NUCLEAR WASTE MANAGEMENT ORGANIZATION
SOCIÉTÉ DE GESTION DES DÉCHETS NUCLÉAIRES

September 2003

NWMO BACKGROUND PAPERS
1. GUIDING CONCEPTS

1-2 THE PRECAUTIONARY APPROACH TO RISK APPRAISAL

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NWMO Background Papers

NWMO has commissioned a series of background papers which present concepts and contextual information about the state of our knowledge on important topics related to the management of radioactive waste. The intent of these background papers is to provide input to defining possible approaches for the long-term management of used nuclear fuel and to contribute to an informed dialogue with the public and other stakeholders. The papers currently available are posted on NWMO's web site. Additional papers may be commissioned.

The topics of the background papers can be classified under the following broad headings:

1. **Guiding Concepts –** describe key concepts which can help guide an informed dialogue with the public and other stakeholders on the topic of radioactive waste management. They include perspectives on risk, security, the precautionary approach, adaptive management, traditional knowledge and sustainable development.
2. **Social and Ethical Dimensions** - provide perspectives on the social and ethical dimensions of radioactive waste management. They include background papers prepared for roundtable discussions.
3. **Health and Safety –** provide information on the status of relevant research, technologies, standards and procedures to reduce radiation and security risk associated with radioactive waste management.
4. **Science and Environment –** provide information on the current status of relevant research on ecosystem processes and environmental management issues. They include descriptions of the current efforts, as well as the status of research into our understanding of the biosphere and geosphere.
5. **Economic Factors** - provide insight into the economic factors and financial requirements for the long-term management of used nuclear fuel.
6. **Technical Methods** - provide general descriptions of the three methods for the long-term management of used nuclear fuel as defined in the NFWA, as well as other possible methods and related system requirements.
7. **Institutions and Governance** - outline the current relevant legal, administrative and institutional requirements that may be applicable to the long-term management of spent nuclear fuel in Canada, including legislation, regulations, guidelines, protocols, directives, policies and procedures of various jurisdictions.

a discussion paper on
THE PRECAUTIONARY APPROACH TO RISK APPRAISAL

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5th September 2003

1 PERSPECTIVES ON PRECAUTION

The 'precautionary principle' is becoming an ever more prominent feature of the regulatory debate on environmental and health threats and of associated national and international legislation [1]. Though subject to a variety of different definitions and interpretations, the essence of the 'precautionary approach' to the governance of risk lies in the granting of greater benefit of the doubt to the environment and to public health than to the activities which may be held to threaten these things.

There exists an extensive literature concerning the detailed legal history of the precautionary principle [2]. In terms of its broad origins in the environment debate, however, the notion of precaution variously embodies or relates to a series of more diffuse themes. These include injunctions that 'prevention is better than cure' [3], that 'irreversible' effects should be avoided [4] and that the interests of future generations should be respected [5]. In terms of its implications for regulatory appraisal, precaution emphasizes the complexity, variability and vulnerability of the natural world. This entails a greater degree of humility over scientific knowledge than is conventional in risk assessment. Rather than being conducted on a 'case-by-case' basis, the scope of appraisal is extended to include the pros and cons of a variety of different alternatives [6] and addresses production systems taken as a whole [7]. This allows identification of options displaying simultaneously lower costs and risks (a 'substitution principle' [8] allowing 'no regrets' strategies [9]). In the process, precaution involves the prioritising of the rights of those who stand to be adversely affected (for instance by shifting the 'burden of proof' [10]). It acknowledges the intrinsic value of non-human life (a 'biocentric ethic' [11]). In

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1 O'Riordan and Cameron, 1994; Fisher and Harding 1999; Raffensberger and Tickner, 1999; O'Riordan and Jordan, 2001; EEA, 2001.

2 Hey, 1991; O'Riordan and Cameron, 1994; Boehmer-Christiansen, 1994; Fisher and Harding, 1999

3 Tickner 1998

4 Jackson and Taylor, 1992

5 Jackson and Tylor, 1992; Dovers and Handmer 1995.

6 O'Brien, 2000

7 Ashford, 1991

8 Tickner 1998

9 Dovers and Handmer, 1995

10 Raffensberger and Tickner, 1999

11 O'Riordan and Cameron, 1994

short, a precautionary approach involves the adoption of long-term, holistic and inclusive perspectives in regulatory appraisal [12].

Each of these themes will be reviewed in some detail in the present paper, with particular regard to the implications for the appraisal of different policy options for the management of radioactive waste. For the moment, it is sufficient to note that the general implications of a precautionary approach extend far beyond the apparently simple formal enunciations of the Precautionary Principle itself. Here, the classic and most globally influential exposition is found in Principle 15 of the 1992 Rio Declaration on Environment and Development, which holds that: "…*Where there are threats of serious or irreversible damage, lack of full scientific certainty shall not be used as a reason for postponing cost-effective measures to prevent environmental degradation*" [13].

This language provides an elegant synthesis of a highly complex set of ideas. But, taken at face value, it raises a number of significant questions. Under the statement of precaution cited above, for instance, what threshold of likelihood is embodied in the notion of a 'threat'? What are to be the criteria of 'seriousness' or 'irreversibility'? By what means and under what authority can the degree of 'scientific certainty' be judged? What is the most appropriate metric of 'cost', and to whom? What is to be the yardstick of 'effectiveness'? These kinds of question are held in many quarters severely to limit the practical applicability of a precautionary approach [14]. Given the prominence of themes of uncertainty and irreversibility and the difficulties in assessing costs over extremely long times periods, the challenges are particularly salient to the field of radioactive waste management [15]. Indeed, these kinds of concern are often taken as a basis for quite strident criticisms of precaution, with highly unfavourable contrasts drawn with what are held to be the 'science based' procedures of conventional probabilistic risk assessment [16].

Drawing on a number of earlier conceptual [17], empirical [18] and policy-oriented [19] studies, the present paper will first examine the extent to which the difficulties identified above are actually confined to a precautionary approach, and the extent to which they are generic challenges in the appraisal of risk. This will allow some judgment to be formed concerning the relative claims to 'sound scientific' status that may be made on behalf of a precautionary approach when compared with conventional risk assessment. The bulk of the paper is then concerned with a review of the more concrete implications of precaution for the practical business of regulatory appraisal. It closes with a series of specific questions that arise for the governance of risk in the radioactive waste management field.

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[12] Stirling, 1999

[13] UNCED, 1992: principle 15

[14] Morris, 2000

[15] NRC, 2001

[16] Byrd and Cothern, 2000

[17] Stirling, 1999

[18] EEA, 2001

[19] Renn et al, 2003

2 RISK, SCIENCE AND PRECAUTION

The Scope and Complexity of Risk

Risk is a complex concept. Even under the most narrowly-defined of quantitative approaches, it is recognised that risk is a function of at least two variables – the *likelihood* of an impact and its *magnitude*. However, it is only very rarely the case that a series of technology, policy or investment options are seen to present only one form of hazard. Normally, the characterisation of risks associated with any individual option requires the consideration of a wide variety of disparate risks. In the energy sector, for example, different sources of risk include greenhouse gas emissions, radioactive wastes, heavy metals, persistent organic pollutants, soil erosion, thermal discharges, ambient noise, ecological disturbance or aesthetic intrusion in the landscape [20] [21]. In the radioactive waste management field, similarly diverse forms of risk arise in excavation and construction, the transportation of materials, the possibility of sabotage or terrorist action, internal fire or explosion, long term dispersion of leachates into groundwater, glaciation or geological disturbance or unintentional intrusion after long passage of time [22]. Each of these risks is manifest in a different way, with different physical, biological, social, cultural and economic connotations.

The conventional response in regulatory appraisal is to identify 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 often human mortality rates, although human morbidity is sometimes included. In some areas, the techniques of cost-benefit analysis are used to impose a common monetary metric on a wider range of impacts and render them comparable with the associated benefits. In this way, it is hoped that the multiplicity of risk magnitudes might usefully be reduced to a single metric, thus apparently simplifying the process of appraisal. This process of reduction is an essential element in what is sometimes referred to as a 'science-based' approach to the regulatory appraisal of risk [23].

Of course, one crucial consequence of this artificial narrowing and conflation of the full diversity of hazards is effectively to exclude from consideration many classes of effect. For instance, it is clear that only a minority of the types of energy risks mentioned above is meaningfully addressed by a mortality, morbidity or monetary metric. Moreover, even with respect to the single issue of human health, risk is an inherently multi-dimensional concept. For instance, are exposures voluntary or controllable? Are they manifest as disease, injuries or deaths? How familiar are the hazards to those affected? How immediately are they realised and how reversible once identified? To what extent are they concentrated in a few large events or dispersed in many small routine incidents? How are they distributed across space, time and society? Mortality, and even morbidity, indices fail to capture these important contextual features.

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[20] Holdren, 1982

[21] Stirling, 1997b

[22] NRC, 2001

[23] Byrd and Cothern, 2000

Beyond this, further scope for divergent approaches to regulatory appraisal lies in the characteristics of the assessment process itself [24] [25] [26] [27]. 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 environmental and health risks? With how wide an array of potential alternatives should each individual technological or policy option be compared in appraisal? Should attention be confined simply to the *implementation* of technological and policy options, or should it extend to their development, processing, decommissioning and disposal, as well as to the various inputs (such as energy and materials) and associated risks at each stage? To what extent should the relative *benefits* of different options be taken into account in appraisal so that they can be offset against the associated hazards and risks?

In an ideal world, the appropriate response to factors such as these is easy to determine. All else being equal, the regulatory appraisal of risk should be as *complete* with respect to different classes and dimensions of risk and benefits and *comprehensive* with respect to different policy alternatives. However, on their own, such aspirations provide only rather loose operational guidance in the practical regulation of risk. Moreover, even were appraisal to be fully complete and comprehensive in some hypothetical sense, then there would still remain the problem of how the different aspects of risk should be framed and prioritised in analysis. For instance, what *priority* should be attached to different effects such as toxicity, carcinogenicity, allergenicity, occupational safety, biodiversity or ecological integrity? What weight should properly be placed on these different impacts and on different groups, such as workers, children, pregnant and breastfeeding mothers, future generations, disadvantaged communities, foreigners, and those who do not benefit from the technology in question. And what about animals, plants and ecological commnities as entities in their own right? Even were the objectives of completeness and comprehensiveness to be entirely and unproblematically feasible, they would not address these issues of framing and prioritization. The problem is, within the bounds set by positive reality, 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 rational choice theory that underlies ‘science based’ risk assessment. It is a lesson that seems to have been forgotten by those who claim that narrow quantitative aggregating techniques are distinguished as being based on ‘sound science’. For there exists no technical discipline, including economics, decision analysis or risk assessment itself, that has developed a definitive way of addressing this problem of comparing ‘apples and oranges’. Even the most optimistic of proponents of rational choice acknowledge that there is no effective way to compare the intensities of preference displayed by different individuals or social groups [28]. Indeed, even where social choices are addressed simply in relative terms, the economist Kenneth Arrow went a long way towards earning his Nobel

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24 Shrader-Frechette, 1990

25 O’Brien, 2000

26 Wynne, 1987

27 Ashford, 1999: 198-206.

28 Bezembinder, 1989

Prize by demonstrating formally that it is *impossible* definitively to combine relative preference orderings in a plural society [29].

Put simply, the point is that "it takes all sorts to make a world". Different cultural communities, political constituencies or economic interests typically characterise these different aspects of environmental and health risk in different ways and attach different degrees of importance to them. These translate into different – but equally reasonable – 'framing assumptions' in formal quantitative appraisal. Within the bounds defined by the domain of available information and plural social discourse, there exists much legitimate scope for divergent interpretation. No one set of values or framings can necessarily be ruled more 'rational' or 'well informed' than can any other.

Although rarely acknowledged, evidence abounds for this kind of intrinsic 'ambiguity' in 'science-based' characterisations of risk in areas extending from food safety, through transport impacts and chemical and industrial hazards to the effects of genetic modification technologies. Box 1 illustrates this phenomenon in perhaps the most intensive, elaborate and mature area for the policy application of 'science-based' comparative risk assessment techniques: the energy sector. This summarises the results obtained in sixty three large scale risk assessments of eight different energy technologies conducted over the past two decades. Environmental and health effects are characterised using the techniques of cost-benefit analysis as monetary 'external costs' expressed in standardised form per unit of electricity production for each technological option. [30] Although individual studies express their results with very high degrees of precision, the results for any one technology vary by several orders of magnitude. So great are the overlaps between the ranges obtained for the different technologies, that not only the absolute values, but even the relative orderings of the options remains intrinsically ambiguous.

This picture – reproduced in virtually all areas where formal risk assessment techniques are applied – illustrates the practical importance of the theoretical difficulties with notions of definitive prescriptive 'science-based' assessment. It is a matter of rationality itself in the business of risk assessment, then, that *there can be no analytical fix for the scope, complexity and intrinsic subjectivity of environmental and health risks*. The answer you get depends to a large extent on the particular set of assumptions that are privileged in analysis. The notion that there can be a single 'science-based' prescription in the regulatory appraisal of risk is not only naïve and misleading, it is a fundamental contradiction in terms.

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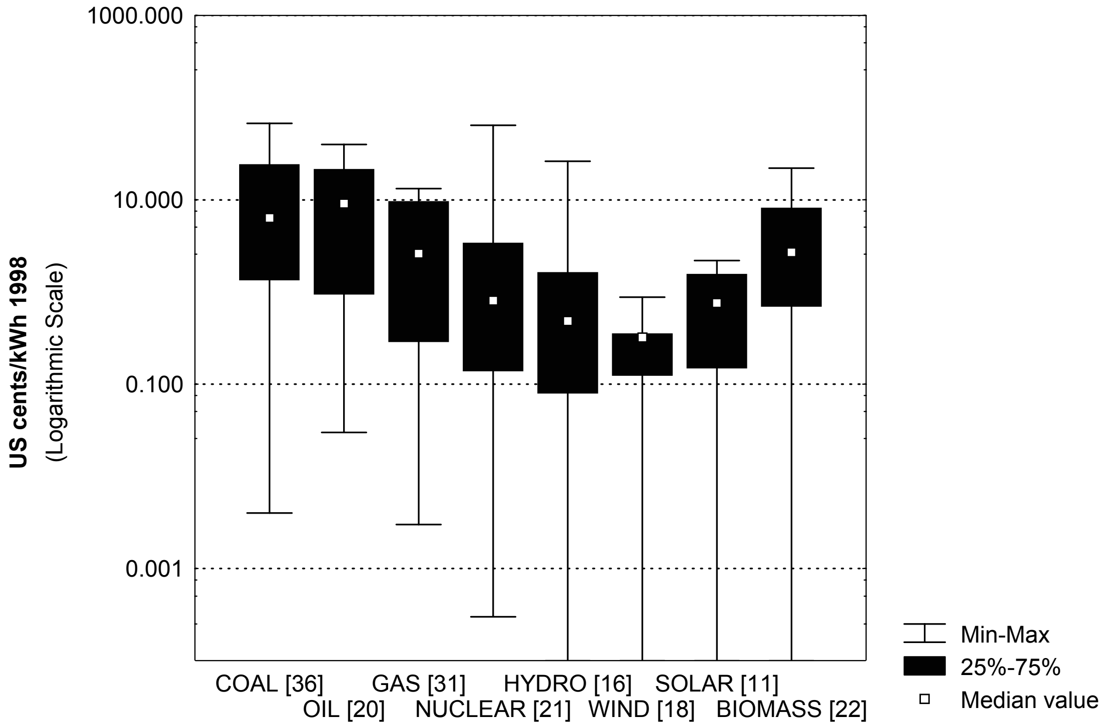
[29] Arrow, 1963

[30] An earlier version of this type of analysis is given in Stirling (1997). The present diagram is from an updated and extended analysis in Sundqvist and Söderholm (2002).

Box 1: Ambiguity of option orderings in risk assessment

(results of 63 detailed studies of the overall risks of 8 different electricity options)



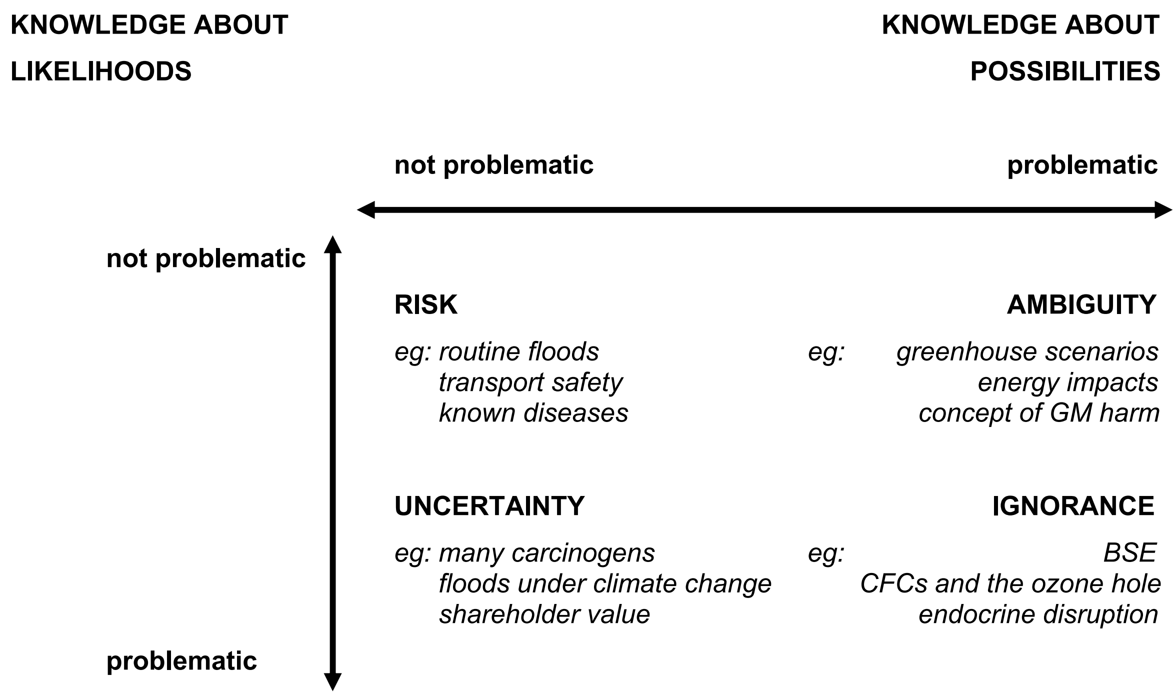
From: Sundqvist and Söderholm (2002).

The Depths of Incertitude

Beyond these questions of rational choice, a further series of intractable difficulties are embodied in aspirations (or claims) to a 'sound science' of risk assessment. Thus far, we have considered only the issues associated with ambiguities in the characterisation of the '*magnitude'* aspects of risk. What of the *likelihoods*? Here we come upon some further profound limitations to the applicability and robustness of probabilistic approaches that are as seriously neglected in conventional regulatory appraisal as are the difficulties discussed above concerning the comparison of magnitudes.

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 illustrated in the top left-hand corner of the diagram in Box 2. 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. Such assumptions may well be felt justified in areas where theoretical models are robust, or where there exist well documented empirical data bearing on relevant circumstances. This may be the case, say, with some transport safety problems or in the epidaemiology of certain well-known diseases. Of course, there exists a host of questions relating to the particular implementation of risk-based approaches (such as those hinging on the distinction between 'frequentist' and 'Bayesian' understandings of probability) [31]. But none of these alter the formal definition of the concept of risk founded on the applicability of probability theory.

Box 2: Formal definitions for risk, uncertainty, ambiguity and ignorance



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 confidently to assign probabilities to these outcomes. This is shown in the lower left-hand corner of Box 2. Here, the analytical armoury is less well developed, with the various sorts of sensitivity and scenario analysis being the best that can usually be managed [32]. Examples of this condition abound wherever the metric of harm is not itself held to be problematic or worthy of discussion, but where the empirical or theoretical basis for risk assessment may be incomplete. In the case of newly emerging pathogens, for example, the possible incidence will lie somewhere on a discrete scale of mortality frequency, but the empirical or theoretical understandings will be inadequate to permit the definition of a probability density function on this scale. Likewise, corporate and wider commercial decision-making often reduces effectively to questions of bottom-line profitability or shareholder value on a simple monetary scale, yet the complexity of the operating environment militates against confident assignment of different probabilities to the different

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31 Stirling, 2003

32 Funtowicz and Ravetz, 1990

increments on this scale. Under such conditions of uncertainty, it is simply the relative likelihoods of a well-defined set of outcomes that are problematic. As a result, though the different options under appraisal may be broadly characterised, they cannot be ranked even in relative terms.

Both risk and uncertainty, then (in the strict senses of these terms), require that the different possible outcomes be clearly characterisable and subject to measurement. The problems with such assumptions have already been shown in the previous section. The multidimensionality, complexity and scope of the different forms of environmental risk and the different ways of framing and prioritising these, can all-too-easily render *ambiguous* the definitive characterisation of the possible outcomes themselves [33] [34]. This may be so, even where there is relatively high confidence in understandings of the likelihood that at least some form of impact will take place This condition of *ambiguity* is shown in the top right corner of Box 2. Beyond the case of energy impacts shown in Box 1, further examples of ambiguity lie in the institutional assumptions around food safety regulation, the selection of hazard categories and vectors in chemical risk assessment and in defining the notion of 'environmental harm' in the regulation of genetically modified crops. The field of radioactive waste management is certainly not short of such ambiguities, with contending views on issues such as the balance to strike between occupational and public exposures, between ionizing radiation and other sources of risk, as well as intergenerational equity, the distributional ethics of siting and the legitimacy of including the phase out of nuclear power as a radioactive waste management option.

Where these difficulties of ambiguity are combined with the problems of uncertainty and compounded by the prospect that certain salient factors may quite simply be unknown, then we face a condition which is formally defined as *ignorance* (bottom right corner of Box 2) [35]. 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, recognition of the condition of ignorance is an acknowledgement of the possibility of surprise. Under such circumstances, not only is it impossible definitively to rank the different 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. Past examples of the importance of this condition may readily be seen in high profile cases such as stratospheric ozone depletion by chlorofluorocarbons, the links between bovine spongiform encephalopathy in cows and variant Creutzfeldt-Jakob disease in humans and the emergence of recognition of the endocrine disruption mechanism in chemicals regulation. These are all examples where the problem lay not so much in the determination of likelihoods, but in the anticipation of the very possibilities themselves. At crucial moments in their regulatory history, these were surprises!

It is quite normal, even in specialist discussion, for the full breadth and depth of such issues to be rolled into the simple concept of 'risk' (and sometimes 'uncertainty'), thus seriously understating the difficulties involved. In order to avoid confusion between the strict definitions of the terms 'risk' and 'uncertainty' as used here, and the looser colloquial usages, the term 'incertitude' can be used in a broad overarching sense to

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[33] Aspects of this are referred to as 'indeterminacy' in Wynne (1992)

[34] Stirling, 2003

[35] Loasby, 1976; Smithson, 1989; Wynne, 1992

subsume all four subordinate conditions [36]. Either way, it is not difficult to see that it is the formal concepts of ignorance, ambiguity and uncertainty – rather than mere risk – which best describe the salient features of regulatory decision making in areas such as energy technologies, toxic chemicals, genetically modified organisms and in significant areas of radioactive waste management. The crucial point is, that intractable uncertainties, ambiguities and ignorance are routinely addressed in regulatory appraisal, simply by using the probabilistic techniques of risk assessment. This treatment of uncertainty and ignorance as if they were mere risk effectively amounts to what the economist Hayek dubbed (in his Nobel acceptance speech) "pretence at knowledge" [37]. Far from displaying a respect for science in regulatory appraisal, the effect of such scientistic oversimplification is actually to ignore and undermine the scientific principles on which risk assessment itself purports to be based. Given the manifest inapplicability – in their own terms – of probabilistic techniques under uncertainty, ambiguity and ignorance, this is a serious and remarkable error. The self-contradictions in aspirations to a 'science-based' approach reliant on quantitative risk assessment, already noted in the last section, are thus further underscored and reinforced.

Why is it that pursuit of (and claims to) the definitive authority of 'science-based' approaches continues to be so prominent in regulatory appraisal? It seems that the elegance and facility of the calculus of probabilistic risk assessment has had a seductive effect on many analysts and their sponsors. This may be understandable, yet it is also curious. Despite the intractability of the condition of ignorance, there is no shortage of operational tactical and strategic alternatives to reliance on probabilistic methods. Indeed, it is in full recognition of the inadequacy of risk assessment in addressing uncertainty, ambiguity and ignorance that we find the real justification and imperative for adopting newly emerging 'precautionary' approaches. The claim is not necessarily that a precautionary approach offers conclusively to *resolve* these difficulties. The point is rather that a precautionary approach at least acknowledges the challenges, renders the implications more explicit and so offers a more robust basis for decision making in the governance of risk.

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36 Stirling, 1998a

37 von Hayek, 1978

3 KEY ELEMENTS OF A PRECAUTIONARY APPROACH

Be more humble about the role and potential of science

One way to sum up the general implications of the precautionary approach, is that it is an acknowledgement and response to the intrinsic difficulties in narrow 'science-based' risk assessment reviewed in the previous section. In a nutshell, precaution entails a greater degree of humility over the role and potential of science in policy appraisal. This theme will unfold in the ensuing discussion, exploring a series of ways in which the appraisal process might be 'broadened out' beyond the confines of conventional narrow risk assessment in order to address the different elements of the difficulties discussed above. Examples will be given of conventional 'sound science' approaches in other areas of environmental regulation, in order to illustrate more clearly the concrete implications for radioactive waste management.

This said, it should be clear right at the outset that no element of this discussion should be taken in any way to undermine or diminish the crucial role of scientific expertise in the appraisal of risk. Scientific and technical evidence and analysis remain absolutely essential. The point is rather that – under a precautionary approach – scientific analysis is seen as a *necessary*, rather than a *sufficient*, basis for effective policy choices. As the former British Prime Minister Winston Churchill is reputed to have remarked "science should be on tap, not on top" [38]. This is as true in radioactive waste management as elsewhere.

A number of practical implications flow from this rather abstract precautionary injunction to greater humility over the role of science. Although some implications are rather far reaching in their procedural or institutional implications, others are more focused on the practice of scientific appraisal itself. One such concerns the precision and confidence with which appraisal results are presented. As discussed above, the results of quantitative expert risk assessment are often expressed with a fine degree of precision, sometimes seriously understating the many sources of uncertainty, ambiguity and ignorance (in the senses discussed in the last section).

The history of environmental regulation provides many examples where the resulting impression of complete or definitive knowledge has led to a vulnerability to surprise. This was the case, for instance, with the effect of chorofluorocarbons on stratospheric ozone [39], the unforeseen cross-generational health effects associated with the pharmaceutical diethylstilbestrol [40] or the ecological effects of the anti-fouling agent tributyltin in marine animals [41]. In these cases, as in many others [42], greater caution over the robustness of the available knowledge might have led to earlier recognition of the associated problems. The radioactive waste management issue is also characterized by a reliance on probabilistic models, often expressed with a high degree of quantitative precision and associated with confident pronouncements concerning the extremely long

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[38] Lindsay, 1995

[39] Farman, 2001

[40] Ibarreta and Swan, 2001

[41] Santillo, et al, 2001

[42] Gee, e al, 2001

of term behaviour of complex natural and engineered systems [43]. Here, as elsewhere, experience argues for greater humility in the precision and confidence with which appraisal results are expressed.

Other practical implications of humility are more substantive than presentational. One such lies in shifting attention away from ambitious – but sometimes unreliable – attempts to quantify *risks*, towards the more modest ambition of characterizing the underlying *hazards*. In the chemicals field, for instance, there is growing recognition that serious or irreversible hazards are often better addressed in terms of qualitative 'intrinsic properties' (such as carcinogenicity, mutagenicity and reproductive toxicity), than in terms of elaborate – but sometimes seriously misleading – quantitative dose-response or exposure-based modeling [44]. These kinds of intrinsic properties become especially important where they are associated with further relatively easily recognized features of the hazard or its context, which may compound the irreversibility of any harm. Examples include situations where the potential threat can be demonstrated to be persistent, highly mobile or subject to bioaccumulation [45]. In short, by focusing rather more on these kinds of intrinsic properties (and rather less on elaborate quantitative modeling), regulatory appraisal becomes more resilient to adverse surprises, and thus more robust in the face of ignorance. In a field such as radioactive waste management, this may be found to hold a host of implications – both for geological site selection as well as for choices between contending engineering concepts.

Scrutinize the burden of persuasion and the thresholds of argument

This shift away from an exclusive preoccupation with the quantitative modeling of risk, and towards a greater degree of attention to the qualitative nature of the hazards themselves is just one aspect of a more deliberate and sophisticated approach to the treatment of scientific evidence in precautionary appraisal. With certain notable exceptions [46], there is a tendency in much conventional scientific policy appraisal to adopt a default assumption that the activity or product under scrutiny is benign. The task of appraisal is then one of attempting to establish whether this default assumption is false. In many fields, greater care is often taken to avoid mistaken regulatory restrictions ('Type I errors') than mistaken approvals ('Type II errors') [47].

In the case of decisions over radioactive waste management options and their siting, however, the large economic stakes, significant technical uncertainties and high political profile serve to challenge this normal practice. Whether implicitly or explicitly, the appraisal process often proceeds with the challenge of demonstrating safety, rather than harm. To this extent, then, appraisal in this field may justly claim to have embodied for many years a certain precautionary element. However, this is sometimes treated more as a function of regrettable political realities, than a legitimate consideration in the framing of scientific evidence and analysis [48]. There typically exists considerable scope for

[43] Merkhofer and Keeney, 1987

[44] EC, 2001

[45] Herold et al, 2003

[46] Abraham and Lewis, 2000

[47] EEA, 2001

[48] NRC, 2001

making this crucial factor more explicit [49]. The relative emphasis to place on the avoidance of Type I, compared to Type II, errors is thus not an exclusively technical matter. Under a more precautionary approach to radioactive waste management, this issue might productively be subject to wider and more deliberate discussion than is typically the case at present.

The appropriate priority to attach to avoidance of Type I and Type II errors is only one element in the general implications of precaution for the conduct of scientific appraisal. In most fields – especially in an area as disparate, complex and uncertain as radioactive waste management – the question of exactly how to constitute scientific 'proof' or 'falsification' can often be highly intractable. In effect, we are more often concerned with fuzzy and subjective social processes of argument and persuasion, than we are with apparently more hard and fast analytical concepts such as the 'burden of proof' [50]. In this regard then, the shift in emphasis from avoidance of Type I to Type II errors noted above, might better be seen as a shift in the *burden of persuasion* towards those who have an interest in pursuing an activity, and away from those who are more skeptical [51]. This more 'processual' understanding may better capture the open-ended and semi-structured nature of the problem.

Alongside this question of persuasion, precaution also directs attention at a number of other issues that are conventionally rolled together as aspects of the 'burden of proof'. For instance, the 'levels of proof' that are required to initiate hazard reduction measures are often much more ambiguous than is readily conceded. Outside the most formalized of scenarios, there exists no uniquely scientific way to define what is meant by a 'level of proof', nor for taking any one such level as being more appropriate than any another. Yet, like the burden of persuasion, this crucial question over the required *weight of evidence* in different contexts typically remains opaque and unaddressed in much conventional regulatory appraisal. In radioactive waste management as elsewhere, the qualitative attributes of different hazards will typically warrant more demanding thresholds of argumentation in certain areas than in others. Under a more precautionary approach, this would not simply be assumed to be a scientific 'given' and so remain buried deep in the analysis. Instead, it would be recognized that the complexity and subjectivity of the issues in question demand that the particular appropriate weight of evidence in any given instance is a matter for explicit discussion and justification.

Enhance the role of monitoring and scientific research

A third practical implication of the precautionary injunction to greater humility over the role of science in appraisal lies in a shift away from reliance on theoretical modeling and artificial laboratory experimentation and towards more empirical field research and monitoring. By placing a greater emphasis on direct measures to monitor the real effects on occupational, public or ecosystem health, a precautionary approach offers a way to be more responsive to manifest harm in the real world. There are a host of cases where it can be shown that this kind of monitoring would have permitted much earlier avoidance of what eventually came to be recognized as serious impacts on human health or the

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49 NRC, 2001

50 Fisher and Harding, 1999

51 EEA, 2001

environment. Examples include the impacts on workers of products such as asbestos [52] and benzene [53]or the environmental effects of polychlorinated biphenyls [54] or from the routine use of antimicrobials in livestock management [55]. Likewise, more strenuous efforts might be made to conduct research into outstanding questions or anomalies in our understanding of particular hazards. A failure to engage in active strategies of scientific enquiry played a significant role for instance, in compounding exposure to the species-jumping cattle disease BSE [56]. By enhancing both scientific research and environmental and health monitoring, we can hope significantly to reduce our exposure to uncertainty and ignorance.

Of course, these kinds of research and monitoring measures can be costly. Their results can be ambiguous or raise more questions than they answer [57]. Either way, this raises a third and final issue that is often rolled together (together with the *burden of persuasion* and the *weight of evidence*) under the rather fuzzy remit of the 'burden of proof'. Who is it that should resource the provision of the necessary information, on the basis of which the various burdens of persuasion or weights of evidence may then apply? Under a more precautionary framework, responsibility for this *resourcing of information* shifts away from those who are concerned about a threat, or society in general, and towards those who have an interest in the products or activities which give rise to that threat. This presents interesting questions over the historic allocation of costs for research into different radioactive waste management options and the extent to which these costs are included in the price of the associated nuclear generated electricity.

In this regard, a shift away from theoretical modeling and laboratory studies and towards field research and monitoring does raise one further particular challenge. In cases where the possible impacts are at the same time potentially serious, highly uncertain and effectively irreversible, there is an obvious tension with the precautionary injunction to regulate the activity on the basis of the intrinsic hazard properties themselves. Here, the process of field research or monitoring itself may be held to present an unacceptable threat. This is a key point at issue, for instance, in the debate in Europe (though not North America) over the role of field trials in assessing the impacts of large scale deployment of genetically modified crops [58]. It is also a major theme in policy decisions concerning the authorization of geological characterization facilities for long term radioactive waste management. Here, a key consideration in some quarters concerns the extent to which authorization of a research facility may lead to a process of political and institutional 'lock in', involving an effective prior commitment to a full scale industrial facility. These political and institutional factors are obviously compounded where appraisal of radioactive waste management options occurs at a time when large scale radioactive waste arisings have already been accumulated, rather than in advance of these commitments.

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52 Gee and Greenberg, 2001

53 Infante, 2001

54 Koppe and Keys, 2001

55 Edqvist and Pedersen, 2001

56 van Zwanenberg and Millstone, 2001

57 Gilbertson, 2001

58 AEBC, 2001

Compare the 'pros' and 'cons' of different policy options

Moving beyond these specific connotations for the role of science, the treatment of 'proof' and the importance of research and monitoring, precaution does hold a series of broader procedural implications. These concern the appraisal process itself, whether conducted by a commercial organization, a public regulatory agency or an independent or academic body. In effect, they involve a series of different dimensions of the 'broadening out' of the appraisal process.

Conventional risk assessment, at its most straightforward, involves an assessment of the possible adverse effects of a particular product or activity, as presented for regulatory approval by a prospective promoter. The question is simply whether the risks presented by this particular product are acceptable. Although not usually explicit, the criterion of acceptability often effectively amounts to existing tolerated poor or worst practice. As has been mentioned, in most areas of industrial activity, the default assumption is that a given product is indeed acceptable, unless the appraisal process can demonstrate otherwise. Here, it is effectively further assumed that the promoters of this product or activity will already have conducted their own assessment of its broader performance in relation to contending alternatives for achieving the same ends. Finally, it is implicitly assumed that the promotion of this particular product or activity will reflect consideration of a full range wider policy options, evaluated from the perspective of society at large rather than under any narrower institutional interests. If there are any grounds for doubt over the scope of the internal appraisals conducted by the promoter, or over the altruism of wider market processes, then the resulting process will be correspondingly incomplete.

With respect to many technologies, processes, activities and consumer products, such incompleteness is not seen as a particular problem. Either existing market processes are held to provide an acceptable approximation to these idealized assumptions, or the potential costs of a more onerous regulatory process are held to be disproportionate to any benefits that might thereby be gained. In other areas, however, the restricted character of conventional risk assessment, and the nature of the associated implicit assumptions, can be highly problematic. In cases such as the marine antifoulant tributyl tin [35], the automobile fuel additive MTBE [40], the use of CFCs as refrigerants [33] and the medical use of X-rays [59] the products in question were each found in retrospect to cause impacts that might quite readily have been avoided through the substitution of more benign alternatives. Likewise, in cases such as asbestos [60], PCBs [61] and benzene [62], the products turned out to be much more readily substituted than was initially thought possible, but the potential substitutes were simply not considered in the initial appraisals or subsequent regulation.

In considering the relevance of these arguments to radioactive waste management, it may be interesting to consider again the case of genetically modified crops. This presents many comparable issues of scale, complexity and potential irreversibility. Here, it is interesting that all sides of the debate (in Europe, where the issues are most acute) express active dissatisfaction with the narrow scope of existing risk assessment

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59 Lambert, 2001

60 Gee and Greenberg, 2001

61 Koppe and Keys, 2001

62 Infante, 2001

procedures. Industry bodies seeking to promote genetically modified crops are concerned that existing risk assessment procedures fail to give due attention to the wider benefits that they envisage being offered to developing countries. For their part, environmental and consumer organizations express concern that there exists no responsibility on the part of the promoter to justify any product in terms of its benefits. In this regard, both sides of the debate are effectively arguing for the same thing. Both are calling for a 'broadening out' of the scope of regulatory appraisal, to include consideration of the justifications and benefits that might be argued in favour of a variety of alternative food production strategies and weigh these up alongside the contending impacts, benefits and uncertainties associated with GM foods.

Under a precautionary approach, then, it is recognised that – where circumstances dictate – there should be the possibility of conducting precisely this kind of broader-based appraisal. Precautionary appraisal explicitly addresses the contending pros and cons of a variety of different options for fulfilling the same ends. The question is not simply "is this acceptable?", but "is this justified?" and "which option offers the greatest societal benefit?". Attention is not confined just to the risks, in a narrow sense, but extends to weighing these up against the countervailing justifications and benefits. The implications for radioactive waste management seem obvious. Where the financial and time commitments envisaged are as large as they are in this sector, and the irreversibilities as pronounced, there seems a particularly strong case for this kind of broad-based precautionary appraisal.

Broaden and deepen interdisciplinary appraisal

In seeking to address the pros and cons of a variety of different options in the manner discussed above, a precautionary appraisal process is also distinctive in extending attention to the full variety of potentially salient impacts, including both direct and indirect consequences. The scope should be both broad (in terms of the range of possible effects) and deep (in terms of the detail in which they are scrutinized). Impacts should not be neglected on the grounds that they are more uncertain or less readily quantified or assigned a monetary value – *the things that are countable are not necessarily the things that count* [63]. Nor should effects simply be excluded on arbitrary administrative or methodological grounds, for instance because they fall outside the remit or jurisdiction of a particular agency or the scope of a particular method. It is often the case that indirect effects are more important than direct effects – for instance where impacts accumulate over time, or where different types of effect add together or interact in complex ways. Examples of this frequently occur in the regulation of other complex environmental effects, such as those presented by many chemicals [64], and it is likely that the long term implications of radioactive waste management may also involve such factors.

In order to achieve this, it is necessary that the appraisal process go to great lengths to include a balanced array of specialist opinions, drawing on a wide range of relevant scientific disciplines. This helps to avoid a situation where – as was the case, for instance, with BSE for many years in the UK – regulation was unduly dominated by a particular

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[63] Holdren, 1982

[64] von Kraus and Harremoes, 2001; Ibarreta and Swan, 2001

profession. In that case it was veterinarians[65], but in the case of radioactive waste management a similar situation may potentially arise with engineering or geology. All disciplines can be somewhat uncritical from time to time over their own favoured models. Exposure to other forms of expertise can help ensure that attention is focused on conditions as they apply in the real world, rather than those that are assumed in such models. For instance, it is a frequent feature of chemicals regulation that engineering models assume that containment systems will perform as planned. This is was the case, for example, in the deployment and regulation of products such as poly-chlorinated biphenols in the electrical engineering sector [66] and methyl tert-butyl ether as a fuel additive in the transport sector [67]. In both cases – as in many others – the models were subsequently found to be flawed. The implications for assumptions over containment in radioactive waste management are obvious. Confidence that such issues have been given due attention can only be increased by involving a full range of relevant technical disciplines.

Ensure independence, acknowledge subjectivity and explore assumptions

In some ways, avoiding reliance on a few technical disciplines is just one facet of the widely acknowledged imperative to keep policy appraisal as independent as possible. Of course, the requirement that appraisal and regulation be objective and disinterested goes well beyond an injunction to involve a variety of specialist or disciplinary perspectives. The responsibility to keep regulatory appraisal as free as possible from wider commercial, organizational or economic vested interests is, of course, well recognized. Given the complexity of the appraisal process and the pervasiveness of such interests, this is not always easy to achieve. Provision for ethical codes of conduct in the science advice process, as well as transparency, freedom of information and independent oversight are all important ways to maintain constant vigilance. In this regard, it is not enough simply to aspire to – or assert – the 'objectivity' of the appraisal process or its participants. As has been discussed earlier in this paper, different, but equally 'objective', technical appraisals can often yield radically different policy implications. In this regard, independence lies not so much in a quest for uniquely objective neutrality, but in the open acknowledgement of the intrinsically subjective and judgmental elements in appraisal.

In short, the precautionary answer lies in 'independence through pluralism' rather than 'independence through objectivity'. The subjective element in appraisal can be acknowledged, while retaining due respect for the 'hard scientific facts', by providing for the balanced and systematic exploration of the implications of different assumptions and value judgments. Conventional appraisal concentrates on a particular set of majority or 'best guess' assumptions and propagates these through the analysis. As has been discussed earlier, this is associated with a tendency for appraisal results to take a rather more definite form than might be suggested by the divergent information and perspectives on which appraisal has drawn. The result is that options appraisal is often taken to be much more prescriptive of policy choices than is actually the case. By failing fully to address the implications of divergent assumptions, appraisal becomes especially

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65 van Zwanenberg and Millstone, 2001

66 Koppe and Keys, 2001

67 von Kraus and Harremoes, 2001

vulnerable to implicit or explicit pressures for the 'justification' of decisions that are already favoured or even committed. This has been a major feature of past episodes of regulatory failure – such as BSE [68]. The very high financial and industrial stakes leave the radioactive waste management field quite significantly exposed to this kind of pressure.

Rather than seeking to provide justification (whether general or specific) for policy decisions, the business of appraisal is far better seen as a matter of exploring the particular ways in which different – but equally legitimate – assumptions can yield a justification for a range of possible decisions. There exists a variety of different techniques by which this can be achieved, including sensitivity, scenario and decision analysis. Such methods can serve to eliminate a wide range of possible decisions, which are supported neither by the technical or scientific evidence nor by any relevant assumptions or value judgements. At the same time, they may reveal the precise way in which a number of alternative decisions may appear reasonable, depending on the particular assumptions that are prioritized. Adjudication between this more restricted set of choices then becomes an open matter of professional or political accountability on the part of the decision makers themselves.

Steps towards this kind of framework have in the past been taken in the radioactive waste management field [69]. Typically, however, the appraisal process fails to fulfil the potential of these kinds of techniques, leaving plenty of opportunities for improvement.

<u>Provide for full participation by stakeholders and the affected public</u>

Once it is appreciated that appraisal results can be highly sensitive to essentially subjective value judgments, the logic of broadening out the regulatory appraisal process extends beyond just the inclusion of different technical disciplines. In discussing the challenge of ambiguity raised earlier in this discussion paper, it was shown how the answers delivered by science can often depend on the questions that you ask and the way that you ask them. Although non-specialists may, by definition, be unable to provide technical answers to scientific questions, it is often the case that they are more able to identify the truly important questions to ask. Only by engaging in appraisal the full range of interested and affected parties, can we ensure that all the relevant questions have been asked of the evidence, and that the particular assumptions and value judgements that have been explored in appraisal actually correspond with those extant in the wider debate. In this regard, provision for the inclusion of stakeholders and the general public in appraisal is not about 'political correctness' or second guessing the technical expertise of specialists. It is about being as rigorous as possible in validating the alternative framing assumptions under which the technical analysis is to be performed [70].

In the case of choices among radioactive waste management options, one of the obvious and crucial points of influence on appraisal for subjective values concerns the way to take account of future generations. Is it appropriate to project current utilitarian calculations of economic benefits and environmental impacts into the remote future? Is the consideration of future streams of benefits and impacts simply a matter of discounting present values?

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68 van Zwanenberg and Millstone, 2001

69 Stirling, 1996

70 Stirling, 1998a

If so, then at what rate? Or does intergenerational equity raise fundamental issues of a different order? Similar crucial assumptions govern the framing of the appraisal exercise as a whole. To what extent is the role of nuclear power in future energy strategies an explicit object of attention? When technological, economic and institutional factors are taken into account, the merits of different radioactive waste management options may depend, entirely reasonably, on this kind of wider policy context. Likewise, thorny questions are raised in decisions over radioactive waste facility siting, involving the distribution of impacts, costs and benefits across different social groups. These are the kinds of issues on which the views of non-specialists are, in principle, as valid as those of specialists.

The benefits of including a wide range of interested and affected parties extends beyond just the exploration of ambiguities resulting from diverging assumptions. Sometimes, public values can also be relevant to addressing ignorance in the more scientific sense introduced earlier. For instance, although not based on technical expertise, widespread aversion to the feeding of ruminants on meat from their own species or to the intensive dosing of livestock with antimicrobials can in retrospect be seen to have been prescient of what were initially scientifically unknown effects arising from these practices. As it turns out in the light of current knowledge, the regulation of both BSE and antimicrobials in animal husbandry might have been more effective if greater attention had been given to these kinds of public sensibilities [71]. Where the options under appraisal raise such issues of principle, therefore, there exist both scientific and ethical reasons for taking public values into account. In the case of radioactive waste, for instance, colloquial institutional and behavioural insights concerning the wisdom of "brushing problems under the carpet" may hold substantive implications for decisions between retrievable and non-retrievable management options.

Finally, there are more straightforward ways in which non-specialists can contribute to the pool of pertinent knowledge, and thus to alleviating our exposure to ignorance and uncertainty as well as ambiguity in the senses discussed earlier. There are many cases, for instance – including in the Great Lakes [72] – where it was local communities who first became aware of the effects of complex mixtures of chemicals in the environment. Likewise, the histories of various environmental pollutants (such as asbestos [73], benzene [74] and PCBs [75]) provide examples of cases where health effects came to be known among communities of workers well before they were recognised by specialist disciplines. Workers can also provide vital insights into real-world conditions, such as the practices actually employed in slaughterhouses crucial to the development of the BSE issue [76]. All these examples may have analogues in the implementation of radioactive waste management options.

The effective engagement in appraisal of communities of workers, local people and other stakeholders certainly presents challenges. Further questions arise over the appropriate

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[71] EEA, 2001

[72] Gilbertson, 2001

[73] Gee and Greenberg, 2001

[74] Infante, 2001

[75] Koppe and Keys, 2001

[76] van Zwanenberg and Millstone, 2001

way to combine these contrinutions in the most efficient and effective way with more traditional procedures for eliciting scientific and technical advice. However, these exists a wide range of deliberative and participatory processes, which allow systematic account to be taken of divergent cultural and ethical perspectives and contending economic and political interests. These include techniques like focus groups, citizens panels and scenario workshops, which can be variously combined with expert-based evidence, analysis or modeling [77]. Other approaches, like consensus conferences or deliberative mapping seek to combine specialist and non-specialist perspectives in a more intimate and mutually challenging fashion [78]. There is enormous scope for developing effective hybrids with techniques like scenario, sensitivity and decision analysis already mentioned. Either way, despite the undoubted challenges, there is no shortage of practical ways forward.

<u>Address options at the earliest stages and consider the strategic resilience of portfolios</u>

A final series of broad responses to uncertainty, ambiguity and ignorance lie beyond the bounds of conventional environmental regulation and touch on the broad area of technology policy. Although these involve issues of direct salience to the challenges of options appraisal in a field like radioactive waste management, they also require inclusion of new and more general considerations. In short, rather than focusing entirely on efforts to characterise the intractable *problems* of ambiguity and ignorance, these involve focusing attention directly on potential *solutions*. Quite aside from the particular benefits, costs, risks and uncertainties associated with individual policy options, there exist a number of important cross-cutting 'strategic properties' associated with the portfolios and development trajectories in which these options are to be embedded. Under a precautionary approach, these strategic properties can sometimes be of greater importance than some of the specific details of the performance of the individual options.

For instance, there is the question of the degree of *diversity* displayed by a portfolio of technology or policy options. It is a well-established matter of common sense that, when we don't know what we don't know, we 'don't put all the eggs in one basket'. Increasing the variety of options in a portfolio, enhancing their mutual disparity or maximizing the balance in their proportional contributions all offer ways directly to hedge against ignorance and surprise [79]. This strategy is all the more robust, because it does not require simplistic attempts to reduce the condition of ignorance, such as to appear tractable to particular favoured analytical techniques like probabilistic risk assessment. Intriguingly, diversification also offers a novel and under-recognised strategy for the accommodating the divergent interests, values and framing assumptions associated with the condition of ambiguity [80]. Where we are unable to identify a single optimal course of action (satisfying all points of view), then a judicious mix of actions may prove much more effective than 'picking winners' or 'engineering consensus'.

Similar considerations are raised by a number of other strategic properties, which – together with the question of diversity – might be referred to as different attributes of

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77 Renn, et al, 1995; Sclove, 1995; Joss and Durant, 1995; Holmes and Scoones, 2000.

78 Davies et al, 2003

79 Stirling, 1994

80 Stirling, 1997

resilience. First, there is the *flexibility* with which commitments may be withdrawn from a particular option should it prove to be the object of adverse surprise as developments or knowledge unfolds. Obviously, this also addresses the possibility of pleasant surprises and, crucially, involves consideration of both technical and institutional factors. Then there is the question of the *adaptability* of options in the face of particular possible developments, involving the degree to which they might be reconfigured in the face of a range of scenarios. Likewise, there are issues around the *robustness* with which the strengths and weaknesses of a portfolio of options complement one another, such as to address the full range of potential developments or stakeholder concerns [81]. In the case of radioactive waste management, there are obvious implications in relation to the sponsoring of different lines of scientific and technical research, as well as the possibility of pursuing in parallel a number of alternative investment programmes.

Of course, none of these strategies offer a 'free lunch'. All are likely to involve trade-offs, diseconomies of scope and scale and to be subject to diminishing returns. All require new institutional innovations to enable the appraisal and management of options at very different stages in their innovation and development trajectories. The increased scale of this governance challenge may also require that options be deliberately addressed at a more aggregated level, spanning different institutional or national jurisdictions. In certain ways, some of these considerations are – if only by default – already a manifest feature of the international radioactive waste management scene. However, there exists considerable scope for making the associated issues more explicit, thus stimulating more effective, deliberate and accountable decision making. Whatever the truth on this, the important point is that – under a precautionary approach – such factors become an explicit focus, alongside the more conventional aspects of option performance.

By devoting greater attention to these general features of technological strategies right from the outset in regulatory appraisal – and at the earliest stages in the innovation process – we might hope to reduce our exposure to the problems associated with uncertainty, ambiguity and ignorance. Either way, persistent preoccupation with the sufficiency of probabilistic methods and the other techniques of conventional risk assessment – and their supposed 'sound scientific' status – seems to have left all these crucial issues neglected.

In conclusion, the adoption of a precautionary approach to options appraisal, in the manner that has been described in this discussion paper, not only makes more explicit the challenges of uncertainty, ambiguity and ignorance, but also offers a number of concrete responses.

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[81] Stirling, 1998b

4 QUESTIONS ARISING FOR RADIOACTIVE WASTE MANAGEMENT

In accordance with the remit provided for this discussion paper, the following final section draws on the preceding chapters to resolve a series of salient questions that might be addressed in a 'public dialogue' process. At first sight, many of these may seem rather open-ended. This is deliberate, in that the issue in each instance is not to identify a particular 'correct answer', but to help catalyse a deliberative process which itself will form part of the solution.

For what it is worth, however, the present author's own responses to many of these questions are addressed in practice in two projects, for which reports are available on the web, or from the author. The first project develops a general architecture for the articulation of precautionary and more conventional forms of regulatory appraisal and is available at: <http://www.aramis-research.ch/d/13406.html>.

The second project involves the design and implementation of a concrete appraisal process, which integrates public participation, stakeholder engagement and specialist deliberation in evaluating the pros and cons of a wide range of technological options in such a way as to fully reflect the associated sensitivities and uncertainties. This can be obtained at: <http://www.deliberative-mapping.org/>.

1 What guidance might be given for analysis concerning the relative priority to attach to *quantitative* and *qualitative* factors, the appropriate degrees of precision and the acknowledgement of uncertainty and variability?

2 What is the appropriate balance to strike in appraisal between the avoidance of *Type I and Type II errors*? How might this be made more deliberate and explicit in terms of the wider trade-offs between unduly restrictive and permissive regulations?

3 What general principles might be adopted concerning the handling of the *burden of persuasion* with respect to the arguments made by different parties concerning various aspects of the appraisal of radioactive waste management options?

4 How might we best characterize explicitly the appropriate *weight of evidence* to adopt as a threshold for different types of investment or regulatory action in different areas?

5 By what means might the strategic balance be made more deliberate and explicit between the role of theoretical models and *empirical field research and monitoring* in informing the appraisal of radioactive waste management options?

6 How should enhanced levels of field research and monitoring be funded, such as to provide *adequate resources* for this important activity, whilst avoiding unduly favouring nuclear generating strategies through public subsidy?

7 What institutional safeguards might be designed to allay concerns over the tendency for the siting of experimental facilities to *'lock-in' policy making* concerning the siting of subsequent industrial plant?

8 What are the appropriate decision making procedures for determining the *overall scope and depth* of a broad-based precautionary appraisal process and the point of diminishing returns after which further effort becomes disproportionate?

9 How might provision best be made for complementing conventional analysis of risks and impacts with assessment of the *countervailing justifications and benefits* associated with of alternative radioactive waste management options?

10 What safeguards can be adopted to ensure that appraisal of the technical aspects of radioactive waste management options does not become unduly *dominated by a particular specialist discipline*?

11 What does it mean in practice, for the authority and legitimacy of appraisal procedures and institutions to shift from a position of '*independence through objectivity*' to '*independence through plurality*'?

12 What practical methods best provide for the systematic exploration of *alternative framing assumptions* and value judgments in appraisal and their articulation with procedures for eliciting divergent public and stakeholder perspectives?

13 How can policy and decision making procedures be adapted – and key actors be persuaded – to make them more receptive to more plural forms of technical advice? In what way might the *enhanced forms of accountability* best be handled?

14 What processes offer the best way to *integrate public participation, stakeholder engagement and specialist deliberation* in such a way as to avoid undue conflict, fatigue, redundancy and inefficiency and such as to elicit the best inputs from each?

15 What principles of process design might best ensure that different stakeholders, interest groups and public constituencies are able not only to engage in the appraisal process itself, but also to exert a *legitimate influence over its design and scope*?

16 What institutional innovations are necessary to allow the appraisal process to address radioactive waste management options at the *earliest stages in their technological or policy development*, before commitments and configurations are set?

17 How might the management of radioactive waste programmes best seek explicitly to address the benefits and trade-offs associated with *strategic resilience in portfolios* of options, including questions of diversity, flexibility, adaptability and robustness?

18 What financial, institutional, accountability and wider governance issues are raised in seeking to make more deliberate and targeted existing processes for the *inter-agency and international co-ordination* of radioactive waste management strategies?

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