 1991 International Atomic Energy Agency, et al, "*Senior Expert Symposium on Electricity and the Environment: key issues papers*", IAEA, Vienna, 1991
- IEC, 1993 IEC (1993): Guidelines for Risk Analysis of Technological Systems. Report IEC-CD (Sec) 381 issues by the Technical Committee QMS/23. Brüssel: European Community.
- Inhaber, 1978 H. Inhaber, "*Risk of Energy Production*", AECB-1119/REV-1, (Canadian) Atomic Energy Control Board, 1978
- IPCC, 1996 J. Houghton et al, *Climate Change 1995 – the science of climate change*, report of IPCC Working Group I, Cambridge University Press, Cambridge
- Jackson and Taylor, 1992 T. Jackson, P. Taylor, *The Precautionary Principle and the Prevention of Marine Pollution*, *Chemistry and Ecology*, **7** 123-134
- Janssen, 1994 R. Janssen, *Multiobjective Decision Support for Environmental Management*, Kluwer, Dordrecht
- Jasanoff and Wynne S. Jasanoff, B. Wynne, 'Science and decisionmaking,' Chapter 1 (Volume 1) in Steve Rayner, Elizabeth L. Malone (eds.), *Human choice and climate change*, Columbus, Ohio: Battelle Press, 1998, pp. 1-87.
- Jasanoff et al 1995 S. Jasanoff, G. Markle, J. Petersen, T. Pinch (eds.), *Handbook of Science and Technology Studies*, Thousand Oaks, Cal.: Sage Publications, 1995
- Jasanoff, 1990 S. Jasanoff, *The Fifth Branch. Science Advisers as Policy Makers*, Cambridge, Mass.: Harvard University Press, 1990.
- Jaynes, 1986 E. Jaynes, *Bayesian Methods: General Background*, in Justice
- Jelsma and Rip, 1995 J. Jelsma, A. Rip, with a contribution by J.L. van Os, *Biotechnologie in Bedrijf. Een bijdrage van Constructief Technology Assessment aan biotechnologisch innoveren.* (The Hague: Rathenau Institute, 1995). ISBN 90 346 32 180. Report of a project to elaborate Constructive TA for firms in the area of biotechnology. English summary available ('Biotechnology in Business').
- Johnson et al, 1998 P. Johnson, D. Santillo, R. Stringer, *Risk Assessment and Reality: recognizing the limitations*, Exeter University
- Jonas, 1979 Jonas, H. (1979): *Das Prinzip der Verantwortung. Versuch einer Ethik für die technologische Zivilisation.* Frankfurt/M.: Insel Verlag.
- Jonas, 1990 Jonas, H. (1990): *Das Prinzip Verantwortung.* In: Schüz, M. (ed.): *Risiko und Wagnis. Die Herausforderung der industriellen Welt.* Band 2. Gerling Akademie. Pfullingen: Neske, 166-181.
- Jordan and O'Riordan, 1998 A. Jordan, T. O'Riordan, *The Precautionary Principle in Contemporary Environmental Policy and Politics*, paper delivered to conference on 'Putting the Precautionary Principle into Practice: how to make 'good' environmental decisions under uncertainty', London Resource Centre, April
- Joss and Durant, 1995 S. Joss, J. Durance, *Public Participation in Science: the role of consensus conferences in Europe*, Science Museum, London

- Jungermann and Slovic, 1993 Jungermann, H and Slovic P. (1993): Charakteristika individueller Risikowahrnehmung. In: Bayerische Rückversicherung (ed.): Risiko ist ein Konstrukt. Wahrnehmungen zur Risikowahrnehmung. München: Knesbeck 89-107.
- Kadvany, J. (1995). From Comparative Risk to Decision Analysis: Ranking Solutions to Multiple-Value Environmental Problems. *Risk* 6, 333.
- Kaplan and Garrik, 1993 Kaplan, S. and Garrik, J.B. (1993): Die quantitative Bestimmung von Risiko. In: Bechmann, G. (ed.): Risiko und Gesellschaft. Grundlagen und Ergebnisse interdisziplinärer Risikoforschung. Opladen: Westdeutscher Verlag: Opladen, 91-124.
- Kates and Kasperson, 1983 Kates, R.W. and Kasperson, J.X. (1983): Comparative Risk Analysis of Technological Hazards. A Review. *Proceedings of the National Academy of Sciences* 80 (21), 7027-7038.
- Keeney and Kirkwood, 1975 R. Keeney, C. Kirkwood, Group Decision Making Using Cardinal Social Welfare Functions. *Management Science* 22(4), 430-437.
- Keeney et al, 1976 R. L. Keeney, H. Raiffa, R. F. Meyer, *Decisions with Multiple Objectives: Preferences and Value Trade-offs*, John Wiley, New York, 1976
- Keeney, 1980 R. L. Keeney, *Siting Energy Facilities*, Academic Press, New York, 1980
- Keeney, Raiffa and Meyer, 1976 R. Keeney, H. Raiffa, R. Meyer, *Decisions with Multiple Objectives: Preferences and Value Trade-offs*, Wiley, New York
- Kelly, 1978 J. Kelly, *Arrow Impossibility Theorems*, Academic Press, New York
- Killick, 1995 T. Killick, Flexibility and Economic Progress, *World Development*, 23, 5, pp721-734
- Kirejczyk and Rip, 1999-05-03 M. Kirejczyk, A. Rip, 'Improving the quality of technology in society through Constructive Technology Assessment,' A.C.L. Verkley and D. Westerheyden (eds),Lemma: 1999, forthcoming.
- Klir and Folger, 1988 G. Klir, T. Folger, *Fuzzy Sets, Uncertainty and Information*, Prentice Hall, New Jersey
- Knight, 1921, F. Knight, *Risk, Uncertainty and Profit*, Houghton Mifflin, Boston
- Kolluru and Brooks, 1995 Kolluru R.V. and Brooks, D.G. (1995): Integrated risk assessment and strategic management. In: Kolluru, R.V.; Bartell, S.; Pitblade, R. and Stricoff, S. (eds.): *Risk Assessment and Management Handbook. For Environmental, Health, and Safety Professionals*. New York: Mc-Graw-Hill, 2.1-2.23.
- Koomey, 1990 J. Koomey, "Comparative Analysis of Monetary Estimates Associated with the Combustion of Fossil Fuels", paper presented to conference of New England Public Utility Commissioners Environmental Externalities Workshop, 1990
- Koomey, 1991 J. Koomey, "Comparative Analysis of Monetary Estimates Associated with the Combustion of Fossil Fuels", paper presented to conference of New England Public Utility Commissioners Environmental Externalities Workshop, 1990
- Kosko and Isaka, 1993 B. Kosko, S. Isaka, Fuzzy Logic, *Scientific American*, July, 62-67
- Krantz et al, 1971 D. Krantz, R. Luce, A. Tversky, *Foundations of Measurement*, Vol. I. New York: Academic Press.
- Krinsky and Golding, 1992 S. Krinsky, L. Golding, *Social Theories of Risk*, Praeger, Westport
- Krinsky, 1997 S. Krinsky, Biotechnology Safety: enabling the safe use of biotechnology, *Environment*, 39, 5
- Krohn and Weyer, 1994 W. Krohn, J. Weyer, 'Society as a Laboratory: the social risks of experimental research,' *Science and Public Policy* 21(3) (June 1994) 173-183.
- Ku, 1995 A. Ku, *Modelling Uncertainty in Electricity Capacity Planning*, D.Phil thesis, 2/95, London Business School
- Kuhlmann, 1998a S. Kuhlmann, Politikmoderation. Evaluationsverfahren in der Forschungs- und Technologiepolitik, Baden-Baden: Nomos Verlagsgesellschaft, 1998
- Kuhlmann, 1998b S. Kuhlmann, 'Moderation of Policy-Making? Science and Technology Policy Evaluation Beyond Impact Measurement - The Case of Germany,' *Evaluation* 4(2) (1998b) 130-148.
- Kuhn, 1970, T. Kuhn, *The Structure of Scientific Revolutions*, Chicago University Press, Chicago
- Lash, Szerszynski and Wynne, 1996 S. Lash, B. Szerszynski, B. Wynne, *Risk, Environment and Modernity: towards a new ecology*, Sage, London
- Law and Bijker, 1992a J. Law, W. Bijker, *Postscript: Technology, Stability and Social Theory* in Bijker and Law (1992)
- Lazarus et al, 1993 M. Lazarus, et al, 'Towards Global Energy Security: the next energy transition - an energy scenario for a fossil free energy future' Stockholm Environment Institute, Greenpeace International, Amsterdam, February 1992
- Lee, 1989 N. Lee, *Environmental Impact Assessment: a Training Guide*, Occasional Paper 18, Environmental Impact Assessment Centre, University of Manchester

- Leist and Schaber, 1995 Leist, A. and Schaber, P. (1995): Ethische Überlegungen zu Schaden, Risiko und Unsicherheit. In: Berg, M.; Erdmann, G.; Leist, A.; Renn, O.; Schaber, P.; Scheringer, M.; Seiler, H. and Wiedemann, R. (eds.): Risikobewertung im Energiebereich. Zürich: VDF Hochschulverlag, 47-70.
- Lele and Norgaard, 1996 S. Lele, R. Norgaard, Sustainability and the Scientist's Burden, *Conservation Biology*, **10**, 2, 354-365
- Levidow et al, 1996 L. Levidow, S. Carr, R. von Schomberg, D. Wield, Regulating Agricultural Biotechnology in Europe: Harmonisation Difficulties, Opportunities, Dilemmas. *Science and Public Policy* 23(3), 135-157.
- Levidow, 1998 L. Levidow, Democratizing Technology - or Technologizing Democracy? *Regulating Agriculture Biotechnology in Europe*. *Technology in Society*, 20(2), 211-226.
- Lindblom and Woodhouse, 1993 C. Lindblom E. Woodhouse, *The Policy-Making Process*, Third Edition, Englewood Cliffs, N.J., 1993.
- Lindsay, 1995 R. Lindsay, Galloping Gertie and the Precautionary Principle: how is environmental impact assessment assessed?, in Wakeford and Walters, 1995
- Litfin, 1995 K. Litfin, 'Framing Science: precautionary discourse and the ozone treaties', *Millenium: Journal of International Studies*, V24, N2, 1995, pp251-277
- Loasby, 1976 B. Loasby, *Choice, Complexity and Ignorance: an inquiry into economic theory and the practice of decision making*, Cambridge University Press, Cambridge
- Löfstedt, 1997 Löfstedt, R.E. (1997): Risk Evaluation in the United Kingdom: Legal Requirements, Conceptual Foundations, and Practical Experiences with Special Emphasis on Energy Systems. *Arbeitsbericht Nr. 92 der Akademie für Technikfolgenabschätzung*. Stuttgart: Akademie für Technikfolgenabschätzung.
- Luce and Raiffa, 1957 R. Luce, H. Raiffa, An Axiomatic Treatment of Utility, in Luce and Raiffa
- Luhmann, 1991 N. Luhmann, *Risk: A Sociological Theory*, de Gruyter, Berlin
- Lumby, 1984 S. Lumby, *Investment Appraisal*, second edition, Van Nostrand, London
- MacGarvin, 1995 M. MacGarvin, The Implications of the Precautionary principle for Biological Monitoring, *Helgolander Meeresuntersuchung*, **49**, 647-662
- MacKay, 1980 A. MacKay, *Arrow's Theorem: the paradox of social choice - a case study in the philosophy of economics*, Yale University Press, New Haven
- MacKenzie and Wajcman, 1985 D. MacKenzie, J. Wajcman (eds.), *The Social Shaping of Technology. How the Refrigerator Got Its Hum* (Milton Keynes: Open University Press, 1985).
- MacKenzie, 1990 D. MacKenzie, *Inventing Accuracy. A historical sociology of nuclear missile guidance*, Cambridge, MA: MIT Press, 1990.
- Malkiel, 1989 B. Malkiel, Is the Stock Market Efficient?, *Science*, **243**, 1313-1318
- Markowitz, 1990 Markowitz, J. (1990): Kommunikation über Risiken - Eine Theorie-Skizze. *Schweizerische Zeitschrift für Soziologie* 16 (3), 385-420.
- Marris et al, 1996 C.Marris, I.Langford, T.O'Riordan, 'Integrating Sociological and Psychological Approaches to Public Perceptions of Environmental Risks: detailed results from a questionnaire survey', CSERGE, Norwich
- May, 1972 R. May, Will a Large Complex System be Stable? *Nature*, **238**, pp413-4
- Mayer 1994 S. Mayer, *An Environmentalist's Perspective*, in Earll 5118
- Mayer and Stirling, 1999 S. Mayer, A. Stirling, Confronting Risk: A Pilot Multi-Criteria Mapping of a GM Crop in Agricultural Systems in the UK. Peer Review Draft, 12 March 1999.
- Mayo, 1982 H. Mayo, Thoughts on the Adequacy of Performance of Technology Assessments. *Technological Forecasting and Social Change* 22, 267-298.
- Mee, 1996 L. Mee, Scientific Methods and the Precautionary Principle. In: D. Freestone and E. Hey (Eds.), *The Precautionary Principle and International Law*, The Hague: Kluwer Law International, 109-131.
- Merkhofer, 1982 M. Merkhofer, A Process for Technology Assessment Based on Decision Analysis. *Technological Forecasting and Social Change* 22, 237-265.
- Meyer et al, 1994 H.J. Meyer, P.E. Morthorst, L. Schleisner, 'Assessment of Environmental Costs: External Effects of Energy Production', submitted to 18th IAEE International Conference, revised version, July 1995, Riso, 1995
- Mikkelsen et al, 1996, T.Mikkelsen, B.Anderssen, R.Jorgensen, 'The Risk of Crop Transgene Spread' *Nature*, **380**, 7/3/96:31
- Miller, 1993 Miller, D. (1993): Deliberative Democracy and Social Choice. In: Held, D. (ed.): *Prospects for Democracy*. North, South, East, West. Cambridge: Polity Press, 74-92.

- Mintzberg et al, 1998 H. Mintzberg, J. Quinn, S. Ghoshal, *The Strategy Process*. Revised European Edition, Hemel Hempstead: Prentice Hall Europe, 1998.
- Morgan, Henrion and Small, 1990 M. Morgan, M. Henrion, M. Small, *Uncertainty: a guide to dealing with uncertainty in quantitative risk and policy analysis*, Cambridge University Press, Cambridge
- Mortimer, 1991 N.D. Mortimer, "Energy Analysis of Renewable Energy Sources", *Energy Policy*, Vol.17, No.4, May 1991
- Moskowitz et al, 1992 H. Moskowitz, P. Preckel, A. Yang. Multiple-Criteria Robust Interactive Decision Analysis (MCRID) for Optimizing Public Policies. *European Journal of Operational Research* 56, 219-236.
- MOW, 1983 Ministerie van Onderwijs en Wetenschappen, *Integratie van Wetenschap en Technologie in de Samenleving*. Beleidsnota, 's-Gravenhage: Tweede Kamer 1983-1984, 18 421, nrs. 1-2. (Policy Memorandum: Integration of Science and Technology in Society)
- Murray, 1998 J. Murray, *Hamlet on the Holodeck. The Future of Narrative in Cyberspace*, Cambridge, Mass.: MIT Press, 1998.
- Myers, 1984 S. Myers, *Finance Theory and Financial Strategy*, *Interfaces*, **14**
- Nijkamp, Rietveld and Voogd, 1990 P. Nijkamp, P. Rietveld, H. Voogd, *Multicriteria Evaluation in Physical Planning*, North Holland, Amsterdam
- Nordlee et al, 1996 J.Nordlee, S.Taylor, J.Townsend, L.Thomas, R.Bush, 'Identification of a Brazil-Nut Allergen in Transgenic Soybeans', *New England Journal of Medicine*, **334**, 688-92.
- North, 1990 D. North, *Institutions, Institutional Change and Economic Performance*, Cambridge: Cambridge University Press, 1990.
- Norton, 1995 B. Norton, *Resilience and Options*, *Ecological Economics*, **15**, pp133-136
- NRC, 1993 National Research Council, Committee on the Institutional Means for Assessment of Risks to Public Health (1983): *Risk Assessment in the Federal Government: Managing the Process*. National Academy of Sciences. Washington: National Academy Press.
- NRC, 1996 H. Fineberg, *Understanding Risk: informing decisions in a democratic society*, National Research Council Committee on Risk Characterisation, National Academy Press, Washington
- O'Neill, 1993 J. O'Neill, *Ecology, Policy and Politics: human well-being and the natural world*, Routledge London
- O'Riordan and Cameron, 1994 T. O'Riordan, J. Cameron, *The History and Contemporary Significance of the Precautionary Principle*, in O'Riordan and Cameron, 1994
- O'Riordan and Cameron, 1994 T. O'Riordan, J. Cameron, *Interpreting the Precautionary Principle*, Earthscan, London
- Ockhuizen et al, 1996 T. Ockhuizen, M. Smith, M. Teuber, R. Walker, R. de Vogel,. *The Safety Assessment of Novel Foods. Guidelines prepared by ILSI Europe novel food task force*. *Food and Chemical Toxicol.* 34, 931-940.
- O'Connor, 1994 M.O'Connor, *Complexity and Coevolution: methodology for a positive treatment of indeterminacy*, *Futures*, **26**, 6, 598-609
- OECD, 1989a OECD, "Energy Technologies for Reducing Greenhouse Emissions", Paris, 1989
- OECD, 1989b Organisation for Economic Cooperation and Development, *Environmental Policy Benefits: Monetary Evaluation*, OECD, Paris
- OECD, 1993a OECD, *Expert Workshop on Life Cycle Analysis of Energy Systems*, OECD, Paris
- OECD, 1993b OECD, *Guidelines for the Testing of Chemicals*, Vos 1 and 2, Paris, 1993
- O'Riordan and Cameron, 1994 T. O'Riordan, J. Cameron (eds), *Interpreting the Precautionary Principle*, Earthscan, London
- Ostrom, 1992 E. Ostrom, *Crafting Institutions for Self-Governing Irrigation Systems*, San Francisco: Institute for Contemporary Studies, 1992.
- Ottinger et al, 1990 R.L. Ottinger, D.R. Wooley, N.A. Robinson, D.R. Hodas, S.E. Babb, "*Environmental Costs of Electricity*", prepared for NYSERDA and US DOE by Pace University Center for Environmental Legal Studies, Oceana Publications, 1990
- Ottinger, 1990 R. Ottinger, "Getting at the True Cost of Electric Power", *The Electricity Journal*, July 1990
- Ouwens et al, 1987 C. Daey Ouwens, P. van Hoogstraten, J. Jelsma, F. Prakke, A. Rip, *Constructief Technologisch Aspectenonderzoek. Een Verkenning* (Den Haag: Staatsuitgeverij, 1987) (NOTA Voorstudie 4)
- Pearce and Nash, 1981 D. Pearce, C. Nash, *The Social Appraisal of Projects: a text in cost-benefit analysis*, MacMillan, London
- Pearce and Turner, 1990 D. Pearce, R. K. Turner, *Economics of Natural Resources and the Environment*, Harvester Wheatsheaf, New York

- Pearce et al, 1992 D. Pearce, C. Bann, S. Georgiou *The Social Cost of Fuel Cycles: report to the UK Department of Trade and Industry*, HMSO, London
- Pearce, 1993 D. Pearce, 'The Economic Value of Externalities from Electricity Sources', Paper presented at Green College Seminar, University of Oxford, April 1993
- Pearce, D. and Markandya, A. (1989). *Environmental Policy Benefits: Monetary Evaluation*. Paris: OECD.
- Perrings, 1991 C. Perrings, *Reserved Rationality and the Precautionary Principle: Technological Change, Time and Uncertainty in Environmental Decision Making*, in Costanza, 1991
- Petersen and Markle, 1981 J. Petersen G. Markle, 'Expansion of Conflict in Cancer Controversies,' in Louis Kriesberg (ed.), *Research in Social Movements, Conflicts and Change*, Volume 4, JAI Press, 1981, pp. 151-169.
- Petringa, 1997 Petringa, N. (1997): *Risk Regulation: Legal Requirements, Conceptual Foundations and Practical Experiences in Italy. Case Study of the Italian Energy Sector*. Arbeitsbericht Nr. 90 der Akademie für Technikfolgenabschätzung. Stuttgart: Akademie für Technikfolgenabschätzung.
- Pimm, 1984 S. Pimm, *The Complexity and Stability of Ecosystems*, *Nature*, **307**, 321-326
- Pinkus and Dixson, 1981 C. E. Pinkus, Anne Dixson, *Solving Local Government Problems: practical applications of operations research in cities and regions*, George Allen & Unwin, London, 1981
- Porter et al, 1980 A. Porter, F. Rossini, S. Carpenter, A. Roper, R. Larson, J. Tiller, *A Guidebook for Technology Assessment and Impact Analysis*. New York: North-Holland.
- Porter, 1995 T. Porter, *Trust in Numbers*, Princeton University Press, Princeton
- Poumadère and Mays, 1997 Poumadère, M. and Mays, C. (1997): *Energy Risk Regulation in France*. Arbeitsbericht Nr. 89 der Akademie für Technikfolgenabschätzung. Stuttgart: Akademie für Technikfolgenabschätzung.
- R. Smits and J. Leyten, *Technology Assessment: Waakhond of Speurhond? Naar een integraal technologiebeleid*, Amsterdam: Free University, PhD dissertation, 1991.
- Ramsay, 1979 W. Ramsay, *"Unpaid Costs of Electrical Energy: health and environmental impacts from coal"*, *Resources for the Future*, John Hopkins University Press, 1979
- Ravetz, 1987 J. Ravetz, 'Usable Knowledge, Usable Ignorance: Incomplete Science With Policy Implications,' *Knowledge* 9(1) (September 1987) 87-116.
- Ravetz, 1992 J. Ravetz, *Three Types of Risk Assessment and the Emergence of Post-Normal Science*, in Krinsky, S. and Golding, D. (eds.), *Social Theories of Risk*, Prager, Westport 1992, pp. 251-274.
- Rawls, 1971 Rawls, J. (1971): *A Theory of Justice*. Cambridge: Harvard University Press.
- Rawls, 1974 Rawls, J. (1974): *Some Reasons for the Maximin Criterion*. *American Economic Review* 1, 141-146.
- Rayner and Cantor, 1987 S. Rayner, R. Cantor, *How Fair is Safe Enough? The Cultural Approach to Societal Technology Choice*, *Risk Analysis*, **7**, 1, 3
- RCEP. 1998 UK Royal Commission on Environmental Pollution, *Setting Environmental Standards*, Twenty-first Report, HMSO, London, 1998
- Renn and Klinke, 1998 O. Renn, A. Klinke, 'Risk Evaluation and Risk Management for Institutional and Regulatory Policy', scoping paper prepared by AFTA-BW for ESTO project on 'Technological Risk and the Management of Uncertainty' conducted for the EC Forward Studies Unit, December 1998.
- Renn, 1989 Renn, O. (1989): *Risikowahrnehmung - Psychologische Determinanten bei der intuitiven Erfassung und Bewertung von technischen Risiken*. In: Hosemann, G. (ed.): *Risiko in der Industriegesellschaft*. Nürnberg: Universitätsbibliothek, 167-192.
- Renn, 1992 Renn, O. (1992): *Concepts of Risk: A Classification*. In: Krinsky, S. and Golding, D.: *Social Theories of Risk*. Westport, CT.: Praeger, 53-79.
- Renn, 1996 Renn, O. (1996): *Kann man die technische Zukunft voraussagen? Zum Stellenwert der Technikfolgenabschätzung für eine verantwortbare Zukunftsvorsorge*. In: Pinkau, K. and Stahlberg, C. (eds.): *Technologiepolitik in demokratischen Gesellschaften*. Stuttgart: Edition Universitas and Wissenschaftliche Verlagsgesellschaft, 23-51.
- Renn, 1997 Renn, O. (1997): *Three Decades of Risk Research: Accomplishments and New Challenges*. *Journal of Risk Research* 11 (1), 49-71.
- Renn, Webler and Wiedeman, 1995 O. Renn, T. Webler, P. Wiedemann, *Fairness and Competence in Citizen Participation: evaluating models for environmental discourse*, Kluwer, Dordrecht
- Rescher, 1983 N. Rescher, *A Philosophical Introduction to the Theory of Risk Evaluation and Management*. London: University Press of America.
- Rescher, 1993 Nicholas Rescher, *Pluralism: against the demand for consensus*, Clarendon Press, Oxford

- Reynolds, 1999 P. Reynolds, 'Mother Nature's Wrath. Scientists try to predict climatic changes for the benefit of the overburdened insurance industry,' *Time* (February 22, 1999) 52.
- Rip and Kemp, 1998 A Rip R. Kemp, 'Technological Change,' in S. Rayner and E.L. Malone (eds), *Human Choice and Climate Change*, Columbus, Ohio: Battelle Press, 1998. Volume 2, Ch. 6, pp. 327-399.
- Rip and Talma, 1998 A Rip, S. Talma, 'Antagonistic patterns and new technologies,' in C. Disco and B.J.R. van der Meulen (eds.), *Getting New Technologies Together* (Berlin: Walter de Gruyter, 1998), pp. 285-306.
- Rip, 1986a A Rip, 'Controversies as Informal Technology Assessment', *Knowledge* 8(2) (Dec. 1986) 349-371.
- Rip, 1986b A. Rip, 'The Mutual Dependence Between Risk Research and Political Context', *Science and Technology Studies* 4(3/4) (Fall/Winter 1986) 3-15.
- Rip, 1988 A. Rip, 'Should Social Amplification of Risk Be Counteracted?', *Risk Analysis* 8(2) (1988) 193-197.
- Rip, 1991 A Rip, 'The Danger Culture of Industrial Society' in Roger E. Kasperon, Pieter Jan M. Stallen (eds.), *Communicating Risks to the Public. International Perspectives* (Dordrecht, Kluwer Academic, 1991) 345-365. ISDN.
- Rip, 1992 A. Rip, 'Expert Advice and Pragmatic Rationality', in Nico Stehr and Richard V. Ericson (eds.), *The Culture and Power of Knowledge* (Berlin and New York: De Gruyter, 1992) 357-373.
- Rip, 1992 A. Rip, 'The Development of Restrictedness in the Sciences,' in N. Elias, H. Martins and R. Whitley (eds.), *Scientific Establishments and Hierarchies*, Dordrecht: Kluwer, 1992, pp. 219-238.
- Rip, 1994 A Rip, 'Science & Technology Studies and Constructive Technology Assessment'. *EASST Newsletter* 13(3), ISSN 0254 9603, Sept. 1994, 11-16. Keynote Speech to EASST Conference, Budapest, 28-31 August 1994. With Comments by John Ziman, Les Levidov, and Andrew Barry.
- Rip, 1995 A Rip, 'Introduction of New Technology: Making Use of Recent Insights from Sociology and Economics of Technology,' *Technology Analysis & Strategic Management* 7(4) (1995) 417-431.
- Rip, 1997 A. Rip, 'A Cognitive Approach to Relevance of Science,' *Social Science Information*, 1997, 36(4), 615-640.
- Rip, 1998 A. Rip, 'Views from Social Studies of Science and Constructive Technology Assessment', scoping paper prepared by CSS Twente for ESTO project on 'Technological Risk and the Management of Uncertainty' conducted for the EC Forward Studies Unit, December 1998.
- Rip, Misa and Schot, 1996 A. Rip, T. Misa, J/. Schot, *Managing Technology in Society*, Pinter, London
- Rip, Nieuwpoort and Verbeek, 1972 A. Rip, A. Nieuwpoort, G. Verbeek, 'Het maatschappelijk kader van milieuchemie,' *Chemisch Weekblad* (1 december 1972) 16-19.
- Rip, Smit and van der Meulen, 1995 A. Rip, W. Smit, B. van der Meulen, 'Radioactive Waste Disposal: Taking Societal Views into Account', in OECD, *Environmental and ethical aspects of long-lived radioactive waste disposal* (Paris: OECD/Nuclear Energy Agency, 1995), pp. 184-201. ISBN 92-64-14373-4. Proceedings of an International Workshop organized by the Nuclear Energy Agency in co-operation with the Environment Directorate, Paris, 1-2 September 1994.
- Rip, van den Belt and Schwarz, 1987 A. Rip, H. Van den Belt, M. Schwarz, 'Theoretische Analyses', in C. Daey Ouwens, P. van Hoogstraten, J. Jelsma, F. Prakke, A. Rip, *Constructief Technologisch Aspectenonderzoek. Een Verkenning* (Den Haag: Staatsuitgeverij, 1987) (NOTA Voorstudie 4), 14-29.
- Rissler and Melton, 1996 J. Rissler, M. Mellon, *The Ecological Risks of Engineered Crops*. Cambridge, MA: MIT Press.
- Rivett, 1980 P. Rivett, *Model Building for Decision Analysis*, Wiley, Chichester, 1980
- Rogers, 1998 M. Rogers, *Scientific and Technological Uncertainty: the precautionary principle scenarios and risk management*, Forward Studies Unit, Brussels
- Rohrmann, 1995 Rohrmann, B. (1995): *Risk Perception Research: Review and Documentation*. Studies in Risk Communication 48, Jülich: Forschungszentrum.
- Rosa, 1997 Rosa, E. (1997): *Metatheoretical Foundations for Post-Normal Risk*. *Journal of Risk Research* 1 (1), 15-44.
- Rosa, 1998 E. Rosa, *Metatheoretical Foundations for Post-Normal Risk*, *Journal of Risk Research*, 1, 1, 15-44
- Rosenberg, 1996 N. Rosenberg, *Uncertainty and Technological Change*, in Landau, Taylor and Wright
- Rowe, 1994 W. Rowe, *Understanding Uncertainty*, *Risk Analysis*, 14, 5, 743-50
- Royal Society, 1992 Royal Society, *Risk: analysis, perception and management: report of a Royal Society study group*, Royal Society, London
- Royal Society, 1998 Royal Society, *Genetically Modified Plants for Food Use*, statement, Royal Society, London
- Rp, 1998 A. Rip, 'Modern and Post-Modern Science Policy,' *EASST Review* 17(3) (Sept. 1998) 13-16.

- Saaty, 1988 T.J. Saaty, *Multi-criteria Decision Making: the analytic hierarchy process*, 1988
- Salo and Hämäläinen, 1992 A. Salo, R. Hämäläinen, Preference Assessment by Imprecise Ratio Statements. *Operations Research* 40(6), 1053-1061.
- Salo and Hämäläinen, 1997a A. Salo, R. Hämäläinen, On the Measurement of Preferences in the Analytic Hierarchy Process. *Journal of Multi-Criteria Decision Analysis* 6, 309-319.
- Salo and Hämäläinen, 1997b A. Salo, R. Hämäläinen, PRIME - Preference Ratios in Multiattribute Evaluation. Helsinki University of Technology, Systems Analysis Laboratory, Research Reports A38???.
- Salo et al, 1998 A. Salo, V. Kauppinen, M. Rask, *Plant Gene Technology in Food Production*. Parliament of Finland, Committee for the Future, Technology Assessment 3.
- Salo, A.A. (1995). Interactive Decision Aiding for Group Decision Support. *European Journal of Operational Research* 84, 134-149.
- Santillo et al, 1998 D. Santillo, R. Stringer, P. Johnston, J. Tickner, The Precautionary Principle: protecting against failures of scientific method and risk assessment, *Marine Pollution Bulletin*, **36**, 12, 939-950
- Sastry and Bodson 1989 S. Sastry, M. Bodson, *Adaptive Control: stability, convergence and robustness*, Prentice Hall, New Jersey
- Schmalz-Bruns, 1995 Schmalz-Bruns, R. (1995): *Reflexive Demokratie. Die demokratische Transformation moderner Politik*. Baden-Baden: Nomos:
- Schneider et al, 1998 S. Schneider, B. Turner, H. Garriga, Imaginable Surprise in Global Change Science, *Journal of Risk Research*, **1**, 2, 165-186
- Schneider, 1991 V. Schneider, *The Governance of Large Technical Systems: the case of telecommunications*, in La Porte
- Schneider, Turner and Garriga, 1998 S. Schneider, B. Turner, H. Garriga, Imaginable Surprise in Global Change Science, *Journal of Risk Research*, **1**, 2, 165-186
- Schomberg, R. 1998. An Appraisal of the Working in Practice of Directive 90/220/EEC on the Deliberate Release of Genetically Modified Organisms. Working Document for the STOA Panel, PE 166.953, Luxemburg, January 1998.
- Schon, 1983 D. Schön, *The Reflective Practitioner. How professionals think in action*, New York: Basic Books, 1983.
- Schot and Rip, 1996 J. Schot, A. Rip, The Past and Future of Constructive Technology Assessment. *Technological Forecasting and Social Change* 54, 251-268.
- Schot and Rip, 1997 J. Schot, A. Rip, 'The Past and Future of Constructive Technology Assessment,' *Technological Forecasting and Social Change*, 54 (1997) 251-268.
- Schot, 1991 J. Schot, *Maatschappelijke sturing van technische ontwikkeling. Constructief Technology Assessment als hedendaags Luddisme*, Delft: Eburon, 1991.
- Schot, Hoogma and Elzen, 1994 J. Schot, R. Hoogma, B. Elzen, 'Strategies for shifting technological systems. The case of the automobile system,' *Futures* 26 (1994) 1060-1076.
- Schwarz and Thompson, 1990 M. Schwarz, M. Thompson, *Divided We Stand: Redefining Politics, Technology and Social Choice*, Harvester Wheatsheaf, New York
- Sclove, 1995 R. Sclove, *Democracy and Technology*, Guildford Press, New York
- Seidler and Levin, 1994 R. Seidler, M. Levin, Potential Ecological and Nontarget Effects of Transgenic Plant Gene Products on Agriculture, Silviculture, and Natural Ecosystems: General Introduction. *Molecular Ecology* 3, 1-3.
- Shackle, 1968 G. Shackle, *Uncertainty in Economics and other Reflections*, Cambridge University Press, Cambridge
- Shackley and Wynne, 1996 S. Shackley B. Wynne, 'Representing Uncertainty in Global Climate Change Science and Policy: Boundary-Ordering Devices and Authority,' *Science, Technology & Human Values* 21 (1996) 275-302.
- Shilberg, 1989 G.M. Shilberg, J.A. Nahigian, W.B. Marcus, "*Valuing Reductions in Air Emissions and Incorporation into Electric Resource Planning: Theoretical and Quantitative Aspects*", JBS Energy Inc., 1989
- Shohet, 1996 S. Shohet, *Biotechnology in Europe: Contentions in the Risk-Regulating Debate*. *Science and Public Policy* 23(2), 117-122.
- Short, 1984 Short, J.F. (1984): *The Social Fabric of Risk: Toward the Social Transformation of Risk Analysis*. *American Sociological Review* 49 (6), 711-725.
- Shuman & Cavanagh, 1982 M. Shuman, R. Cavanagh 'A Model Conservation and Electric Power Plan for the Pacific Northwest, Appendix 2: Environmental Costs', Northwest Conservation Act Coalition, Seattle, November 1982.
- Simha, Hemalatha and Balakrishnan, 1979 S. Simha, D. Hemalatha, S. Balakrishnan, *Investment Management: introduction to securities analysis*, Institute for Financial Management & Research, Madras, Vora and Co., Bombay

- Slovic, 1987 Slovic, P. (1987): Perception of Risk. *Science* 236 (4799), 280-285.
- Smith, 1994a, P. Smith, Fuzzy Applications in Project Appraisal: Part 1 discrete fuzzy sets, *Project Appraisal*, **9**, 2, 99
- Smith, 1994b P. Smith, Fuzzy Applications in Project Appraisal: Part 2 fuzzy numbers, *Project Appraisal*, **9**, 3, 195
- Smithson, 1989 M. Smithson, *Ignorance and Uncertainty: emerging paradigms*, Springer, New York
- Snow and Palma, 197 A. Snow, P. Palma. Commercialization of Transgenic Plants: Potential Ecological Risks. *BioScience* 47(2), 86-96.
- Sparks and Shepherd, 1994 P. Sparks, R. Shepherd, Public Perceptions of the Potential Hazards Associated with Food Production and Food Consumption: An Empirical Study. *Risk Analysis* 14, 799-806.
- Starr and Zeleny, 1977 M. K. Starr, M. Zeleny, *Multiple Criteria Decision-Making*, North Holland, Amsterdam, 1977
- Stirling, 1994 'Diversity and Ignorance in Electricity Supply Investment: addressing the solution rather than the problem', *Energy Policy*, **22**, 3
- Stirling, 1996 'Optimising UK Electricity Portfolio Diversity', chapter in G. MacKerron and P. Pearson, (eds), '*The UK Energy Experience: a model or a warning?*', Imperial College Press
- Stirling, 1997 'Multicriteria Mapping: mitigating the problems of environmental valuation?', chapter in J. Foster (ed), '*Valuing Nature: economics, ethics and environment*', Routledge, London
- Stirling, 1998 A. Stirling, Risk at a Turning Point?, *Journal of Risk Research*, **1**, 2, 97-110
- Stocker et al, 1991 L. Stocker, F. Harman, F. Topham, "*Comprehensive Costs of Electricity in Western Australia*", Canberra, 1991
- Suter, 1990 G. Suter, *Uncertainty in Environmental Risk Assessment in Furstenberg*, 1990
- Suter, 1993 G. Suter, *Ecological Risk Assessment*, Lewis, Boca Raton
- Szekely, 1986 G. Szekely, *Paradoxes in Probability Theory and Mathematical Statistics*, Reidel, Dordrecht
- Tickner, 1998 J. Tickner, A Commonsense Framework for Operationalizing the Precautionary Principle, paper presented to Wingspread Conference on Strategies for Implementing the Precautionary Principle, Racine, WI, 23-5/1/98
- Tittes, 1986 Tittes, E. (1986): Zur Problematik der Wahrscheinlichkeitsrechnung bei seltenen Ereignissen. In: Kompes, P.C. (ed.): Technische Risiken in der Industriegesellschaft. Erfassung, Bewertung, Kontrolle. Wuppertal: GfS, 345-372.
- Tol, 1995 R. Tol, results cited in Externe 1995.
- Troyer and Markle, 1983 R. Troyer G. Markle, *Cigarettes. The Battle over Smoking*, New Brunswick, N.J.: Rutgers University Press, 1983.
- UKNCCB, 1995 UK National Consensus Conference on Plant Biotechnology, *Final Report of the UK National Consensus Conference on Plant Biotechnology*, Science Museum, London
- UNCED, 1992 Final Declaration of the UN Conference on Environment and Development, Rio de Janeiro, June 1992
- UNEP, 1985 United Nations Environment Programme, "*Comparative Data on the Emissions, Residuals and Health Hazards of Energy Sources*", Environmental Impacts of the Production and Use of Energy, Part IV, Phase I, UNEP, 1985
- US, 1997 Risk Assessment and Risk Management in Regulatory Decision-Making. The Presidential/Congressional Commission on Risk Assessment and Risk Management. Final Report, vol. 2.
- van den Berg et al, 1995 N. van den Berg, C. Dutilh, G. Huppes, *Beginning LCA: a guide into environmental life cycle assessment*, CML / Unilever / Novem / RIVM
- van den Daele and Neidhardt, 1996 W. van den Daele, F. Neidhardt, "Regierung durch Diskussion" - Über Versuche, mit Argumenten Politik zu machen,' in Wolfgang van den Daele, Friedhelm Neidhart (Hrsg.), *Kommunikation und Entscheidung. Politische Funktionen öffentlicher Meinungsbildung und diskursiver Verfahren*, Berlin: Edition Sigma, 1996 (WZB-Jahrbuch 1996), pp. 9-50.
- van den Daele et al, 1997 W. van den Daele, A. Pühler, H. Sukopp, *Transgenic Herbicide-Resistant Crops. A Participatory Technology Assessment. Summary Report*, Berlin: Wissenschaftszentrum Berlin für Sozialforschung, July 1997.
- Van Dommelen, 1997 A. van Dommelen (ed.), *Coping with Deliberate Release. The Limits of Risk Assessment*, Tilburg/Buenos Aires: International Centre for Human and Public Affairs, 1997.
- van Heffen, Maassen and Rip, 1999 O. van Heffen, P. Maassen, A. Rip (eds.), *Sociale wetenschappen van ontwerpmethodologie*, Enschede: Twente University Press, 1999.

- van Oost, 1994 E van Oost, Nieuwe functies, nieuwe verschillen. Genderprocessen in de constructie van de nieuwe automatiseringsfuncties 1955-1970, Delft: Eburon, 1994. (PhD Thesis, University of Twente)
- Vatn and Bromley, 1994 A. Vatn, D. Bromley, Choices without Prices without Apologies, *Journal of Environment Economics and Management*, **26**, 1994
- Vlek and Cvetkovitch, 1989 C. Vlek and D. Cvetkovitch, *Social Decision Methodology for Technological Project*, Kluwe, Dordrecht
- von Neumann, J. and Morgenstern, O. (1944). *Theory of Games and Economic Behavior*. Princeton, NJ: Princeton University Press.
- Von Piechowski, 1994 Piechowski, M. von (1994): Risikobewertung in der Schweiz. Neue Entwicklungen und Erkenntnisse. Univ. Ms.
- von Schomberg, 1996 R. von Schomberg, 'The Laborious Transition to a Discursive Policy Process on the Release of Genetically Modified Organisms,' in Van Dommelen (1996), 147-156.
- von Schomberg, 1997 R. von Schomberg, Argumentatie in de context van een wetenschappelijke controverse. Een analyse van de discussie over de introductie van genetisch gemodificeerde organismen in het milieu, Delft: Eburon, 1997. PhD Thesis, University of Twente.
- Von Schomberg, 1998 R. Von Schomberg, *An Appraisal of the Working in Practice of Directive 90/220/EEC on the deliberate release of genetically modified organisms*, final study, STOA PE 166.953 final, European Parliament, January 1998
- von Schomberg, 1998b R. von Schomberg, 'Memorandum of Evidence', in HoL, 1998
- von Winterfeldt and Edwards, 1986 D. Von Winterfeldt, W. Edwards, *Decision Analysis and Behavioural Research*, Cambridge University Press, Cambridge
- Voogd, 1983 H. Voogd, *Multicriteria Evaluation for urban and Regional Planning*, Pion, London
- Wakeford and Walters, 1995 T. Wakeford, N. Walters, *Science for the Earth*, Wiley, London
- Walker, 1998 V. Walker, Risk Regulation and the "Faces" of Uncertainty. *Risk* 9, 27.
- Wallner, Narodoslowsky and Moser, 1996 H. Wallner, M. Narodoslowsky, F. Moser, Islands of Sustainability: a bottom-up approach towards sustainable development, *Environment and Planning A*, **28**, pp1763-1778
- Wallsten, 1986 T. Wallsten, *Measuring Vague Uncertainties and Understanding Their Use in Decision Making*, in Winterfeldt and Edwards
- Wathern, 1988 P. Wathern, *Environmental Impact Assessment: Theory and Practice*, Unwin Hyman, London
- Watson, 1994 S. Watson, The Meaning of Probability in Probabilistic Safety Analysis, *Reliability Engineering and System Safety*, **45**, 261-9
- WBGU, 1999 German Scientific Advisory Council on Global Change (1999): Welt im Wandel. Handlungsstrategien zur Bewältigung globaler Umweltrisiken. Jahresgutachten 1998. Berlin et al.: Springer (in print).
- Weatherford, 1982 R. Weatherford, *Philosophical Foundations of Probability Theory*, Routledge and Kegan Paul, London
- Weber, 1985 M. Weber, A Method of Multiattribute Decision Making with Incomplete Information. *Management Science* 34, 431-445.
- Weber, 1987 M. Weber, Decision Making with Incomplete Information. *European Journal of Operational Research* 28, 44-57.
- Weinberg, 1972 A. Weinberg, 'Science and Trans-Science,' *Minerva* 10(2) (April 1972) 209-222.
- Wheelis et al, 1998 M. Wheelis et al, *Manual for Assessing Ecological and Human Health Effects of Genetically Engineered Organisms*, Scientists Working Group on Biosafety, Edmonds Institute, Washington, 1998
- Whiteman, 1985 D. Whiteman, 'Reaffirming the Importance of Strategic Use. A Two-Dimensional Perspective on Policy Analysis in Congress,' *Knowledge* 6(3) (March 1985) 203-224.
- Winkler, 1986 G. Winkler, *Necessity, Chance and Freedom*, in Winterfeldt and Edwards
- Wolpert, 1992 L. Wolpert, *The Unnatural Nature of Science*, London
- Woodhouse, 1996 E. Woodhouse, When Expertise Goes Awry, and When It Proves Helpful. Proceedings of the 1996 International Symposium on Technology and Society, Technical Expertise and Public Decisions, June 1996, 200-206.
- Wynne, 1987 B. Wynne, *Risk Management and Hazardous Waste: Implementation and the Dialectics of Credibility*, Springer, Berlin
- Wynne, 1992 B. Wynne, Uncertainty and Environmental Learning: reconceiving science and policy in the preventive paradigm, *Global Environmental Change*, 6/92, p111-127
- Wynne, 1996 B. Wynne, Patronising Joe Public, *Times Higher*, 12/4/96, p13

- Yager, 1992 R. Yager, Decision Making Under Dempster-Shafer Uncertainties, *International Journal of General Systems*, **20**, 233-245
- Zadeh and Kacprzyk, 1992 L. Zadeh, J. Kacprzyk, *Fuzzy Logic for the Management of Uncertainty*, Wiley, New York
- Zielhuis, 1972 R. Zielhuis, 'Gezondheid als basis voor normstelling,' *Chemisch Weekblad* (1 Dec 1972) 13-15.
- Zilleßen, 1993 Zilleßen, H. (1993): Die Modernisierung der Demokratie im Zeichen der Umweltpolitik. In: Zilleßen, H.; Dienel, P.C. und Strubelt, W. (Hrsg.): Die Modernisierung der Demokratie. Opladen: Westdeutscher Verlag, 17-39.