EARTH SCIENCE, ENVIRONMENTAL RISK AND DECISION MAKING:

THE ROLE OF CONCEPTUAL GEOSCIENCE IN A CONSULTATIVE APPROACH TO ENVIRONMENTAL DECISION MAKING.

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ABSTRACT

The research presented in this thesis examines the changing nature of environmental decision-making processes and their implications for scientists. The fundamental issue is how can we get the right science, in an appropriate social context, to support environmental decision-making? This question is considered by examining the issues surrounding the management of radioactive wastes. Specifically, the research looks at the qualities and culture of the geosciences in fostering participatory risk analyses.

The primary aim of the work is to identify vehicles for debate in order to build a knowledge platform shared by a range of stakeholders. Social science theory is used to guide scientific practice in risk assessment. The thesis has been structured into three sections;

- A literature review examining modern trends in the social framing of decisions and the management of risk;
- An analysis of the specific case of radioactive waste management;
- New studies exploring the implications of increased stakeholder engagement in evaluating the risks from the deep geological disposal of radioactive wastes.

Overall, it is concluded that opportunities for developing and sharing knowledge between scientists, stakeholders and the public can and should be created. Because of the highly quantitative nature of risk analyses, this sharing is best addressed at a conceptual, qualitative level. Important considerations are that the knowledge building process is iterative and reflexive and that dialogue between participants begins early in the process. If an appropriate process is adopted, conceptual understanding can be used to support both social learning and quantitative analysis for expert regulation. A methodology for a participatory risk assessment for deep geological disposal is advanced. The research concludes that conceptual models can provide vehicles for debate, but the construction of a shared knowledge platform is more elusive.

LIST OF ACRONYMS

ALARA	As Low As Reasonably Achievable
ALARP	As Low As Reasonably Practicable
AM	Argumentation Map
ANDRA	French Radioactive Waste Management Agency
BATNEEC	Best Available Technology Not Entailing Excessive Cost
BGS	British Geological Survey
BNFL	British Nuclear Fuels
BPEO	Best Practicable Environmental Option
BSE	Bovine Spongiform Encephalopathy
CBA	Cost-benefit Analysis
COWAM	Communities and Waste Management
CRA	Comparative Risk Assessment
CV	Contingent Valuation
DEFRA	Department for Environment Food and Rural Affairs
DiP	Decision in Principle
DOE	Department of the Environment
DTI	Department of Transport and Industry
EA	Environment Agency
EC	European Community
EDF	Electricite de France
EIA	Environmental Impact Assessment
EIS	Environmental Impact Statement
EKRA	Swiss Experts Group for Disposal Concepts
ENRESA	Spanish Radioactive Waste Management Agency
EPA	Environmental Protection Agency
ERA	Environmental Risk Assessment
FEP	Features, Events, Processes
GPA	Generic Post Closure Performance Assessment
HARPHRQ	Code for the modeling of radionuclide speciation
HAZOP	Hazard and Operability
HLW	High Level Waste
HoL	House of Lords
HSE	Health and Safety Executive
IA	Impact Assessment
ICI	Imperial Chemical Industries
ILW	Intermediate Level Waste
JNC	Japan Nuclear Fuel Cycle Development Corporation
KASAM	Swedish National Council for Nuclear Wastes
LCA	Life Cycle Assessment
LLW	Low Level Waste
LOFRA	Netherlands – Site Selection Committee
MASCOT	Probabalistic assessment modeling code
NAGRA	Swiss National Nuclear Waste Agency
NAMMU	Continuum Groundwater modeling code
NAPSAC	Discrete fracture network modeling code
NASA	National Aeronautics and Space Administration
NEA	Nuclear Energy Agency

NGO	Non-Government Association
NIREX	Nuclear Industry Radioactive Waste Executive
Nirex	United Kingdom Nirex Limited
NRC	National Research Council
NRPB	National Radiological Protection Board
NUMO	Nuclear Waste Management Organization of Japan
NUSAP	Number Unit Spread Assessment Pedigree
ONDRAF/NIRAS	Belgian Radioactive Waste Management Agency
PANOIL	Groundwater test interpretation code
PEG	Potentially Exposed Group
POSIVA Oy	Finnish Radioactive Waste Management Agency
POST	Parliamentary Office of Science and Technology
PRA	Probabilistic Risk Assessment
PSA	Probabilistic Safety Assessment
PTA	Participatory Technological Assessment
R&D	Research and Development
RA	Risk Analysis
RAWRA	Czech Radioactive Waste Repository Authority
RCF	Rock Characterisation Facility
RISCOM	European program for transparency and public participation in nuclear waste management.
RWMAC	Radioactive Waste Management Advisory Committee
SAFIR	Belgian Safety Assessment
SEA	Strategic Environmental Assessment
SFR	Swedish Repository for LLW and ILW
SIA	Social Impact Assessment
SKB	Swedish Nuclear Fuel and Waste Management Co.
SKI	Swedish Nuclear Power Inspectorate
SSI	Swedish Radiation Protection Authority
STUK	Radiation and Nuclear Safety Authority of Finland
TA	Technical Assessment
UK	United Kingdom
UKAEA	United Kingdom Atomic Energy Authority
URL	Underground Rock Laboratory
USDoE	United States Department of Environment
VL	Visual Language
VLLW	Very Low Level Waste
WIPP	Waste Isolation Pilot Plant

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1 INTRODUCTION

The aim of this thesis is to contribute to good practice in environmental decision-making. The research examines how to increase opportunities for broad interaction and knowledge building about the cause and effect of environmental processes. These issues are examined in the context of assessing the risks from the disposal of radioactive wastes deep underground. The developments proposed in this thesis centre around encouraging debate to build a knowledge platform that is shared by both scientific and non-scientific participants in the decision-making process.

Environmental policy-making is becoming increasingly complex. The notion of sustainability places a responsibility on today's societies to consider economic, social and environmental issues alongside each other. Decision-makers – often representing the UK Government – are now seeking to make decisions about projects presenting a risk to the environment based on a measure of public consensus. They are adopting stakeholder dialogue and consultation as part of the decision-making process. Traditional practices for bringing scientific knowledge into decision-making are called into question by this new way of working, which challenges the long-established, technocratic approach of judging the acceptability of environmental risk against a set of regulatory criteria established by a limited set of stakeholders.

These new processes for environmental decision-making call for various stakeholders[1] and public constituents[2] to come together and share issues, concerns and values about the decision in hand. The premise is that all these individuals and groups have knowledge relevant to the decision. The hope is that by sharing this knowledge, the resulting decision will have solid social, environmental and economic foundations. However, such knowledge sharing modifies the demands on scientists holding expert knowledge about environmental processes. Meeting these demands requires some careful and reflective consideration about how different forms of knowledge are prepared, presented and debated during the decision process.

[1] A stakeholder is an individual or group of individuals who are directly or indirectly affected by the decision and therefore can be viewed as having a stake in its outcome.
[2] The term public constituents is used here to describe the wide range of different individuals and groups who together constitute the society in which the decision is being made.

1.1 Aims

My objective is to examine the changing nature of environmental decision-making processes in order to identify ways of evolving the knowledge building processes that support these decisions. The fundamental issue is how can we get the right science in an appropriate social context to build an effective knowledge base for decision-making?

The primary aim of this thesis is to identify vehicles for shared knowledge building that take into account modern trends in the social framing of decisions and acknowledge the value of other (less expert) forms of knowledge about environmental processes. I have used social science theory to guide the development of scientific practice in the field of environmental risk assessment. My main focus has been to find new ways of building analytic-deliberative decision-making into the specific decision-problem of radioactive waste disposal. My hypothesis is that qualitative descriptions, captured in conceptual models offer potential as a vehicle for debate. Such debate is necessary in order to build a platform of shared knowledge that can be used to inform risk analysis in environmental decision making.

1.2 Audiences

Shared knowledge building raises issues for social *and* physical scientists since they will both be challenged to think outside traditional comfort zones. However, the thesis is primarily aimed at physical scientists who may be involved in providing expert knowledge into consultative environmental decision-making. In particular, I hope to make a contribution to the literature supporting good practice in the nuclear industry.

The work presented in this document sits on the boundaries between scientific practice and social science theory. Both areas of work have their own language and informal codes of conduct. One of the difficulties of presenting work that sits on such interfaces is that there are two distinct bodies of academic research to reflect, and two distinct sets of language and mindset. Therefore, the contents of this thesis cover a very broad range of topics from a range of different academic disciplines. The scope of the thesis is therefore broad and has been structured to reflect a line of integrated thought, rather than any conventional topical arrangement according to discipline..

1.3 Context

This thesis originates from the experience of working with Nirex (the company charged with developing proposals for the safe long-term management of the UK radioactive wastes) in the 1990's. During that time, the national policy for the management of certain types of radioactive waste was to dispose of them deep underground. The development of proposals to meet that policy were based on assessments of the potential risks to humans from radioactivity returning to the surface environment for very long times into the future. An important component of research was to understand how the geology and hydrogeology at the site of the repository would affect its evolution and the consequential migration of radionuclides. To inform this research, one of the major site investigation and geoscience programmes in the UK at the time was undertaken in West Cumbria by Nirex.

A major focus of this site investigation programme was the integration of various aspects of geoscientific information into a conceptual understanding of the repository site, and the integration of this understanding into models capable of calculating risks from the repository. Having developed an understanding of the site, Nirex applied for planning permission to undertake further research from a mined underground facility, a "Rock Characterisation Facility or RCF. However, Nirex was not successful in gaining planning permission. The research leading to this thesis was initiated by a personal view that this failure partially stemmed from a naïve approach to the use of scientific knowledge in a decision making process for a project of such social significance.

The viewpoint from which this thesis is written has been developed from experience as a practising scientist working on the long-term management of radioactive waste - a difficult and dynamic area of environmental policy. I have worked, directly and indirectly, for Nirex, for 15 years. Over these years, I have experienced much satisfaction and much frustration over the use of "my" scientific information in public and corporate decision-making. These highs and lows have been partly determined by the quality of interaction between scientists, other stakeholders and public constituents. In consequence, although it remains a prerequisite that the cognitive content of scientific information is of high quality, it is no longer sufficient to ensure that the information is used effectively in decision-making. Since I believe that scientific information has a fundamental role to play in the decision-making process, this thesis explores new ways of ensuring that the value of science is maintained in decision-making processes where scientists are not the only source of knowledge.

1.4 Methodological approach

The approach taken for this research is outlined below. As with any research undertaken over a prolonged period of time, the ideas evolved during the process.

1.4.1 Literature Review – Framing the problem (Section 1)

My starting point for the research is the assumption that scientific knowledge in general, and geoscientific knowledge in particular is important to evolving forms of environmental decision-making. Initially, this assumption is explored against the background of literature that discusses:

- the changing context for environmental decision-making (chapter 2);
- participation and its role in decision-making (chapter 3);
- risk analysis and the treatment of uncertainty (chapter 4)

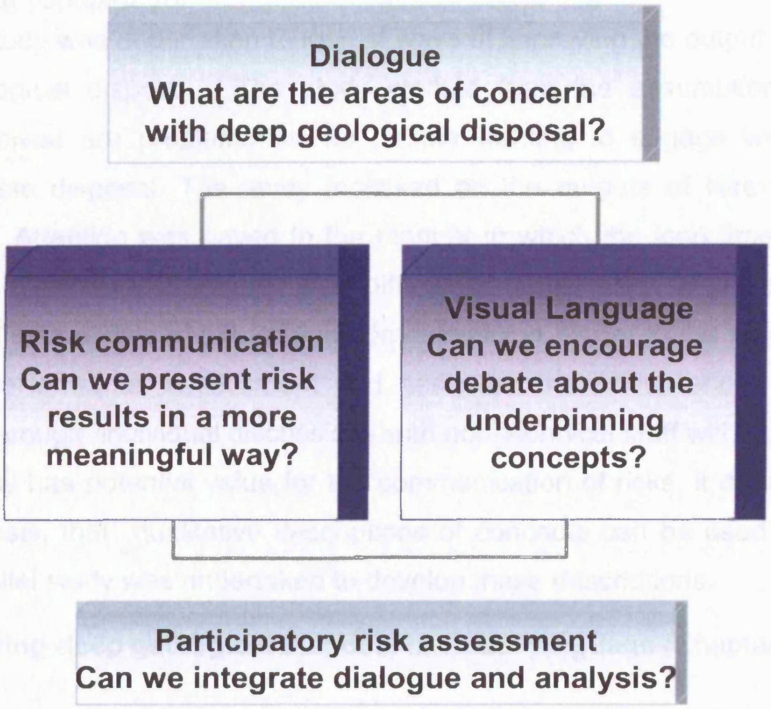
This literature review suggests that the manner in which this knowledge has been used in the past has inhibited opportunities for stakeholders to engage with science during the decision-making process (chapter 5). Traditionally in many industries, scientific knowledge has been bought into decisions about the environment in the form of an assessment of environmental risk. Such risk assessments use scientific knowledge and mathematical models to make calculations of potential harm to the environment arising from a proposed course of action. I suggest that the highly quantitative nature of these risk evaluations can, in isolation, mask the value of the scientific contribution to environmental decision making. In essence, shared knowledge building is constrained by the highly technical nature of the risk analysis.

1.4.2 ***Case Study Analysis – The specific case of radioactive waste management*** *(Section 2)*

The validity of my conclusions from the literature review is tested against case study material drawn from the radioactive waste management industry (Chapters 6,7 and 8). This topic is controversial and requires an assessment of potential environmental risks about which there is a large amount of uncertainty. My experience has been in this area, having worked for Nirex, an organisation charged with developing options for the safe management of certain radioactive wastes in the United Kingdom. Nirex's experiences give rise to empirical information available from the eighties and nineties about how scientific knowledge has been used in making decisions on behalf of society. Specifically, the difficulties of using "performance assessments" (the term used for assessments that examine the long term risks from disposing of radioactive waste deep underground) are considered. The relationships between values and knowledge in the performance assessment is explored, together with the cultural difficulties of using such a highly expert process to encourage debate with those holding different expertise.

As a result, I argue for greater use of conceptual presentations of the physical and chemical processes giving rise to environmental risk as a common platform for knowledge building. This argument is tested in a series of linked empirical studies (Section 3). The linking between these studies is shown in Figure 0.

Figure 0: Linking between the studies presented in Section 3



1.4.3 A dialogue about issues and concerns with deep geological disposal of radioactive wastes. *(Chapter 9)*

A series of public focus groups were commissioned to talk about public concerns about the deep geological disposal of radioactive waste. The aim was to identify areas of common interest that could form a focus for the development of visual representations of important concepts relevant to the risk analysis.

Eight focus group were established across the UK. Each focus group met for a two hour session on two consecutive weeks. The groups were selected to reflect different demographics and were arranged and managed by an independent facilitator.

As well as analysing the results of the dialogue, reflective practice was applied to the design and development of the dialogue process since it involved extensive discussions between analysts from Nirex and a facilitator with no prior knowledge of radioactive waste management.

The study identified many areas of interest. Concerns about long timescales and worries about contamination underground were taken forward into the next study. These concerns go right to the heart of the risks associated with deep geological disposal.

1.4.4 Presenting the outcomes of long-term risk results for deep geological disposal *(Chapter 10)*

An analytical study was undertaken to look at ways of improving the output of risk analyses for deep geological disposal. The study worked from the assumption that the long timescales involved are problematical for people wanting to engage with the issue of radioactive waste disposal. The study focussed on the outputs of Nirex "performance assessments". Attention was payed to the manner in which the long timescales involved are conveyed. This issue emerged as a difficult communication area from the dialogue work described above. The study applied communication theory to the results of the most recent Nirex performance assessment and assessed the effectiveness of the revised *presentations through individual discussions with non-technical staff within Nirex.*

Whilst this study has potential value for the communication of risks, it did not address the central hypothesis, that qualitative descriptions of concepts can be used as vehicles for debate. A parallel study was undertaken to develop these descriptions.

1.4.5 **Presenting deep geological disposal in visual language** (Chapter 11)

Participatory research was used to develop visual representations of the key concepts about the role of rocks in deep geological disposal. Visual Language is a novel communication technique. The assumption behind this study was that a visual representation could encourage debate and deliberation about the science of deep geological disposal. Iterative review and development was used to develop the visual language.

Initially, a set of visual representations were developed. Contextual representations were developed to address some of the issues identified from the dialogue work, more detailed representations were developed from knowledge of the important processes captured in the risk assessments.

The first pass representations were subject to focus group discussions within Nirex, using groups of individuals designed to reflect different levels of familiarity with the scientific concepts of deep geological disposal. Comments from these groups were used to develop a second version. This second version was subjected to an independently facilitated workshop involving 10 participants from the social science academic community. A review report was produced from this workshop. This review report was used to assess the potential for visual language to act as a vehicle for dialogue.

1.4.6 **Integrating dialogue into risk analysis** *(Chapter 12)*

Both the previous studies were essentially about communication and dialogue. A key issue for the research was to determine whether the outcomes of this dialogue could be included as an integral component of the risk analysis process. The risk assessment processes used by Nirex were revisited to look at how the assessment process could incorporate the findings of the preceding studies. The aim of this was to propose a new approach to risk assessment where analysis and deliberation were integrated into a single process.

1.5 Limitations of the research

Given the above context, it will be apparent that the research outlined above was undertaken whilst I was an employee of Nirex. Hence I was a participant-observer, not an objective researcher. This has several consequences for the research:

- whilst I have sought to preserve an impartial view through the research, there will be some embedded values that arise from having worked in a radioactive waste management implementation organisation for a long time. For example, I have not seriously questioned whether or not radioactive wastes should be managed by deep geological disposal, except peripherally when exploring value judgements in Nirex's performance assessment.
- Essentially, any dialogue presented in this thesis was undertaken under Nirex sponsorship and with a Nirex brand associated with it. One way of minimising the consequences of this has been to use independent facilitators for the major dialogue components. However, ultimately Nirex funded all of this external work which may have influenced the participants views and the way they responded to the dialogue.
- Nirex's stated mission over this period was to "develop safe, environmentally sound and socially acceptable options for the long term management of radioactive wastes". Whilst there is no conflict between Nirex' mission, the goals of this research and my own personal values, I had to adapt some of the research programme to address broader needs than those of the research alone. This means that the integration and resolution of the various empirical studies is not as strong as it might have been. Specifically, a logical conclusion to the research would be a testing of the participatory performance assessment method developed at the end of this research. This would have involved dialogue work which, due to changing policy contexts, Nirex did not feel able to undertake at the time.
- And finally, Nirex is a very focussed organisation, whose mandate relates solely to the management of radioactive wastes. This focus is shared by Nirex's employees. Therefore the research is similarly very focussed on radioactive waste management. My employment within a particular industry, whilst providing an extremely valuable source of experience and information during the research

process, may have limited the extent to which I was able to identify and see connections into other research fields and industry applications.

It is also worth noting that the research has focussed on the visual representation of information into dialogue and debate. This will undoubtedly reflect my own preferences for visual forms of information. The research could equally have considered the contribution that could be made from other forms of information. However, the goal of the research is not about information provision, it is about engaging interest and capturing the consequence of dialogue. Therefore, it seemed appropriate for me to have chosen to try and capture the dialogue in the information form with which I am most comfortable.

And finally, with the emphasis of the research being on the radioactive waste management industry, it is necessary to consider its applicability outside the field. Decisions about the management of radioactive waste are affected by a number of issues. These issues reflect the growing body of academic literature on decision analysis, risk perception, deliberative democracy, trust, credibility and transparency. Decision-makers have to deal with a great many different views on:

- the long term environmental significance of the wastes
- the dread of radiation,
- connotations with nuclear weapons
- the historical legacy of the nuclear industry in general
- inevitable links with the future of the nuclear industry

Many other environmental projects have to face a similar mixed bag of issues, some of which derive from the scientific evaluation of a project, others which derive from social values and past history. Therefore, although this thesis has been generated on the basis of experiences with radioactive waste management in the 1990's it has a more general applicability to other projects that pose a long-term risk to the environment. Nevertheless, this more general applicability is not explored thoroughly within this thesis.

1.6 Structure of this thesis.

This thesis has been structured into three sections. Section 1 analyses existing literature relevant to the research. Section 2 analyses the specific case study of radioactive waste management. Section 3 presents the empirical work undertaken to address the research questions arising from the first two stages. The next Chapter is the start of the literature review and presents an overview of the issues arising in the emerging field of environmental decision-making.

Section 1

The role of science in environmental decision-making: Framing the Problem

2 ENVIRONMENTAL DECISION MAKING AND ENVIRONMENTAL DEBATE

The context for environmental decisions is changing at local, national and international levels. In consequence, both the process for, and the content of environmental decision-making need to be rethought. This raises questions about the knowledge that is required to support new, socially inclusive processes and the processes that affect those holding such knowledge. This chapter explores these questions to establish the context for the research in this thesis.

2.1 Environmental decision-making – a definition

The environment is a shared resource. It responds to any action that we take. We are learning about our relationships with the environment all the time, and realising that for any action, there are many possible futures that could reasonably be considered, often with widely diverging consequences. Environmental decision-making is about determining an appropriate course of action, despite the associated uncertainty.

Environmental decision-making needs to consider whether our actions could threaten the ability of the environment to sustain our societal norms. Changes to the environment are becoming more significant as we become increasingly aware of the long-term impacts of our past actions. Over the last few decades the concept of environmental decision-making has grown, culminating in the ratification of the principles of sustainable development at the Earth Summit at Rio de Janeiro in 1992 [WCED, 1987]

2.2 The influence of sustainable development

It is impossible to separate economic development from its impact on the environment. Raw materials and energy are provided by the environment in which we live and economic growth generates waste products that require disposal. In consequence, the environmental resources on which economic development is based are eroded [WCED, 1987]. Societies are therefore challenged to find ways of pursuing economic development that are sustainable and will limit degradation of the environment on which they are reliant. In consequence, since the Rio Earth Summit in 1992, sustainable development and sustainability have become key elements of environmental policy.

Sustainable development provides a framework for weighing up the potential benefits of economic developments against the risk of detrimental impact on the environment. This concept now dominates the national and international environmental policy arena. Its intentions are captured in a commonly used definition proposed by the World Commission on Environment and Development. This states that "*sustainable development is development that meets the needs of the present generation without compromising the ability of future generations to meet their own needs*".

Agenda 21 of the 1992 Rio Conference on Environment recommends that the widest possible participation should be encouraged. Principle 11 of the Rio Declaration on Environment and Development states that " environmental issues are best handled with the participation of all concerned citizens at the relevant level..." (WCED 1987). In response, successive governments in the United Kingdom have been seeking to describe how sustainable development will be put into practice [DETR,1999b; DoE, 1994]. Increasingly, governmental organisations are seeking to integrate economy, society and the environment in setting environmental policy at both national and local government levels. Internationally, a convention on "Access to Information, Public participation in Decision-making and Access to Justice in Environmental Matters" (the Aarhus convention) [UN, 1998] was developed through the United Nations in 1998 to provide a global framework for addressing these issues.

Consequently, decision-makers are seeking to consult prior to, and during the determination of a course of action that will impact the environment [Munton and Collins, 1998, Parliamentary Office of Science and Technology, 2000]. The decision analysis and operational research literature reflects the major effect that such "deliberative democracy" is having on decision-making processes [Bell et al, 1988]. Essentially, this work implies the need for new relationships between all those interested in, and affected by, the decision. [Petts and Leach, 2000]. An aim of deliberative democracy is to empower "society at large" to influence decisions about what constitutes an acceptable development [Bohman and Rehg, 1997]. Under the framework of sustainable development, "society at large" includes both current generations, who are able to speak for themselves, and future generations whose needs have to be anticipated.

A common position adopted in many genuine attempts to respond to the principles of sustainable development is the idea of "balancing" between:

- Environmental issues, often informed by researchers and practitioners in science, engineering and technology;
- Economic issues, such as those that determine productivity, viability and maintain a healthy economy;
- Social Issues, that determine individual and collective quality of life.

The idea is that by considering these three pillars of sustainable development, the perceived benefits of a decision can be weighed against possible detriment. However, the benefits of economic development are not distributed equally across society or across the globe [Giddens, 1999]. In addition, the "environment" means different things to different people, and different people may have different opinions as to what constitutes an "adverse consequence". The art of balancing the benefits of economic development against potential environmental risk requires consideration of what will be gained from the development and what could be harmed by the development [DETR, 1999b]. However, there are no simple answers to these questions. For different people, the answer will differ depending on their personal values and by value judgements[a]. These differences have fuelled debates on underlying ethical questions such as:

- how much value should we place on future generations?
- what value do we place on economic development?
- to what extent do we need to minimise consequences?

Answers to these questions vary significantly between the international, national and local scales and depending on whether individual benefits or collective benefits are of concern. Additionally, anticipation of the needs of future generations in these three areas is extremely difficult since the future is, by definition, uncertain. This has led to an often observed problem in interpreting the principles of sustainable development. It is very difficult to move from fairly general statements of principle towards ideas of best practice and measurement criteria that are acceptable to all players.

These questions about how to interpret the principles of sustainable development may mask a deeper issue. Some workers express a concern that this difficulty in interpreting the "balance" model of sustainable development has obscured the underpinning ideology – that technical, economic and social factors *all* need to be healthy if sustainability is to be achieved. This is the concept of "deep sustainability" [UNESA, 2002, Lovins et al, 2001].

Deep sustainability highlights the importance of the social processes surrounding an environmental decision. Whereas in the balance model, it is possible to separate knowledge about environmental, social and economic factors on the assumption that these factors will be "weighed" against each other at some point, deep sustainability calls for them all to be interwoven together. The balance model is therefore more comfortable for specialists with a particular form of expertise since it allows them to

[a] A value judgement is a subjective judgement informed by a specific set of moral and ethical standpoints.

remain within their discipline on the assumption that "someone else" will do the balancing act. The model of deep sustainability challenges those involved to think outside the boundaries of their own particular expertise and experience. In consequence, it is redefining the boundaries of knowledge pertinent to environmental decision-making.

Since the eighties, there has been a lot of thinking and analysis of the role of different kinds of knowledge in environmental policy making. Research [Giddens, 1990, Beck, 1992a] suggests that we are undergoing a change so that anxiety, uncertainty, radical doubt and reflexivity are replacing past "truths" such as trust in experts and belief in Government. Giddens identifies that this "reflexive modernisation" undermines knowledge and erodes levels of trust in those in authority. This includes the authority that scientists once enjoyed as the purveyors of knowledge.

This contemporary thinking does not seek to downgrade science – rather to place it effectively within its social context. Both Beck and Giddens identify that risks to the environment are a major preoccupation and Beck cites Immanuel Kant's conclusion from "A critique of pure reason (published in the 18th Century) that *"scientific rationality without social rationality is empty, but social rationality without scientific rationality is blind*" [Beck, 1986]. The question thus becomes how can we get the right science in an appropriate social context to build an effective knowledge base for decision-making?

2.3 Knowledge and environmental decision-making

Environmental decision-making responds to demands for new approaches to managing our relationships with the environment. Scientists have always been part of the decision-making process thanks to the knowledge that they bring to the decision. However, mounting evidence of failures to adequately assess the consequences of our action is leading towards lack of confidence in this traditional knowledge base. The power of scientific knowledge used in isolation is waning (Beck 1992b).

Knowledge can be defined in several, equally legitimate ways. For example, in one dictionary [OED] it is defined both as "the facts or experiences known by a person or a group of people" and "consciousness or familiarity gained by experience or learning". In this thesis, I have adopted the second definition and in so doing I am suggesting that knowledge extends beyond facts. The rationale for this claim arises from the need to inform environmental decisions by knowledge arising from:

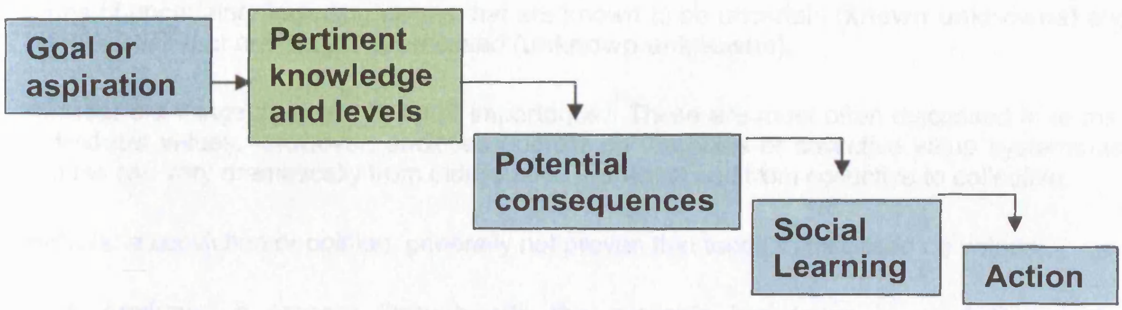
- science and technology, which provides an understanding of processes affecting the environment;

- the social landscape in operation, which is a way of describing the important values and concerns held by those individuals, groups and cultures (stakeholders) that will be affected by the development, now and in the future; and
- the results of consultation, which enables the decision-maker to develop a view on the general acceptability of the risk and the perceived benefits of the project at the time of consultation.

Not all of this information will be factual, but under sustainable development all will be pertinent to the decision. Box 1 clarifies further definitions of terms used in this chapter of the thesis.

Simplistically, a linear relationship between knowledge and decision making can be considered. This relationship is illustrated in Figure 1

Figure 1. A simplistic view of knowledge and decision-making



This linear model implies that the acquisition of knowledge for decision-making is relatively straightforward – a collation exercise that is undertaken as a precursor to the decision-making process. It is easy to see how scientific knowledge fits into this linear approach. For example, the Earth Sciences would provide knowledge bases such as mineral reserve estimations, aquifer potential assessments or site characteristics to inform cost-benefit analyses for resource development decisions.

Box 1: Definitions of terms relating to "knowledge"

Knowledge: consciousness or familiarity gained by experience or learning

Facts: a truth verifiable from experience or observation

Information: knowledge acquired through experience or study

Expert: a person who has extensive skill or knowledge in a particular field. This could be in a particular scientific discipline, or in the fields of economics or social science. Their knowledge (**expert knowledge)** is necessary, but not sufficient for the decision.

Expert Knowledge: tends to be structured and organised according to specific cultural guidelines dictated by the profession and its history.

Lay knowledge: This knowledge is also relevant to the decision but is likely to be experiential and can be very unstructured. It tends to be quite context specific. Within that context, the layperson could be an expert (as defined above). However, the context can be quite narrow. In this definition of the term lay knowledge would not necessarily be held by the experts since they are more likely to deal with generalities and principles.

Social Learning: The development of a collective knowledge and understanding that can be used to inform policy development. This can include developing the individual understanding of the participants and also improving the availability of information to society in general. Social learning is generally achieved when all partners modify their behaviours.

Uncertainty: something that is not accurately known or predictable. There are many different types of uncertainty including issues that are known to be uncertain (**known unknowns)** and also uncertainties that are not yet appreciated (**unknown unknowns**).

Values: the things that held to be of importance. These are most often discussed in terms of an individuals values. However, societies operate on the basis of collective value systems as well. Values can vary dramatically from individual to individual and from collective to collective.

Beliefs: a conviction or opinion, generally not proven that tends to be based on values.

Risk Analysis; a process through with the available knowledge is used to examine the consequences of a course of action in terms of future behaviour, impact or potential.

Stakeholder: An individual or group of individuals who are directly or indirectly affected by the decision and therefore can be viewed as having a stake in its outcome.

However, this initial information requires further evaluation to consider what may happen in the future – potential consequences. This requires the incorporation of a new set of information, much of which is uncertain and which draws on expertise from both inside and outside the scientific arena. This enables:

- the evaluation of mineral reserves to evolve into an assessment of economic potential;
- aquifer vulnerability plans to be developed from aquifer potential studies; and
- site specific risk assessments to be developed from the information provided from site characterisation.

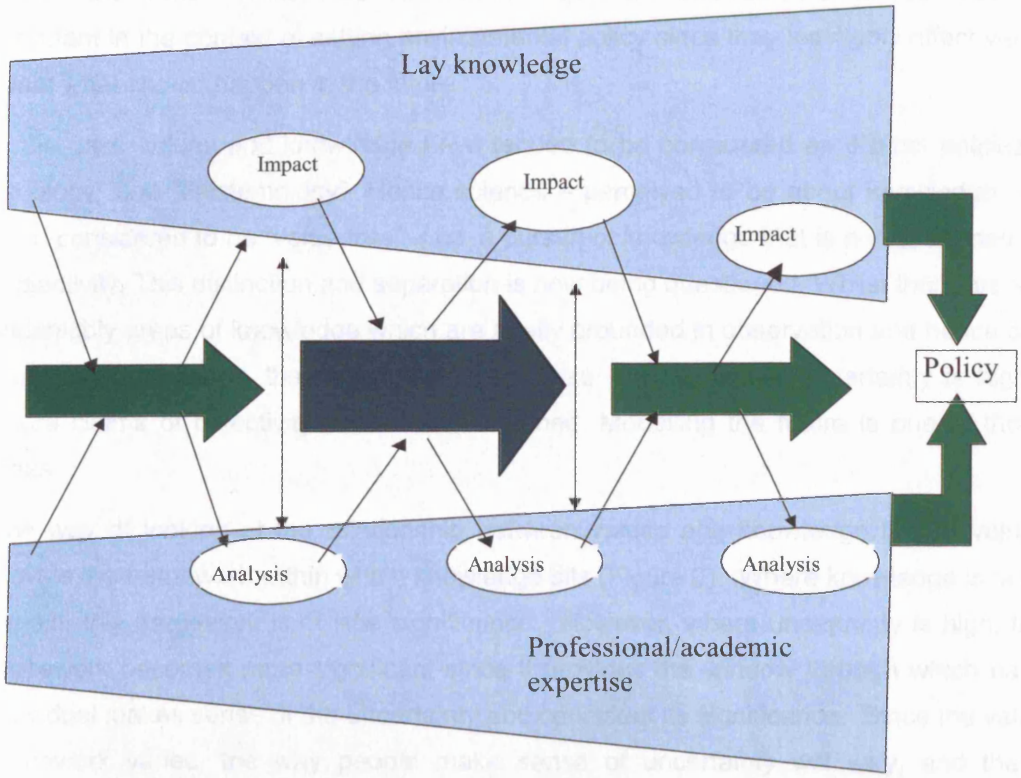
These transformations are typically achieved using some form of “risk analysis” [DETR, 2000], which is a calculation of potential consequences. Traditionally, it has been the risk analysis that has formed the knowledge platform on which environmental decisions have been based [Royal Society, 1992].

The National Research Council of the United States identifies risk analysis as “an activity that applies analytical techniques to the understanding of risks [National Research Council, 1996]. It involves estimating the likelihood of occurrence and possible severity of particular kinds of harm”. Risk analysis will be discussed in more detail in Chapter 4. The point to be made here is that the validity of risk analysis as the main vehicle of knowledge for environmental policy-making is now under challenge. Whilst it fits well into the linear approach shown in Figure 1, it does not easily accommodate knowledge from outside the natural and physical sciences – either social, economic or lay knowledge. New processes that integrate social, economic and technical issues imply a need for both expert knowledge provided by the scientific, social and economics professionals and also lay knowledge provided by the community at large

The integration of new forms of knowledge into the decision-making process challenges previously adopted cultural attitudes. True integration is unlikely to be best achieved with a linear model of knowledge development. Iteration and recursion between stakeholders with different forms of knowledge is likely to be required, so that one body of understanding can develop and evolve from another, and then feed back. Such iterations will enable the different forms of knowledge to work together and generate new ideas and values.

Figure 2 is a schematic representation of this new relationship between lay knowledge, professional/academic expertise and policy development. There is little new in the figure, except perhaps the idea of more closely linking unstructured lay views about impacts, with structured expertise and analysis. This goes in all areas of expertise – linking worries about the “pounds in my pocket” with a cost benefit analysis, linking concerns about environmental impacts with risk analysis.

Figure 2. Iterative and recursive knowledge development



2.4 Uncertainty, knowledge and values

Because we are still learning about our relationships with the environment, there will be uncertainty about the potential consequences of an action whatever the knowledge base bought into the decision-making process. The benefits of a project could vary widely within these possible futures, as could the potential harm. Finding a way through this minefield of potential futures requires a level of subjective judgement [Beck, 1992b]. Judgement is strongly influenced by the values held by the individual (person or organisation) making the judgement [Keeney, 1998]. Therefore, the conclusions of different individuals in the face of such large uncertainty can be markedly different, even directly opposing. However, both conclusions can be valid for the state of knowledge.

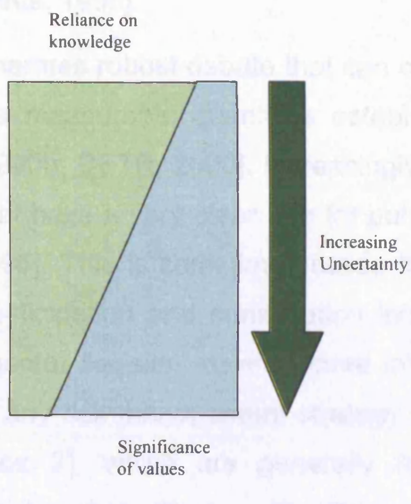
The Royal Commission on Environmental Pollution address this issue in their 21st report on the Setting of Environmental Standards [RCEP, 1998]. They identify the very close linkages between knowledge, uncertainty and values.

Values are what we care about [Keeney, 1998] and are thus inherently personalistic. They guide our actions and influence our decisions. They are subjective and colour our view of the world. Whilst I do not wish to major on a discussion of values, they are important in the context of setting environmental policy since they inevitably affect views about what should happen in the future.

In the past, values and knowledge have tended to be considered as distinct entities – "axiology" and "epistemology". Hence science – perceived to be about knowledge has been considered to be "value-free" – i.e. a pursuit of knowledge that is not influenced by subjectivity. This distinction and separation is now being questioned. Whilst there are still undeniably areas of knowledge which are totally grounded in observation and hence can claim to be objective, there are also other areas – those where uncertainty is high - where claims of objectivity are often questioned. Modelling the future is one of those areas.

One way of looking at the relationship between values and knowledge is that values provide the framework within which knowledge sits (Figure 3). Where knowledge is fairly certain, this framework is of little significance. However, where uncertainty is high, the framework becomes more significant since it provides the window through which each individual makes sense of the uncertainty and considers its significance. Since the value framework varies, the way people make sense of uncertainty will vary, and these variations need to be juggled by the decision-maker to determine an appropriate way forward. Very often, these variations can lead to significant debate about the wisdom of a particular course of action.

Figure 3. **General relationship between knowledge, values and uncertainty** (see Box 1 for definitions)



2.5 Environmental debates – why do they happen?

To help evaluate the consequences of a decision, the decision maker often seeks knowledge about the potential risks of a project. The definition of "risk" is difficult [Royal Society, 1992]. Several distinct classes of risk can be identified and are discussed in Chapter 4. Historically, risk was an intuition – a general good or bad feeling [Giddens, 1999]. As the insurance industry grew up it became a much more quantitative measure, based on the frequency and consequences of particular events determined from historical records [Adams,1995]. The quantitative approach to risk has been carried into the environmental sector [RCEP, 1998, DETR, 2000], where risk is defined in terms of some measureable quantity or set threshold [DEFRA, 2002a, EA, 2000, EA, 1997]. Risk assessment or risk analysis is the art of determining how close to that measurable quantity one will get [DETR, 2000]. Many industries have used this approach to environmental management based on linking together environmental standards, risk assessment, evaluation and characterisation in a logical process that could lead towards deciding on a course of action [Tran et al, 2000].

However, we are now realising that:

- we do not always know what hazard is posed by the set threshold [Coveney and Highfield, 1995]
- risk is a perceived thing and is conditioned by culture and by the type of person you are. - one persons risk may be another persons thrill [Wildavsky and Dake, 1990].
- The acceptability of a risk is very individualistic [Slovic, 1987].
- The risk may change once a risk is understood – we affect the world around us and are not separate from it [Adams, 1995].

Consideration of these issues generates robust debate that can challenge the adequacy of risk thresholds, targets or the measurable quantities established by the scientific community [Shrader-Frechette, 1990b; DETR, 2000]. Increasingly, calls are being made for decision-making processes that have a very clear role for public participation [Stern and Fineberg, 1998, Fischoff, 1995]. This is sometimes called the analytic-deliberative model of decision-making. As participation and consultation increase in profile as an essential component of environmental decision making, more intuitive factors are once again fundamental influences on any risk management strategy. These factors are risk acceptability and perception (Box 2), which are generally not included in a risk assessment. They are also both factors that will vary with different values.

Box 2: Terms in common use for risk management

Term	Definition used in this thesis	Examples	Comment
Risk assessment **Or** **Risk analysis**	the quantitative evaluation of the risk associated with an action, event or development	The risk of a bridge failure .	typically the domain of scientists and engineers. Much work has gone into method development
Risk evaluation	a judgement about the significance of the risk	Informs a decision such as: • I will/will not cross the road; • the risks are significant because the threshold is exceeded	
Risk management	Typically what is done by the decision maker, and in the context of environmental projects (s)he is having to act in the interests of a wide range of stakeholders	Determines a course of action such as: • Speed Limits to reduce the risk of road accidents • Welfare state to reduce the risk of extreme poverty • Comprehensive education to ensure a certain level of education for all	
Risk characterisation	Risk characterisation has been termed the way in which the risk analysis is translated to the risk manager	Statements such as "this is not a problem" Dealt with by triarge nurses in Accident and Emergency units	Can be difficult for projects involving many stakeholders with different characteristics and cultural backgrounds because "perception" and " acceptability" of risk will vary
Risk perception	The appreciation of the significance of the risk	Smokers vs non-smokers	Will vary dramatically according to personal characteristics and values, organisational culture and business and relevance to the individual or organisation
Risk acceptability	the level to which the benefits outweigh the detriments	Accepting the Newbury bypass because it reduces congestion in the town centre.	Will vary dramatically according to personal characteristics and values, organisational culture and business and relevance to the individual or group

Sociological and anthropological studies indicate that perception and acceptance of risk have their roots in social and cultural factors. Some workers [Short, 1984] argue that response to hazards is based on the influences transmitted by friends, family, fellow workers and respected public officials. Other workers [Wildavsky and Douglas, 1982] suggest that people, acting within social groups downplay certain risks and emphasize others as a means of maintaining and controlling the group. Risk acceptability and risk perception are therefore strongly influenced by personal and subjective judgements.

Descriptive research has indicated that there are some identifiable factors that affect the perception of risk. Early work by Starr [Starr, 1969] was based on seeking to explain historical evidence of societal response to risk. This identified that the level to which the exposure to risk was considered to be voluntary was critical in risk perception. Starr concluded that :

- The acceptability of risk from an activity is roughly proportional to the third power of the benefits for that activity
- The public will accept risks from voluntary activities (such as skiing) that are roughly 1000 times as great as it would tolerate from involuntary hazards (such as food preservatives) that provide the same level of benefit.

Starr's work is limited because it implies that a universal measure of benefit could be established. In view of the inhomogeneity of values held by different individuals and groups, such a measure would never be acceptable to all stakeholders. Nevertheless, Starr's work does imply that, because long term risks to the environment generally expose people to risks that are deemed to be involuntary and unlooked for, they will be perceived in a worse light than voluntary risks. Hence the apparent inconsistency between the acceptability of environmental risk and the acceptability of much higher levels of voluntary risk (e.g. smoking).

Further work sought to measure individual risk perceptions in relation to different risk problems more directly, rather than relying on historical evidence [Renn, 1991]. This research identified the importance of contextual factors such as perceived controllability, catastrophic potential and dread. This research [Covello et al, 1988] also suggested that perceived risk *is* quantifiable and predictable for different groups with different relationships to the risk problem. This pattern of perception is termed the "psychometric paradigm". Table 1 is taken from a discussion of the psychometric paradigm and illustrates peoples quantitative judgements about the riskiness of diverse hazards [Slovic, 1987].

Table 1: Ordering of perceived risks for 30 activities and technologies
(after [Covello at al 1988)

Activity or technology	League of women voters	College students	Active Club members	Experts
Nuclear Power	1	1	8	20
Motor vehicles	2	5	3	1
Handguns	3	2	1	4
Smoking	4	3	4	2
Motorcycles	5	6	2	6
Alcoholic beverages	6	7	5	3
General(private) aviation	7	15	11	12
Police work	8	8	7	17
Pesticides	9	4	15	8
Surgery	10	11	9	5
Fire fighting	11	10	6	18
Large construction	12	14	13	13
Hunting	13	18	10	23
Spray Cans	14	13	23	26
Mountain climbing	15	22	12	29
Bicycles	16	24	14	15
Commercial aviation	17	16	18	16
Electric power (non-nuclear)	18	19	19	9
Swimming	19	30	17	10
Contraceptives	20	9	22	11
Skiing	21	25	16	30
X-rays	22	17	24	7
High school and college football	23	26	21	27
Railroads	24	23	29	19
Food preservatives	25	12	28	14
Food colouring	26	20	30	21
Power mowers	27	28	25	28
Prescription antibiotics	28	21	26	24
Home appliances	29	27	27	22
Vaccinations	30	29	29	25

2.5.1 How do you enable a debate about risk?

Differences in risk perception and risk acceptance are the key factors that fuel environmental debates. It is these highly cultural factors that motivate people to adopt different positions when considering courses of action that have widespread and distributed impacts on the environment. The legitimacy of these different and personalistic views about risk have not always been appreciated. Those involved in risk analysis have often tried to convey the "real" meaning of risks to others - efforts that have been frustrated and frustrating for both the audience and the communicator. So although the desire for a debate is there, it can be difficult to make the debate happen. Much of this comes down to the difficulties of risk communication.

In an analysis of the history of risk perception and communication, Fischhoff has described the evolution in risk communication research [Fischoff, 1995]. He identifies a number of stages and concludes that although each stage makes progress, it also identifies additional, more complicated problems to solve".

Table 2 reproduces Fishhoff's evolutional stages in risk communication research. Each stage is characterised by a focal communication strategy, which the communicater hopes will "do the trick".

Table 2: Stages in risk communication research

Stage 1	All we have to do is get the numbers right
Stage 2	All we have to do is tell them the numbers
Stage 3	All we have to do is explain what we mean by the numbers
Stage 4	All we have to do is show them they have accepted similar risks in the past
Stage 5	All we have to do is show them that it is a good deal for them
Stage 6	All we have to do is treat them nice
Stage 7	All we have to do is make them partners
Stage 8	All of the above

A common theme in these risk communication strategies is the hope that they will influence the audience – presumably by persuading them that the development they are proposing or opposing is a good or a bad thing. Therefore, all these risk communication strategies are examples of *strategic action,* as defined by Habermass [1971]. It is not surprising that a feeling of "us and them" can easily develop, particularly given the complexity of environmental risk.

Enabling debate about environmental risks requires that all sides be bought into a dialogue about the benefits, detriments and uncertainty surrounding a project. Chapter 3 discusses the nature of dialogue in more detail, but a desired outcome of dialogue is the development of new meanings and understanding on the part of all participants. Ideally, communicating risks into the debate needs to be done as a form of *communicative* action [Habermass, 1971]. However, because of different values, something that starts as a genuine attempt to communicate risk in an unbiased manner may be interpreted as a one sided attempt to stifle debate and discussion.

Historically, institutions have adopted an analytically dominated (technocratic) approach to decision-making. This institutional approach has been based on genuine attempts to quantify risks based on scientific, technical and mathematical analyses. However, the attitudes of the public to the risks will be more intuitive and will be much more strongly influenced by feelings and individual experiences. It is not surprising that this can lead to a fundamental disjoint between the two approaches. Recognising this helps explain some of the difficulties in enabling true dialogue about environmental issues.

2.5.2 Environmental risk, trust and legitimacy

The general public is often sceptical of the industrial claims regarding safety and risk [Slovic, 1999]. In the nuclear industry, factors such as potential harm to future generations, possible catastrophic consequences and undefined environmental effects are often cited [Covello et al, 1988]· Industry has tended to respond that the public has an irrational perception of radiation risks – particularly those from man made (as opposed to natural risks) [Cohen, 1983]. This tends to underplay what might be called morally relevant factors influencing public perception of risk and highlights a fundamentally different approach to considering the term " risk".

Debates about risk assessments often come down to a question of not only who we are going to protect from harm and at what cost, but also who we are going to allow to be harmed and by how much. Such decisions represent a fundamental problem of moral philosophy, and therefore decision-makers are often faced with conflicts and dilemmas that are grounded in matters of values and ethics.

In general terms, past decisions have been founded in "utilitarian" ethics [Benn, 2000]. Utilitarianism is an ethical approach based on ideas expounded by Bentham of achieving the " greatest happiness of the greatest numbers". It is society based, focussed on overall outcomes and therefore readily lends its support to economic risk/cost benefit actions. The distribution of harm or benefits (who pays and who gains) within society is not relevant within utilitarian ethics.

However, environmental risks *are* distributed – both in time and space. Moreover, to the public, who pays and who benefits is a highly relevant question. An alternative ethical approach [Benn, 2000] is to treat the individual as an end in themselves – not a means to an end. The focus of such a "deontological" approach is on human rights, autonomy and freedom. Clearly there is tension between the two different approaches, both of which seek to describe moral behaviour.

It is therefore not surprising that there is a public mistrust of the traditional institutional approach to dealing with environmental risk. Numerous recent studies point to lack of trust as a critical factor underlying environmental debates and the management of technological hazard [see Slovic, 1999]. If trust is the problem then it is unlikely that the solution is simply one of risk communication: If you trust the risk manager, communication is relatively easy. If trust is lacking then no form or process of communication will be satisfactory.

Many models have been put forward for building trust between participants in environmental debates [e.g. Renn and Levine, 1991]. Many common themes come out of these ideas, some of which are outlined below.

Trusted sources are perceived to be both knowledgeable and concerned with public welfare, whereas distrusted sources are perceived to distort information and to provide biased information [Slovic, 1999]. The "elaboration likelihood model (ELM)" [Renn and Levine, 1991] is an influential social psychological theory of communication that proposes both a "central route" and a "peripheral route" to the way an individual processes information. The central route involves the receiver of information processing the incoming information. The peripheral route is influenced by external, often subliminal factors surrounding the information, and the receiver may make up his mind about the accuracy of the information without undertaking any central processing at all. Most often, this will result in the information being discounted. High credibility (honesty, competence, consistency etc) will encourage central processing and low credibility will act to encourage peripheral processing.

The Åarhus convention, with its focus on "Access to Information and to Justice", considers trust to be a critical aspect of any societal process. The nature of trust is taken up by the European Commission in their Guidelines on the collection and use of expertise [CEC, 2002] and trust in scientists and experts is an issue often taken up in the media and in documents seeking to deal with the relationships between science and society [House of Lords, 2000].

Trust relies on competence and credibility. Renn and Levine [1991] identify five contributing factors that all tend to be judged based on historical experience. An individual will judge an institution depending on how it has behaved in the past with respect to:

- competence;

- objectivity;
- fairness;
- consistency;
- faith.

So the way an individual trusts information cannot be divorced from the information source and from the past history of the source.

A recent trend in building credibility for organisations is to adopt the principle of transparency. Transparency initially meant better/clearer/more detailed/less detailed/different explanations of technical solutions to other stakeholders. It was about packaging technical information. This was called the "deficit model" [House of Lords, 2000]. However, as research and reality have moved on, it has been increasingly realised that transparency needs to encompass both technical issues and judgements grounded in ethics, morality and values. Transparency also needs to address the relationship between them, and the roles and relationships of different groups involved in the debate.

So modern trends in decision-making encourage deliberation and discussion between a wide cross section of society through the transparent presentation of information, values and relationships. Transparency is not a route to trust [O'Neill, 2002]. Indeed, if trust existed then there would be no need for transparency. However, transparency can help with legitimacy, which may eventually provide a route to trust.

In accordance with the principles of sustainable development, a legitimate decision-making process must be managed so as to provide fairness and equity in terms of

- the risks and burdens placed on future generations (inter-generational equity), and
- resource allocation and decision-making within contemporary generations (intra-generational equity).

The Åarhus Convention seeks to tackle this by identifying Access to Information and Access to Justice as key elements of a legitimate process.

2.6 Conclusions

In conclusion, there are large uncertainties surrounding decisions about the environment. Such decisions require a knowledge platform that considers the potential risks to the environment. However, environmental risk is a culturally understood factor and its significance is very subjective. Values therefore influence decisions involving environmental risk to a very large extent. The legitimacy of decisions made using processes that do not easily accommodate social values is therefore compromised.

An important aspect of evolving decision-making processes is the ability to integrate values and knowledge so that they can sit alongside each other. In such a way, it may be possible to build dialogue between different groups, and ensure a broad range of opinion is built into environmental decisions. Therefore environmental debate becomes an intrinsic part of the decision-making process and decisions become more participatory.

These ideas have informed the development of *processes* for environmental decision-making. In the next chapter, current trends in these processes are explored with a view to identifying their ability to incorporate both social values and technical knowledge.

3 THE PARTICIPATORY TREND IN ENVIRONMENTAL DECISION MAKING

To understand something of the knowledge requirements for environmental decision-making, it is necessary to explore the nature of the processes that they are to inform. Participatory processes for decision-making are subject to much academic scrutiny at the moment. Many researchers are working to describe "analytic deliberative" models of contemporary environmental decision-making. Key issues to consider are:

- The stakeholders involved in the decision;
- Ways of encouraging deliberation between the stakeholders;
- The process by which the decision is made

This chapter examines trends in these issues.

3.1 Environmental decision making – past practice

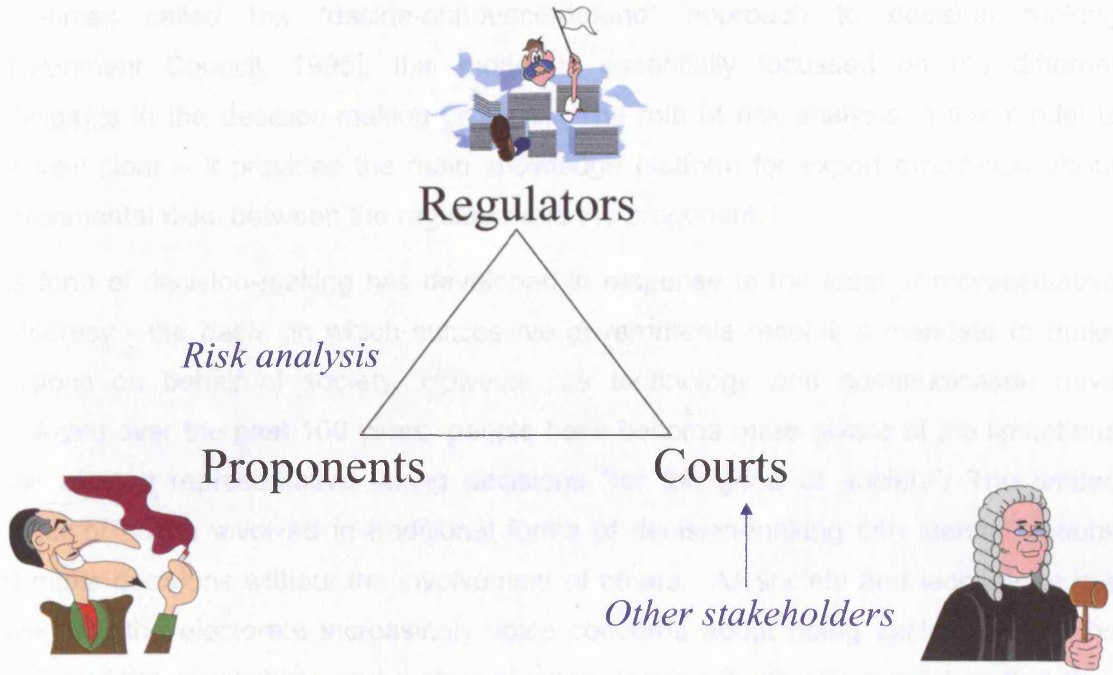
As discussed in Chapter 2, environmental decisions in the past - whether to proceed with a project, and how to manage the risks it presents - have been based on a technical analysis of risks, and a view as to whether or not those risks comply with regulations. The philosophy has been that there should be no restriction *per se* to any development providing that the developer meets the regulations. However, it is acknowledged that developers responding purely to market forces may place a relatively low value on protecting the environment. Therefore, environmental standards are established, often in legislation to ensure protection of the environment [DEFRA, 2002a, EA, 2000, EA, 1997]. These standards are typically based on scientific analysis and on judgements about environmental limits and carrying capacity. Monitoring organisations (regulators) such as the Environment Agency are in place to ensure compliance with regulations and contravention is pursued through the law courts. The key factors in this traditional form of environmental risk management are:

- The establishment of policy in the form of regulatory requirements
- The technical assessment of environmental risk based on "rational" evaluation of impacts against the concept of societal good;
- A review of levels of compliance with regulatory requirements;
- The application of "scientific" evaluations of environmental risk in dialogue between the regulator and the developer;

- A few major "stakeholders"[b] – who are generally institutions of some sort or other.

The stakeholders identified in this form of environmental decision-making are the developer, the monitoring organisation and the courts, all of which use scientific reasoning and logic to justify their positions. Policy and regulation provide the decision-making framework within which the stakeholders operate. Figure 4 seeks to capture this process

Figure 4. The stakeholders involved in traditional forms of decision-making



(Whilst the icons used in this diagram are stereotypical caricatures, they do reflect some of the perceptions that have arisen from traditional forms of environmental decision-making. The use of such highly value-laden images is intended to reinforce the polarisation that can arise between the key actors).

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[b] A "stakeholder" has an interest in the project at hand or its consequences. They can be individuals, groups or institutions. A distinction is now generally made between "stakeholders" and the "public".

Public values play little part in this traditional form of environmental decision making, except where they are implicitly taken into account in determining environmental standards or where the courts choose to make them a priority. In addition, there is little opportunity for input from other stakeholders except during the development of legislation (generally before a specific issue or project is on the table) and during any legislative procedure taken through the courts (generally once proposals have been extensively developed). In both instances, the views of other stakeholders can only be taken into account via secondary representation: in the first case through parliamentary procedure and in the second case through the courts. If the court action is one of prosecution due to contravention of regulatory requirements, it is often "after the event" and environmental damage has already occurred.

Sometimes called the "decide-announce-defend" approach to decision making [Environment Council, 1995], this model is essentially focussed on the different <u>participants</u> in the decision-making process. The role of risk analysis in this model is relatively clear – it provides the main knowledge platform for expert discussion about environmental risks between the regulator and the proponent.

This form of decision-making has developed in response to the ideal of representative democracy - the basis on which successive governments receive a mandate to make decisions on behalf of society. However, as technology and communication have developed over the past 100 years, people have become more aware of the limitations of an elected representative taking decisions "for the good of society". The limited number of actors involved in traditional forms of decision-making can identify options and make decisions without the involvement of others. As society and technology has moved on, the electorate increasingly voice concerns about being excluded from the creation of the alternatives and their evaluation, leaving them with a solution that they felt they had had no input into.

A possible response to this is deliberative democracy [Bohman and Rehg, 1997], which adopts the idea of the "common good" as an ideal. It encourages forums for discussion. Instead of assuming that opinions are in some way fixed and even measurable (on which representative democracy is based), it encourages the development (and change) of positions and even values through debate between equal partners. For deliberative democracy to work, there must be public participation – i.e. the involvement of members of the public, in particular those that have a stake in the decision in hand.

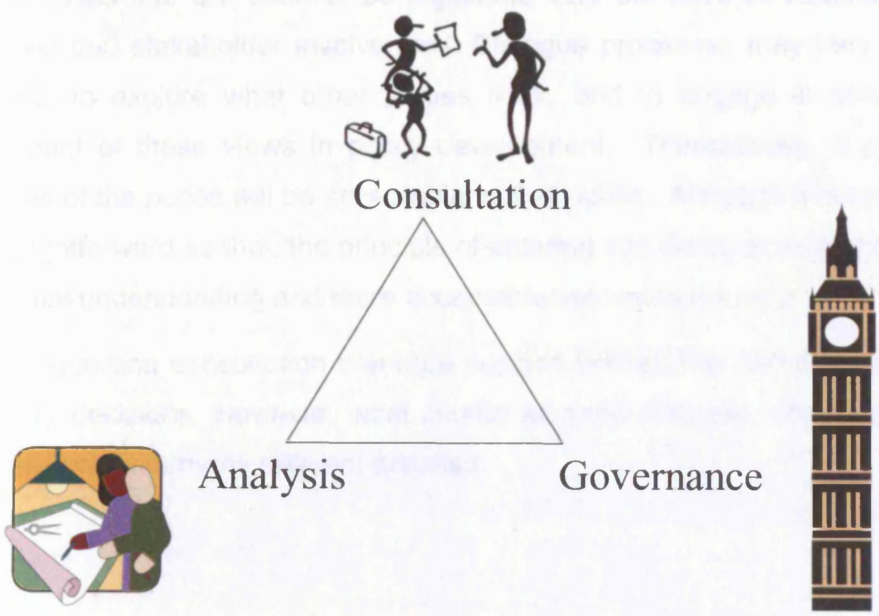
These ideas have generated an evolution in decision-making to one in which both analysis and deliberation are key parts of the decision process.

3.2 Analytic-deliberative approaches – modern trends in environmental decision-making

Chapter 2 has highlighted the limitations of basing decisions too strongly on a technical analysis of environmental risk. Social factors are not explicitly brought into the decision-making process; highly variable (cultural) factors such as risk perception, risk acceptability and the implications of uncertainty are not tackled and the perception of the analysis often comes down to a question of trust and credibility. Inevitably, environmental decision-making has been evolving to meet these challenges.

Since policy and regulation are central pillars of a democratic society, they will always play an important part in setting the framework for environmental decision making [DETR,1999b]. Additionally, it is reasonable to assume that analytical science and technical knowledge will continue to play an important part in informing judgements about environmental risk, be it via a quantitative risk analysis or by some other means. However, under deliberative democracy, an additional dimension is called for – social interaction. The way these three processes interact will determine the ability of the decision-maker to adopt an "acceptable" course of action. This represents a much more process-oriented approach to environmental decision-making than those used traditionally. The key components of such an approach (sometimes called an analytic-deliberative approach) are shown in Figure 5.

Figure 5. The components of an analytic-deliberative approach to environmental decision-making



In this model the term "analysis" includes any form of expert knowledge or specific analytical input to the decision process. This includes risk analysis as well as other specific analytical studies such as cost-benefit analyses or social impact studies. "Governance" refers to the way in which we organise ourselves as a society and includes regulations and legislation as well as the Government and Parliament. "Consultation" highlights the need to create opportunities for a wide spectrum of stakeholders to influence all aspects of the decision-process.

3.3 Public participation and dialogue

Central to the development of new participatory decision-making will be processes that enable dialogue between a wide range of interested parties and organisations. Dialogue is one of a suite of terms which include consultation, participation and deliberation (see Box 3). These practices share a commitment to discussion between stakeholders as part of determining a course of action.

There is a history of such participation in the UK. Public participation arose primarily out of land-use planning, regeneration initiatives, sustainable development initiatives, the ethos of "customer facing" service delivery, and the democratic deficit (Petts and Leach, 2000). More recently, Participatory Technology Assessment (PTA) and Environmental Impact Assessment (EIA) are active areas in which dialogue and consultation is central to the assessment process [Jamison, 1998].

Processes that are seen to be legitimate vary but have in common the necessity for public and stakeholder involvement. Dialogue processes may vary but they share the ability to explore what other parties think, and to engage in some way with taking account of these views in policy development. Theoretically, a policy based on the views of the public will be acceptable to that public. Although it is unlikely to be quite as straightforward as that, the principle of entering into dialogue as a means of engendering mutual understanding and more acceptable outcomes remains valid.

Dialogue and consultation therefore support deliberative democracy and should enable better decisions. However, what counts as good dialogue, why, and for whom, remain questions with many different answers.

Box 3: Distinctions and definitions relating to participation

The terms used to describe various aspects of consultation and dialogue are often used more or less interchangeably. Behind each term there is nevertheless a depth of theory and social and philosophical analysis. There is also a vast range of practice. Relatively simple definitions are provided below:

Dialogue
Dialogue can be defined as interaction and mutual learning - a 'conversation with a centre, not sides'. Stakeholders are brought together for the purpose of finding common ground, redefining the terms in which they operate, identifying areas of agreement and disagreement, and, crucially, developing enhanced understanding of each other and of potential ways forward. A key outcome of dialogue is the development of new meanings and understanding on the part of all stakeholders.

Consultation
Consultation is the provision of opportunity for stakeholders to comment upon issues and proposals during the course of their development. Crucially, consultation implies that the power to make decisions, and the extent to which comments are taken into account, remains at the discretion of the institution that instigates the consultation.

Deliberation
Deliberation is a form of discourse or debate. Theoretically and ideologically, deliberation requires those involved to be equals, both in terms of access to information and justification of arguments. Deliberation involves reasoned debate between relevant stakeholders.

Participation
Broadly, participation describes the act of taking part in a process. Although participation can take place solely through taking account of a wider range of views, there is a sense in which participation implies proactivity on the part of the stakeholder. Participation in taking decisions, as opposed to being consulted on those decisions assumes that a measure of accountability for that participation is accepted by the participant. However, the degree of public participation in decision-making depends on the amount of power transferred from the decision-maker to the participant.

Social Intelligence
Social intelligence is information about the public/society, such as that gathered in survey data on public values or opinions. Social intelligence can be gathered purely to serve the interests of the sponsoring organisation, or can be used in an attempt to reflect public preferences. Dialogue, consultation and deliberation can all offer means to gather social intelligence.

Stakeholders and the Public
The terms 'stakeholder' and 'public' need attention if not definition. 'Stakeholder' is used widely, and variously, to mean everyone who has an interest in an issue, or those directly affected, or the institutional parties involved. There is no over-riding definition. In practice, "stakeholder dialogue" often includes only institutional representatives, sometimes using bodies such as the National Consumers' Council or environmental non-governmental organisations (NGOs) to 'represent' the public interest.

'Public', too, can be a complex term. There are multiple groups within the 'public', individual members of whom may also be members of other groups. In terms of consultation and dialogue practices, it is crucial to consider who the relevant publics are, and how they might best be represented within a process.

Social Learning: The development of a collective knowledge and understanding that can be used to inform policy development. This can include developing the individual understanding of the participants and also improving the availability of information to society in general

3.3.1 *Public Participation Processes and their application*

A host of consultation and dialogue techniques have been developed. These have been adequately described in a number of reports [New Economics Foundation, 2001; DETR, 1998; LGA and LGMB, 1998; Audit Commission, 1999; Petts and Leach, 2000]. Table 3 presents a simple classification of dialogue processes and highlights key differences. These differences tend to reflect the different purposes for which dialogue can be undertaken. Indeed a key factor in developing participatory approaches to societal decisions is to select participatory processes that are fit for the topic and the audience [Petts and Leach, 2000].

Over the last few years extensive experience in processes involving consultation and dialogue has been gained. Much of this has been within local government, driven by the government programme to build on and develop Local Agenda 21 initiatives [LGA and LGMB, 1998] in conjunction with a desire amongst many government officers to introduce more participatory practices [Summers and McKeown, 1996]. Much, too, has been done in the Health Authorities, where service users are increasingly being included in decision-making procedures [Ling, 1999; NHS, 1998]. The Environment Agency, and the National Radiological Protection Board, are both exploring different mechanisms of public consultation and stakeholder dialogue. Additionally, technology assessment (TA) practices are in development . Recently, the Cabinet Office issued a Code of Practice in written consultation (www.cabinet-office.gov.uk/servicefirst/index/consultation.htm).

In the commercial world, a driver for participation has been the recognition by large businesses that they are out of touch with their key stakeholders. Dialogue is being increasingly adopted to rectify this situation, most famously between Greenpeace and Shell after the Brent Spar occupation by Greenpeace activists [Murphy and Bendell, 1997].

However, in the light of this experience, some shortcomings in current consultation practices are now being observed. A key issue is that ways of integrating the outcomes of public participation into decision making are ill-defined in practice. Partly, this could be explained as a result of consultation occurring too late in the decision-making process. The decision-maker "knows" what the issues are and what options are realistic, but the participants wish to discuss the broader issues. Often the decision-maker may already have rationalised these broader issues in his/her own mind according to his or her set of values and priorities. It can be frustrating to have to "take a step back", but this step is necessary to ensure that the range of perspectives about the problem are aired and discussed. This is the issue of "framing".

Table 3: Differences and distinctions between stakeholder dialogue, public consultation and public deliberation.

	Stakeholder dialogue	Public consultation	Public Deliberation
Who is involved?	Generally involves representatives of interested organisations meeting together for discussion of identified issue Can include members of public, but to date has done so only rarely Organisations who do not usually meet/communicate brought together	Involves members of the ordinary public, self-selected and/or selected as demographically representative or representative of relevant groups	Usually interpreted as involving members of the public, but can be interpreted as deliberation by elites taking place in the public eye.
Issue characteristic	Issue is often contentious, and opposing parties are brought together	Issue may not be contentious, but involves some development or appraisal	Not necessarily bound to a particular issue, and in any case allows related issues to be considered
Purpose	To share knowledge To identify areas of agreement and disagreement To develop possible ways forward	To elicit public views on issue	To develop, through engaging in debate, considered responses and reasoned decicions
Interaction between agency and public	Very limited unless public included as stakeholders	May be distant, usually mediated by convenor of consultation process.	Dependent on way in which deliberation is organised
Relationship with decision making	Often provides useful input but is open to manipulation or misunderstanding by decision maker	Theoretically provides authority for decisions, but in practice dependent on interpretation of outcomes by decision maker	May have no relationships with decisions, but in principle provides the basis for making the best decision
Examples	Any form of meeting between stakeholders where interaction and discussion takes place	Range from traditional forms of consultation (consultation papers, questionnaires) to more innovative forms (local forums, citizens' panels)	Few if any examples of deliberation under ideal conditions, but citizens' juries and other debating forums with full access to information partially fulfil requirements, and many processes have deliberative elements.

3.3.2 Framing

A key issue in the analysis of environmental (and other) controversy is that of "framing" or problem definition [RCEP, 1998, Stern and Fineberg, 1996]. Framing is sometimes thought of as the lens through which an issue is seen – different lenses provide different ways of seeing. Another commonly used explanation of framing is that paying attention to the way a problem is framed is paying attention to the question of "what is this issue about?" For example, decisions about toxic wastes, in particular radioactive wastes can be about broad issues such as:

- whether or not society should be producing such wastes at all.
- how can future generations and non-humans be represented
- who has the right to make decisions
- the dominance of scientific knowledge over other forms of knowledge

or it can be about narrower technical issues such as

- migration of contaminants in ground water,
- issues of the certainties and uncertainties of hydrogeological modelling.

Framings affect all types of public participation. A good dialogue process is one which enables all framings to be articulated and considered with equal relevance. In the UK, a classical public inquiry process will include a number of framings, such as traditional planning concerns (traffic, disruption), pollution, and, under the Environmental Impact Assessment process, evaluation of alternatives. However, concerns that fall outside the framework of the subject under discussion are generally excluded.

Some different framings become associated with particular social groups and are a representation of their values and priorities (sometimes called "worldview"). For example, scientific experts working within nuclear institutions commonly frame the problem as being one of 'controllable risks' amenable to technical and regulatory management. The public, by contrast, may see the problem as to do with issues of responsibility for the risks and the ethical questions of where waste is placed and how associated risks are distributed. Some environmental NGOs disengage from discussing what to do with radioactive wastes because entering in to such a dialogue could be seen as legitimising continued nuclear power production.

This provides an insight into the reasons why there is widespread public antipathy towards radioactive waste repositories. Institutional framing and public framing are at odds [Hunt and Wynne, 2000]. The public are concerned about issues that are left out of traditional decision-making processes and institutional thinking. As stated above, a good dialogue process is one which recognises the different frames of different groups. Thus, to develop legitimate decisions and hence effective management strategies, institutions need to find out what other views exist, to accept the legitimacy of these, and to integrate them into management proposals. The range, nature and sequencing of opportunities for interaction are determined by the decision-making process adopted.

3.4 The importance of the decision-making process:

It is all very well to identify:

- who the key stakeholders are;
- what elements need to go into making a decision about the environment (for example, analysis, governance and consultation); and
- how to create opportunities for deliberation and dialogue.

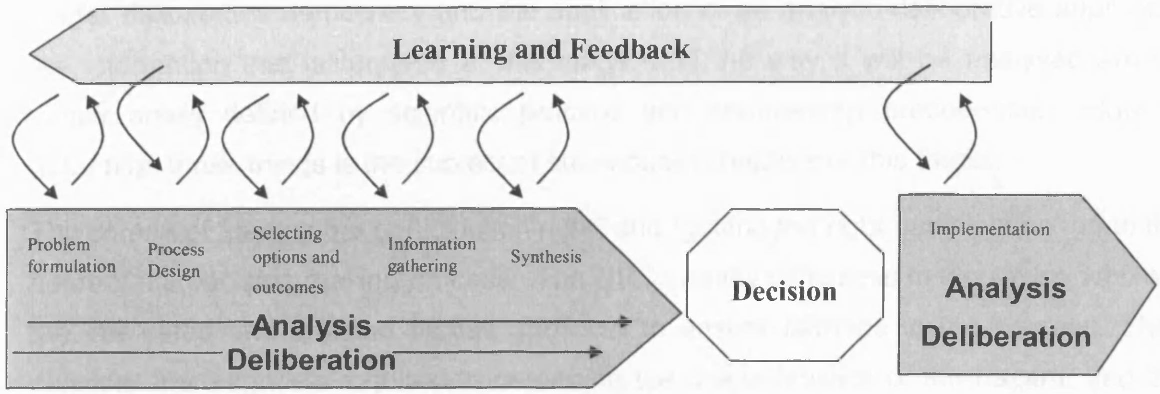
However, these factors need to be linked together if they are to be effectively applied towards a common purpose. It is the decision-making process that links these factors together. It is therefore critical to be clear about this process. There is much discussion of decision - making processes in the academic literature – in particular the operational research journals. Generally speaking, workers identify models of decision-making in three categories.

"Normative models" describe an 'ideal' approach where stakeholders apply a purely logical process to the decision problem. "Descriptive models" claim to describe how individuals make decisions in their everyday lives (Bell et al 1988). These descriptive models are based on 'real' human behaviour. These two types of model distinguish between perceived rationality (normative) and actual behaviour (descriptive). In fact, actual behaviour may well be rational, if a much wider set of values and complex social interactions are recognised than in normative models. Therefore, "prescriptive models" are identified, which combine the elements of the descriptive approach that recognise social interactions, with the logic applied in the normative approach. The intention is that these models describe workable decision making techniques that are defensible against critical analysis and acceptable to a wide range of stakeholders.

3.4.1 Components of an analytic-deliberative decision process

The US National Research Council have considered these prescriptive issues in proposing a new approach for informing decisions in a democratic society [Stern and Fineberg, 1996]. Figure 6 is a schematic diagram reproducing key elements of their representation of the decision-process.

Figure 6. Elements of an analytic-deliberative decision-making process [redrawn from Stern and Fineberg, 1996]



Central to this approach is the idea that opportunities for learning and feedback between all stakeholders need to be established at all steps in the decision making process. The process should not be seen to be linear and mechanistic: rather it is a series of steps that all need to be reviewed at each stage in the process.

A key question for this thesis is how do analysis and deliberation respectively contribute to this decision-process? This is considered in detail by the NRC [Stern and Fineberg, 1996] who identify several criteria that are necessary, but not sufficient for the effective implementation of an analytic deliberative approach to decision making. These criteria are identified in Box 4.

Box 4. Criteria identified by the Stern and Fineberg [1996] for effective application of an analytic deliberative approach to decision making

- Getting the science right
- Getting the right science
- Getting the right participation
- Getting the participation right
- Developing an accurate, balanced and informative synthesis

The criteria of "getting the science right" and "getting the right science" are fundamental to the information gathering and knowledge building stage. They are about the *content* of the decision. These criteria reflect the call for the application of sound science within the principles of sustainable development. Much has been written about "sound science" and the Royal Commission on Environmental Pollution wrote extensively in their 21st report on *Setting Environmental Standards* about best practice for scientific assessment and technological options appraisal [Office of Science and Technology, 2000, RCEP, 1998]. However, how to "get the right science" is another matter entirely. Under deliberative democracy and the application of an analytic-deliberative approach, the information that is required at this stage, and the way it will be analysed are no longer solely defined by scientific practice and engineering precedence. How to determine these things is the subject of subsequent chapters of this thesis.

The criteria of "getting the participation right" and "getting the right participation" go to the heart of the decision-making *process.* The NRC identify difficulties in identifying who are the interested and affected parties and how to ensure fairness in the process. They consider the diagnosis required to determine the characteristics of the hazard, and the characteristics and knowledge about risks. They state that the effort involved in this diagnosis may be extended or very brief, depending on the decision situation. However, the decision-maker is still left with the problem of deciding who will be involved in this diagnosis. Whatever his or her choice, it will remain vulnerable to challenges of preconception.

So if both process and content are important, who is it that determines when the process and the content are legitimate? Who says that the *right* science has been used and the *right* participation has been achieved? This is a common omission in the participatory-decision literature. Additionally, whilst there are many participatory decision-making techniques available for decisions involving multiple stakeholders [Hunt and Wynne, 2000, Armour, 1996], these mainly present the decision situation to the stakeholders in terms of selecting a course of action from at least two alternatives. Essentially, the problem formulation stage has been completed for them, and often they are invited to join in a defined decision-process. This implies *a priori* knowledge of the objectives of the decision and the best way of making it. It also requires those involved in the decision to accept that the alternatives are:

- mutually exclusive (the alternatives cannot exist at the same time);
- independent (one option is not dependent on the other);and
- cover the full range of uncertainty.

Recent developments in decision theory challenge these assumptions. Keeney [Keeney, 1998] states that values should be the driving force of our decision making and the focus of the time and effort we spend thinking about decisions.

Objectives are based on values – the reason for taking a course of action is the desire to avoid undesirable consequences and achieve desirable ones, which are value judgements and therefore subjective. There is therefore an increasing demand for early participation in establishing decision objectives and identifying potential alternative courses of action *as part of the problem formulation and process design*.

3.4.2 The importance of the "front end" of decision-making

Research has indicated that focusing people's attention first on their values or objectives helps those involved in the decision making to create more inventive alternatives, which match their requirements more accurately [Heerboth et al, 1980; Ho and Keller, 1988]. This suggests that the stage of problem formulation is multifaceted and involves understanding:

- who are the stakeholders (or interested and affected parties)?
- what are their values?
- What are the objectives of the decision being made?
- How will the decision be made?

Where there are different values, priorities and framings, this can be extremely difficult to manage. Hence widening stakeholder involvement in environmental decision-making increases the difficulties of establishing objectives and criteria for the decision that is being considered. Nevertheless, practical experience in managing hazardous wastes [Hunt and Wynne, 2000, USEPA, 1995; Ferguson and Malina, 1999] has shown that this is a fundamental step, enabling the principles and framework for guiding the whole process to be shared and allowing stakeholders to influence the whole of the decision-making process.

This has led to the idea of "front end consultation" [Hunt and Simmons, 2001] – dialogue with the stakeholders at the time of establishing the objectives of the decision – as part of the decision-making process. The 'front end' encompasses the early stages of any process. It focuses on identifying stakeholders' issues and concerns and integrating these into the decision making process. Throughout each of the phases of the decision making process it is essential that there is involvement of stakeholders, including the public, so that the varied perspectives on the issue can be identified and taken into account.

Early stakeholder involvement in the decision-making process has several advantages:

- *Defining the problem* – asking stakeholders to develop and express their values allows them to define the problem and hence gives them...
- *Increased influence* – allows stakeholders to influence the process
- *Increased understanding* – helps stakeholders to understand more about their differences and the situation and identifies common ground. Helps responsible institutions to better understand stakeholder concerns.
- *Increased involvement* – in social decisions, values are what are important to the public. If debate focuses on the technical issues of a decision or options this can exclude the public. Focusing on values involves the public.
- *Wider ownership* – involving stakeholders in the process increases their ownership of the outcomes. This in turn should lead to more robust and acceptable decisions.
- *Developing relationships* – the processes of engagement can assist in developing positive relationships between parties with conflicting views.
- *Less adversarial* – focusing on values makes it easier for stakeholders to understand their differences and identify common ground [French et al, 1992].
- *Guide information collection, option development and option evaluation* – early involvement can help identify appropriate information requirements and valuable research. It can also help identify the criteria against which options for a decision can be evaluated.

So although a front-end consultation incurs an increased initial spend, it can significantly reduce the total costs and time incurred in finding a long-term implementable solution. This is because early involvement helps to ensure the work undertaken addresses the issues people are concerned about, it also helps to reduce the chance of litigation and lack of public support for the outcomes because people are involved throughout the process.

3.4.3 Not forgetting the "back-end"

There needs to be some means of monitoring and evaluating the outcome of a decision. This is particularly important for environmental decisions since the outcome of decisions can be uncertain. This area is often neglected, because it can be taken to imply a poor decision, which generally reflects badly on those accountable. However, this is a short-sighted view in the context of sustainable development and given the uncertainties in assessing environmental impact. Environmental monitoring systems, performance targets and environmental auditing can be used to test the outcome of a decision in terms of protection of the environment. It should be accepted that it may be necessary to revisit decisions if they do not ultimately achieve the identified objectives. This requires that the evaluation process is fed back into the decision making process.

This linkage between monitoring and the decision-process is often overlooked. However, it is an important part of ensuring social learning and improving both the processes and the content of decisions in the future.

As an ideal, analytic-deliberative decision-making reflects that fact that experience has taught us the benefits of a better integration of different forms of knowledge, the acknowledgement of values and a greater level of dialogue between stakeholders. These principles sound self-evident. However, the question of whether it can be done in practice needs to be considered.

3.5 Challenges raised by a participatory approach to environmental decision-making

3.5.1 Collective Choice and social negotiation

There are some intrinsically human factors that make the delivery of a legitimate and truly participatory decision extremely difficult. In ancient times philosophers and reflective thinkers identified that there is no uniquely rational way of resolving contradictory perspectives. In translation [Waddell, 1929], a poem by Boethius (a fourth century Roman philosopher) opens with the lines

"*This discord in the pact of things, this endless war betwixt truth and truth which singly hold and yet together give the lie to him who seeks to yoke them both*"

Stirling argues that the many different aspects of environmental decisions are *incommensurable* and therefore the assessment approach of resolving all these conflicts analytically in an objective manner needs to be rethought [Stirling, 2002]. Making choices on behalf of a pluralistic society cannot be done using the rules governing individual choice.

"Expected utility theory" is a generally accepted model of rational choice [Cayford, 2001] and has been widely applied to describe economic behaviour. Until recently, utility theory has predominated in expert literature describing decision-making [Savage, 1990]. By accepting utility theory as a model for decision-making, it is assumed that all rational people would wish to adopt the basic principles of the theory and will make rational choices when faced with a decision problem. However, the theory is based on individual choices (either of the institution or of a person) and on the idea that the decision-maker knows what is good or best. These ideas break down when applied to collective choices, and when the decision-maker has to take into account a wide range of needs and values. Environmental decisions are generally matters of public policy, which are collectively decided. Therefore, the applicability of utility theory to environmental decisions can be challenged. This can be illustrated by considering two decisions – one based on individual choice and one on collective choice.

If I need a kettle. I will need to choose which kettle to buy. In making that choice, I will need to take into account a few things – like how large it needs to be, whether it should be gas or electric, jug or round, fused or not. I will make a rational choice, based on my preferences and some consideration of practicalities.

However, consider three individuals (Amy, Alice and Andrew) making a collective choice about ice cream. The potential choices are vanilla, chocolate and raspberry. Their individual preferences are given in Table 4. Individually, their choices would be rationally based on these preferences. However, an analysis of the group preferences indicates that two of them prefer vanilla to chocolate, two of them prefer chocolate to raspberry and two of them prefer raspberry to vanilla. As a group, they do not have a rational set of preferences on which to make the selection. There is no possibility of a process producing the "preferred" outcome, because, as a group, there are no clearly defined preferences.

Table 4: The problem of collective choice

Person	*1st choice*	*2nd choice*	*3rd choice*
Amy	Chocolate	Raspberry	Vanilla
Alice	Vanilla	Chocolate	Raspberry
Andrew	Raspberry	Vanilla	Chocolate

This does not mean that they won't make a collective choice – other things will come into play. Alice may detest raspberry, whereas Andrew is reasonably happy with any of the choices and Amy ate chocolate yesterday. So they choose vanilla. There may be a number of other sensible choices. However, those other choices will be based on a process of "social negotiation" between the three of them. Making the decision requires a deeper consideration of values and weightings.

The above illustration seeks to draw out some of the limitations of "rational" or prescriptive decision making processes. In a democratic society, environmental decisions, especially when viewed through the framework of sustainable development, should be collective decisions.

In an attempt to identify practices for developing such collective decisions legitimately, international frameworks are being set up to provide guidelines and codify what it means to be sustainable. The Rio declaration and the Aarhus convention are examples on a global and international scale and participatory assessment techniques describe specific processes that help to achieve legitimacy (Hunt and Wynne 2000, Petts and Leach,2000). However it is possible that these frameworks may mask the underlying issue and essentially human problem of whether a legitimate collective choice is possible, given the multifaceted and cultural consideration of environmental risk.

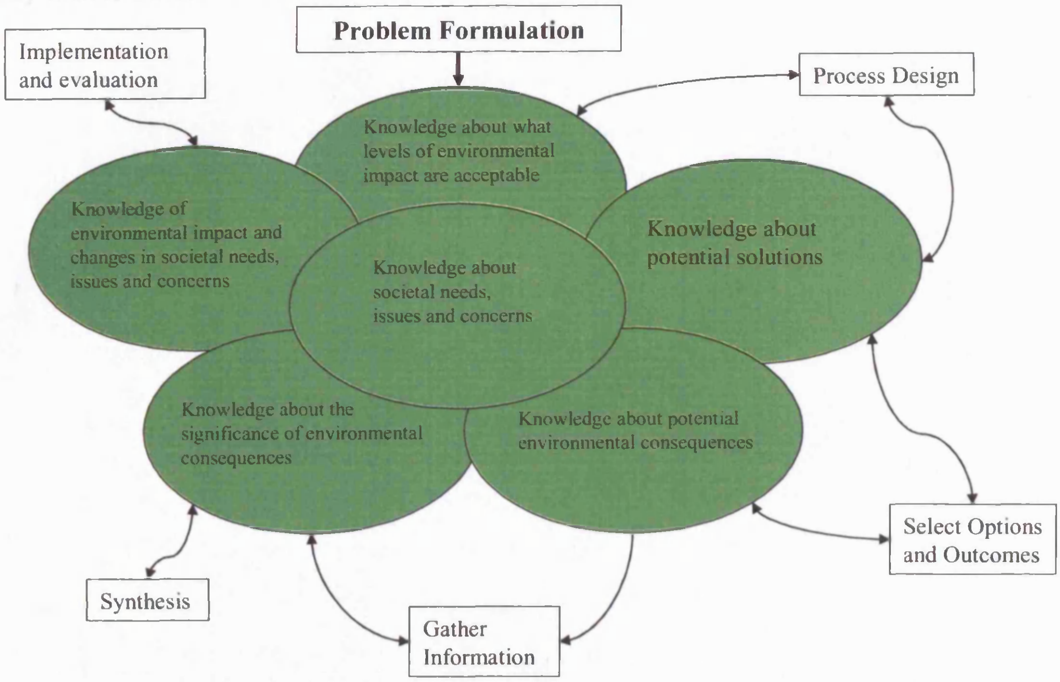
3.5.2 Developing a shared knowledge platform

In any decision–process, knowledge is accumulated throughout the process. This places a requirement for an iterative and recursive process. Information may be gained at a later stage that will suggest a need to revisit the knowledge on which an earlier stage was based. This notion was also developed by Stern and Fineberg [Stern and Fineberg, 1998] who also identify that the development of knowledge through the decision-process should:

- involve more than scientific expertise, and
- be iterative so that at each stage, the option of reverting to an earlier one should be possible.

Figure 7 identifies schematically the sorts of knowledge relevant to making decisions involving environmental risk. The six stages of Stern and Fineberg are used. The traditional emphasis of decision-makers has been on the development and evaluation of options – the right hand side of Figure 7. Science and engineering have therefore had a dominant role in knowledge development for environmental issues since they provide an unrivalled source of expertise on the causes, effects and likelihood of environmental harm. There is a lot of emphasis in the environmental science literature on best practice for determining environmental options. Principles such as: best practicable environmental option studies (BPEO); best available technology not entailing excessive cost (BATNEEC); and, in the world of potential exposure to ionising radiation, as low as reasonably achievable (ALARA); and as low as reasonably practicable (ALARP) are adopted by experts and are often written into regulations and environmental standards .

Figure 7. Knowledge requirements for environmental decision-making.



Despite the best of intentions, it is quite common to provide a risk analysis and a social impact assessment as separate chapters within an EIA submission. The process is integrated but the content is not. This still leaves the decision-maker in the position where (s)he has to determine the relative ascendancy of social and technical issues. Ideally, the decision maker would benefit from social negotiation to bring together all the issues and establish common ground and understandings. This social negotiation needs to occur between representatives of very different cultures.

This is where the analogy with three people choosing ice-cream (three individuals with a common background and language) breaks down and leads to a number of practical issues for those seeking to inform the decision-making process. Not least these include the need for those providing knowledge to work with a much broader range of stakeholders and to acknowledge their own cultural framings of a particular problem. To scientists, these issues are challenging enough without the added complications of seeking to integrate values and lay knowledge into the knowledge platform for the decision.

In the next chapter the role of analysis in decision-making is considered. The discussion is largely focussed on the understanding and calculation of risk, and the treatment of the uncertainty that is inherent in the concept of risk.

4 RISK, UNCERTAINTY AND ANALYSIS

As discussed in the preceding chapters, environmental decisions are often based on an evaluation of risk, which is predominantly informed by scientific knowledge. This chapter looks generally at the relationships between risk, uncertainty and analysis and reviews contemporary thinking about their role in decision-making.

4.1 Hazard, risk and chance.

The Oxford English Dictionary defines risk as "the chance or possibility of danger, loss, injury or other adverse consequences". The original use of the term risk in the 16th and 17th century appears to refer to sailing in uncharted waters in an era of global exploration by western voyagers [Giddens, 1999]. Subsequently, the term became used by the great merchants and bankers of the middle ages as they sought to come to terms with the possibility of a less than favourable return on their investments. Risk therefore became associated with the idea of events that may or may not happen – an uncertain (uncharted) future. It cannot now be divorced from ideas about what the future may bring.

Hazard, danger and risk are terms that are often used interchangeably. Whilst there is general agreement in the literature that they are not synonymous [Adams,1995], most workers adopt their own definitions of the terms. There is a general consensus that a hazard is an object or situation that <u>could</u> give rise to harm and a danger is a situation where there is a real possibility of harm [OED]. Risk is the likelihood of circumstances arising that result in harm occurring. Implicit in all these discussions is the idea that danger should be minimised, and hazards avoided.

In very general terms, risks to the environment from economic developments arise in a number of ways:

- by extracting and/or depleting natural, mineral or biological resources
- by affecting ecological resources due to physical disturbance
- by affecting ecological resources due to direct contamination or indirect contamination via contaminant migration
- by creating a range of waste products which need management

4.1.1 Characterising risk

In a Reith lecture in 1999 [Giddens, 1999], Giddens identified two types of risk:

- External (or natural) risk: the risk of adverse consequences arising because of a natural event (e.g. bad harvest, floods, plagues, earthquakes, and famine).
- Manufactured risk: the risk to the environment created by the actions of developing societies.

There are historical records of the consequences of natural events. It is therefore possible to make a calculation of external risk on the basis of these past records. The insurance industry is therefore able to offer to take on external risks in return for premiums. For example, they will generally insure houses against subsidence and natural disasters. Lloyds of London have been insuring against external risks for centuries.

However, manufactured risk is often less tangible. The consequences of our activities on the environment are not always obvious and may well not be understood. Manufactured risks are increasingly the subject of high profile debates as environmental conditions are experienced that do not appear to be solely the result of natural events. Examples would be the depletion of the ozone layer, global warming and the BSE scare [Hoffman and Wynne, 2002].

Over the last century, awareness of risk has shifted from an almost exclusive consideration of external risk (landslip, flooding, and meteor impact) to debates that are dominated by consideration of manufactured risks [Giddens, 1994]. However, for manufactured risks with a long-term impact on the environment, there is little history. Therefore, calculations of risk are difficult and it is impossible to insure against manufactured risks. In this thesis, the term "environmental risk" is used synonymously with manufactured risk.

In 1994, the Royal Society referred to three types of risk [Royal Society, 1994]:

- risks for which statistics of identified casualties are available (e.g. the failure of buildings due to seismic events, the chance of flooding under different circumstances)
- risks for which there may be some evidence, but where the connection between suspected cause and injury to any one individual cannot be traced (e.g. the BSE scare, pollution effects from traffic schemes, pollution effects from landfill, the continued depletion of natural energy resources)
- experts' best estimates of the likelihood of events that have not yet happened (e.g. risks from a radioactive waste disposal facility, the greenhouse effect)

The first type correlates well with the idea of external risk, and the last two give examples of manufactured risks. The distinction made between risks for which there is some evidence and best estimates of potential risk indicates some layering of environmental risks. In both cases, high levels of uncertainty about cause and effect would dominate any calculation of risk. Even so, both types of risk are grounded in some idea of what might happen in the future and its associated uncertainty (the "known unknown").

Researchers considering the nature of science within society will also identify the possibility of "unknown unknowns" – risks that may happen in the future for which there is no current conception [Hoffman and Wynne, 2002]. The occurrence of BSE arising from a change in stock feeding practice is an example where consequences were unknown at the time of action. It is difficult to know how to approach the issue of unknown unknowns, other than to recognise their existence.

The use of insurance to spread risk is discussed above. However, environmental risk is inevitably one where the risks are distributed, both in time and in space. Because the environment is a shared resource any change to it can result in impacts that are widely distributed. This raises questions about how the risk should be shared between those who engage in a project voluntarily or who benefit directly, and those who are affected with no direct benefit. An example of this would be the consequences of passive smoking, where someone who does not smoke is at risk from the habit of one who does.

Sometimes, the timescales over which environmental risk can be distributed may be very long indeed. For example, people are at risk from the coal tar linings which were used to line lead water mains at the turn of the century. As these linings degrade, polycyclic aromatic hydrocarbons can be released into drinking water, some of which are carcinogenous. The risk from these coal tar linings (which may have been unknown or unappreciated at the time of installation) are distributed in time because they are a consequence of deterioration. In this case, the risks have been passed on two or three generations.

So environmental risk is characterised by very high levels of uncertainty about:

- cause and effect on the environment
- likelihood of occurrence
- impact on society(s)
- spatial and temporal distribution of impact.

This inevitably makes environmental risk an inherently multidimensional issue. When this is coupled with the fact that our notions of what constitutes the environment tend to be socially constructed, the it is inevitable that there will be high level of debate and discussion over environmental issues.

4.1.2 *Risk and the future*

Risk is therefore a concept that is only relevant in a society that wishes to control the future in someway. For risk to matter, society has to be bothered about consequences. Hazards have always existed. Under certain circumstances they could lead to "adverse consequences". They become risks when an attempt is made to calculate the likelihood and potential benefits and/or detriments of those circumstances occurring. Risk is therefore a calculation of the future, which is why it cannot be separated from ideas of probability and uncertainty.

The Royal Society [Royal Society, 1992] illustrate this by reference to Nelson's column. Nelson's column is the hazard. It may be damaged (by wind, rain, vandalism), in which case it becomes a danger (a thing likely to cause harm [OED] due to pieces falling off causing harm to people in Trafalgar Square. The risk is a measure of the probability of this harm occurring in a given period (i.e. 10 years). Determining the risk requires:

- consideration of the susceptibility of Nelsons Column to damage by different events;
- the likelihood of those events occurring over the time period of interest;
- the likelihood that as a result of this damage, pieces could fall off; and
- the possibility that it could land on people below. In short, it requires a prediction of a possible future.

This can also be illustrated by reference to the investments market. Financial markets fluctuate in strength. This is a hazard. If I invest £1000, I want it to increase in the future. There is a danger that my money will diminish due to the fluctuation of the markets. I will therefore make a prediction about what the markets will do over the period of investment and evaluate the consequences in terms of my £1000. Certain markets will show a greater potential increase than others will. However, those that could show the greatest potential increase are likely to fluctuate more dramatically and there will be a higher level of uncertainty about my prediction. The risk associated with investing in that market is therefore greater than the risk associated with investing in a less volatile commodity.

4.1.3 *The cultural understanding of risk*

Alternatively, one can view the investments market as the "chance" to get a great return on a financial input. Used in this way, "chance" implies a more positive approach to future uncertainty. Therefore, for gamblers, the "chance" that ones number may come up is a cause for optimism. Like "risk", "chance" arises because of the essential unknowability or indeterminability of the future. However, unlike risk, the concept of chance suggests that future uncertainty is an opportunity to be exploited.

The fact that two such similar concepts co-exist with such different connotations tells us quite a lot about the markedly different ways in which individuals can react to future uncertainty. It implies that the understanding of risk is essentially cultural - a characteristic which is well researched and documented in the literature [Beck, 1992b , Thompson et al, 1990] - and raises many questions when considering how to generate a common platform of knowledge about environmental risk.

4.1.4 Risk sharing

The notion of insurance has arisen in tandem with the concept of risk and offers the potential for risks (and rewards) to be shared. The insurance industry calculates risks and offers to take on the risk in return for payment. For the insured, it is a way of managing or controlling risk. For the insurer, it is a "chance" to exploit uncertainty and probability theory for potentially large financial rewards (i.e. a gamble). Sound ethical principles underlie this concept of risk sharing – helping ensure the greatest happiness of the greatest numbers – the concept of utilitarianism [Benn, 2000].

However, workers considering societal trends and the increasing move away from fundamental beliefs to a more questioning and value-driven society identify that the traditional concept of insurance may struggle to deal with long term and global risks to the environment [Beck, 1992a]. This is partly because of the lack of information on which to base the risk sharing. What is the risk that is being shared? It may be that the hazard to the environment has not even been recognised yet. Or the quantification of the risk may not be possible since there has been no evidence of it as yet. In such a climate of uncertainty, ensuring the greatest happiness of the greatest numbers is no longer a simple question of paying to reduce exposure to risk. Contemporary society is seeking to get to grips with the very specific set of issues raised by long term and global risks to the environment [Adams,1995] and the very significant level of associated uncertainty. Traditionally, a risk analysis is undertaken to help understand these issues and deal with the associated uncertainty. Traditionally, a risk analysis is undertaken to help understand these issues and deal with the associated uncertainty.

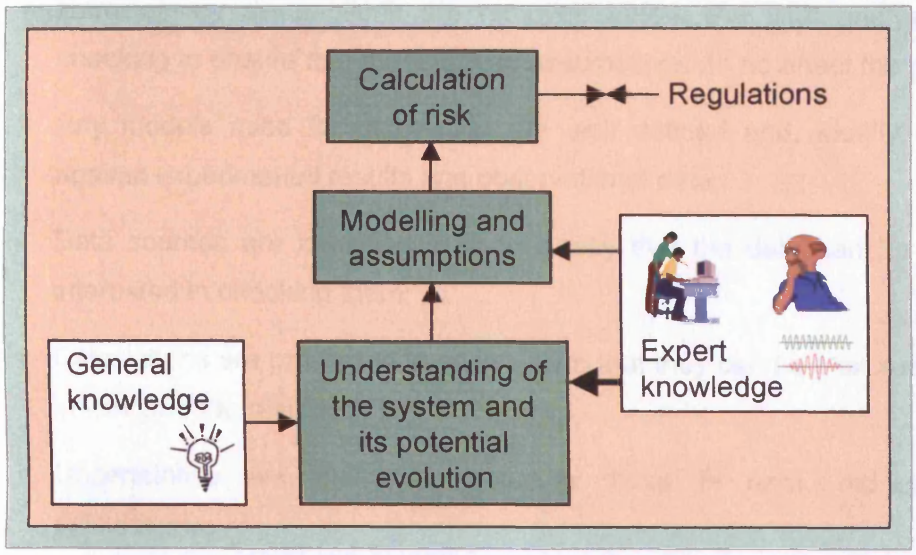
4.2 Risk analysis and its role in decision making

The scientific analysis of risks, essentially using models to calculate what might happen in the future, has played a central role in the decision-making process [Stern and Fineberg, 1996; Royal Society, 1992]. Methods for the scientific analysis of risk have been developed over the past forty years in order to provide objective assessment of environmental impact and safety. The origins of risk assessment related to well structured mechanical and engineering processes [Wynne, 1995]. Methods have since been adapted to the less well structured problems of environmental risk management. Whilst there are differences of approach in different industries [Power and McCarty, 1998, Stirling, 1999] they generally have in common the idea of either:

- determining compliance with regulations using some agreed way of dealing with uncertainty (e.g. for land contamination, flood defence, aerosols, landfill or radioactive waste disposal) ; or
- predicting potential future impact – sometimes on a global scale (for example, in terms of global climate change and strategic hydrocarbon predictions, or human health implications from dose-effect relationships).

The choice of approach tends to be determined by disciplinary precedence rather than any intrinsic distinction from other approaches [Power and McCarty, 1998]. Risk analysis uses modelling to represent a course of action and the processes that may occur as a consequence of the project. Figure 8 shows the general relationship between the scientific understanding underpinning the risk analysis and the calculation of risk itself.

Figure 8. The risk analysis process



A good environmental risk analysis is an exercise in gathering observational data, adapting it to novel cases about what might happen in the environment using expert judgement and integrating the pieces with some model. It is an application of many scientific principles, rather than a scientific pursuit in its own right.

Many methods of risk analysis have developed. For many issues, it is possible to draw fairly tight boundaries around the problem and a risk analysis is a fairly straightforward exercise. However, in the environmental arena, risk analyses have become increasingly sophisticated and complex in order to handle the inherently multidimensional nature of the problem. Boundaries are diffuse and it can be difficult to constrain the issues because:

- there will be ambiguity over the level of regulatory compliance because many possible futures need to be taken into account;
- it is not possible to test the environmental consequences;
- precedent projects may have given rise to unforeseen consequences and may have exposed limitations in the regulatory framework.

In consequence, the results of a risk analysis are challengeable. Stern and Fineberg's call for "getting the science right" is partly relevant here. The decision-makers need the assessment to be as robust and credible as possible. Good quantitative analysis has several characteristic features [Stern and Fineberg, 1996].

- It is consistent with state-of-the-art scientific knowledge;
- Any assumptions used are clearly explained, used consistently and tested for reasonableness;
- The analysis is checked for accuracy (e.g. of calculations);
- Unnecessary assumptions are removed before the final analysis is reported, after checking to ensure that the removed assumptions do no affect the results;
- Any models used for calculation are well defined and, ideally, validated by testing against experimental results and observational data;
- Data sources are identified in such a way that the data can be obtained by anyone interested in checking them;
- Calculations are presented in such a form that they can be checked by others interested in verifying the results;
- Uncertainties are indicated, including those in data, models, parameters and calculations;
- Results are discussed clearly, indicating what conclusions they can support.

However, this is only part of the story in understanding the robustness of the risk analysis. Adopting a good analytical approach to the risk analysis is necessary, but not sufficient for a robust risk assessment.

Where there is a large amount of uncertainty in the physical and chemical processes that could arise as a consequence of the project, fairly complex modelling techniques are often employed – to ensure that a wide range of different scenarios about the future are adequately captured.

Much work has been done to develop participatory assessment techniques. These have been reviewed in the academic literature [Petts and Leach, 2000]. There are a number of common assumptions to these techniques which have been discussed elsewhere [Stirling, 2001] but include:

- The assumption that there exists a rational chain of inference from any single set of proposals;
- The assumption that the consequences of any action can be predicted given sufficient understanding of the initial and boundary conditions
- That an "optimum" solution can be identified;
- That standards and performance measures can be defined

Participatory assessment offer a potential way forward in developing shared knowledge about risks based on inclusive determination of what the right science is (and hence what the scope of the assessment should be). Nevertheless, even the most inclusive approach to a risk analysis will not be able to provide risk calculations that can be used with complete confidence.

4.3 Factors affecting confidence in risk results

Philosophical and reflective thinking about the role and application of natural science in society has raised a number of issues that pose direct challenges to the risk analysis as a source of knowledge. To fully understand the confidence with which an analysis can be used, the decision-maker must consider issues such as:

- Who did the analysis?
- What information went into it? what conceptual assumptions were made? How do the models calculate risks?
- How reliable are the models?

They are even being challenged with the question

- But is it science?

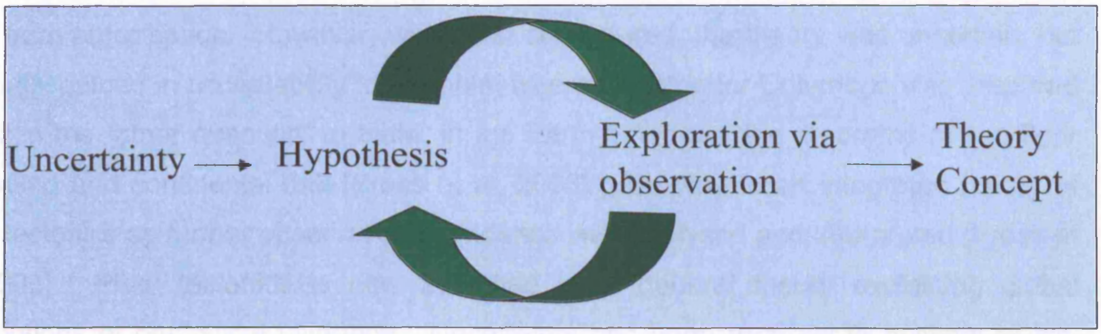
And underlying all these questions is the issue of how to handle uncertainty.

4.3.1 Uncertainty and science

Uncertainty is intrinsic to science and also cannot be divorced from risk. For a long time, the premise has been that the scientific method should be well equipped to provide tools and strategies for dealing with uncertainty and risk.

Generally speaking, the scientific method involves developing hypotheses to explain the way the world works based on observation and measurement. This is illustrated in Figure 9.

Figure 9. A schematic representation of the scientific method



However, there is much interest at the moment in what constitutes "good science" particularly in areas where uncertainty is high and systems are complex. Guidelines are being produced in many policy areas for improving the knowledge base on which policy is founded [RCEP, 1998; Office of Science and Technology, 2000; CEC, 2002]. A common theme in these guidelines is the importance of quality in scientific advice and the Commission of the European Communities suggests that quality is based on:

- The excellence of the scientists, as endorsed by the judgement of peers, but ensuring that the breadth of expertise is appropriate for the task
- The extent to which experts act in an independent manner (i.e to minimise vested interests); and
- Pluralism (the assemblage of a diversity of viewpoints)

The Royal Society, in their report on Science and Society [House of Lords, 2000] identified that scientists may lose their objectivity when providing knowledge about the *application* of scientific information. In such situations, choices are being made about the significance of any remaining uncertainty. Where this uncertainty is high (for example if the system under consideration is complex or has many interdependencies) vested interests based on personal value systems may (consciously or subliminally) come into play. In such situations, even more weight on pluralism and breadth is required if scientific advice is to be of high quality. Hence peer review and a multidisciplinary approach become central aspects of providing scientific advice to the decision-making process.

The process of peer review – the practice of subjecting the derived theory or concept, and its basis in observation to scrutiny by other experts – has always been central to the scientific method. Other scientists may develop concepts further by additional exploration and eventually theories become more or less accepted based on how well they pass through the peer review process and how well supported they are by observation. Thus the theory that the world is round is now "proven" – we can see that it is so from outer space. However, when first conjectured, the theory was uncertain, but gradually gained in acceptability to the point where Christopher Columbus was prepared to sail in the "other direction" to India. In the Earth Sciences, the theorems of sea floor spreading and continental drift [Press et al, 2003] gave way to an integrated theory of plate tectonics as further observational evidence was analysed and interpreted [Press et al, 2003]. Plate tectonics is now accepted as a general theory explaining global distributions of geological evidence. Uncertainty has been reduced to minimal levels. However, it is not "proven" and it is possible that evolved theories may be developed in the future. Therefore, peer review is a way of achieving some form of scientific consensus in lieu of fact.

4.3.2 Uncertainty and credibility

As discussed earlier, risk is a concept that is concerned with the future, which is uncertain. Therefore, any risk analysis is going to have to deal with uncertainty. There are numerous different classifications of uncertainty. Some workers classify it in terms of its nature. For example, Wynne [Wynne, 1994, Hoffman-Reim and Wynne, 2002] identifies uncertainty in the categories;

- Risk – where cause, effect and likelihood are known
- Uncertainty – which is where the causal factor is known but the likelihood of its occurrence is not – there is incomplete knowledge;
- Ignorance – where causal factors are not known
- Indeterminacy – which are things which cannot be known because they depend in part on unchecked behaviours

In this classification system, "risk" is a form of quantified "uncertainty". In both cases the causal factor is known – the distinction is whether or not there is sufficient information to quantify cause, effect and likelihood. Since these could be said to be subjective judgements in their own right, the following discussion will group "risk" in with uncertainty.

Taking Wynne's classification system, risk analysis seeks to deal with "risks" and "uncertainty" but cannot be expected to deal with "ignorance" and "indeterminacy". Therefore, many workers argue that these analyses do not completely handle uncertainty. Wynne argues for at least an acknowledgement of the limitations of the analysis in order to place the knowledge it provides appropriately within a social and moral framework. From Wynne's work, it is apparent that there is a very real credibility problem for the process of risk analysis, which has, in the past, claimed to be a comprehensive vehicle for capturing and managing uncertainty.

The nature of the uncertainty, and the manner in which it is handled will influence the credibility of the risk results. Funtowicz and Ravetz discuss this issue extensively [Funtowicz and Ravetz, 1992]. As uncertainty increases, it becomes more difficult to establish acceptance and precedent practice becomes less relevant. Funtowicz and Ravetz identify that as uncertainty increases, shifts in peer acceptance, colleague consensus, available observations and theoretical structure occur. Table 5 reproduces their ideas about "research pedigree", a concept that can be closely related to analytical credibility.

Table 5: Factors influencing analytical credibility – after [Funtowicz and Ravetz, 1992]

Rank	Theoretical structures	Data input	Peer-acceptance	Colleague consensus
4	Established theory	Experimental data	Total	All but cranks
3	Theoretically-based model	Historic/field data	High	All but rebels
2	Computational model	Calculated data	Medium	Competing schools
1	Statistical processing	Educated guesses	Low	Embryonic field
0	Definitions	Uneducated guesses	None	No opinion

A quick look at Table 5 identifies that environmental risk assessment is up against some tough challenges in terms of establishing a high pedigree or level of credibility. Firstly, we have identified that we do not know what will happen in the future. As the timescales for which we want to understand risk get longer and longer, it gets less and less easy to test the assumptions we make against experimental observations. Hence analysts are relying on theory, calculation and expert judgement. This puts the pedigree of risk analyses generally in the area of 0 - 2. Nevertheless, thanks to the interpretative practices of the natural sciences, we are not completely in the dark. In particular the earth sciences give the analyst the chance to build models and understanding based on at least "educated guesses", if not historical and field data. (Rank 3).

An alternative and more typically technocratic approach is to classify uncertainty in terms of its source:

- Uncertainty about the future
- Uncertainty in data
- Uncertainty about models

Risk analysis sits most comfortably with an uncertainty classification system based on the source of the uncertainty. This is unsurprising since they both stem from the technical arena. In very general terms, the risk analysis deals with future uncertainty by postulating ideas about the future (scenarios) and considering consequences. This is true whether the analysis is a comprehensive performance assessment for radioactive waste disposal or a HAZOP study for a construction project although the terminology may be different. The concepts captured in a scenario tend to be represented using theoretically based models (suggesting a ranking of 3 on Table 5). However, parameterising these models can be very difficult since there may be little or no prior experience of them (implying a very low rank). This leads to high data uncertainty.

Ideally, data uncertainty is handled by seeking more information. However, when analysing risks into the future this may not be possible since it may not be possible to predict all the possible combinations of conditions that affect a specific parameter. Additionally, the inherent variability of natural environmental systems means that heterogeneity may also add to uncertainty. Whilst it is theoretically possible to envisage complete knowledge about variability on all scales, when dealing with the environment this is impractical and it is not possible to predict with complete confidence how this variability may evolve. So data uncertainty tends to encompass both uncertainty and variability in specific parameters.

Commonly the analyst takes recourse in probability theory to help handle data uncertainty. This enables the analyst to capture uncertainty in a particular parameter by describing the possible range of values of the parameter and its likelihood of being that value. Essentially a probability distribution function is generated.

Expert judgement is often used to generate these probability distribution functions. The level of empirical observation and experience available to guide this judgement makes the difference between the loose terminology of educated and uneducated guesses used in Table 5. This would suggest a ranking of 0 – 1 on Table 5. However, whatever the level of observation available to guide the development of probability distribution functions, probability theory assumes total knowledge of the range of possible values the parameter may take on. Ignorance and indeterminacy are not allowed for within probability theory. Without acknowledging this, any method of treating data uncertainty remains vulnerable to challenge.

An example of how this challenges risk analysis for hazardous waste disposal is given in Schrader-Frechettes book on Burying Uncertainty [Schrader-Frechette, 1990b]. She identifies a distinct difference between "two point logic" and "three point logic based on the idea that it is not sufficient to adopt a "closed-world" approach to data uncertainty. The chances of a parameter being less than x is not necessarily one minus the chance of it being more than x since there is not complete knowledge about the system in the first place. In other words, in some situations, it should not be claimed that the area under a probability distribution curve is equal to 100%.

Some workers are now moving to develop new approaches to capturing knowledge about parameters, which do not assume complete knowledge. Workers considering risks from natural hazards with fairly long-term implications (i.e. earthquakes) have developed a classification system based on [Blockley and Godfrey, 2000]:

- fuzziness;
- incompleteness; and
- randomness

Methods are being developed to enable this classification system (FIR) to be incorporated into a system for modelling processes and consequences in the oil and engineering industries.

Model uncertainty is uncertainty that arises from the theoretical and computational processes used to turn information into calculations. Verification and validation are processes that are available to build confidence in models. Verification ensures that the model does numerically what it is supposed to do – i.e. that if it says it is going to add two and two and make four, it does. Validation is a way of testing whether a theoretically based model reproduces key aspects of the system it is describing. However, where the model is predicting into the future, complete validation is not possible until the implementation/evaluation stage of the decision-making process, which may last for many generations into the future and which is, in any case, after the event. At best it may be possible to validate parts of the model and build confidence by peer review and (hopefully) peer acceptance and colleague consensus. However, where validation is not possible it is difficult to conceive of achieving consensus outside competing schools (Rank 2 on Table 5).

So there is unlikely to be a single rank on Table 5 that applies to all the uncertainties accommodated within the risk analysis. This suggests limitations to the applicability of the research pedigree ranking system to the multifaceted nature of a risk analysis. The NUSAP system" offers another classification as shown in Table 6 [Funtowicz and Ravetz, 2001].

Table 6: The NUSAP system of uncertainty classification

Classification	Relevance	Examples	Description
Technical	Where the complexity of the system being considered can be dealt with using the traditional tools of applied science	Numerical uncertainty	Determining what is the right number to use for a specific,defined problem
		Unit uncertainty	Determining an appropriate measure for a specific, defined problem
		Spread	Determining the inherent variability of the system
Methodological	Where more complex aspects of knowledge must be dealt with such as reliability, extrapolation and subjectivity. Here personal judgements are required and have an impact on how uncertainty is handled	Assessment	Determining an appropriate way of representing the system
Epistemological	Where there are often conflicting stakes because ignorance and indeterminacy are at the core of the issue and values become very significant	Pedigree	Determining the origin and trustworthiness of knowledge based in some measure by who has it, how it was derived and what went into its derivation (Table 2.1) .

The focus of the traditional risk analysis is on technical and methodological uncertainties – numbers, units, spread and assessment methods. However, epistemological uncertainties exert a significant influence over the risk analysis process.

There is no doubt that a range of different types of uncertainty are addressed within the risk analysis. Hence experience and expert judgement play a large part in the construction and credibility of the risk analysis. Since expert judgement plays such an important role, the credibility of the risk analysis becomes intimately linked with the credibility of those undertaking it – the experts.

4.3.3 Experts and values

Unsurprisingly, risk analysis is seen as an expert activity. This is both a strength and a weakness. The strength is in its sophistication and pedigree, and its amenability to good analytical method and scientific peer review. Its weakness centres around the fact that there are many knowledge's (both within the term "science"[c] and external to it) that are relevant to establishing environmental risks and these are not all captured in a technical risk assessment. Indeed, concerns have been expressed that that the experts in industry, consultants and contractors and the regulator operate as a very closed community [Rothstein and Irwin, 1998]. This inevitably raises questions about impartiality, vested interests and open mindedness.

The House of Lords Select Committee on Science and Technology recognised this in 2000 in their third report on Science and Society (Summary, Chapter 2) when they identified that "*Science is conducted by individuals; as individuals and as a collection of professions, scientists must have morality and values and must be allowed, indeed expected, to apply them to their work".* The problem is that this individuality on the part of scientists is not always recognised outside the profession. Since this individuality reflects the moral priorities of the scientist (which are also presumably reflected in his/her choice of professional affiliation) there will always be some scepticism about the motivating factors behind a risk analysis.

Another difficulty in making sense of expert information and knowledge is that, where there is significant uncertainty, experts with similar training and background can come up with different understandings and concepts. Often these different understandings can have equal validity because they call on different research and the actual truth is not known. This difference of view can induce a sense of conflict amongst experts that further undermines any expert authority which they hold.

Environmental decision -making often comes down to discussion of who you are going to allow to be at risk and by how much. These are subjective, value driven judgements. In the face of high uncertainties, these value judgements will affect all choices about how to handle uncertainty within a model. Taking Wynne's classification system, only incompleteness (reduceable uncertainty) is likely to be amenable to value-free judgements

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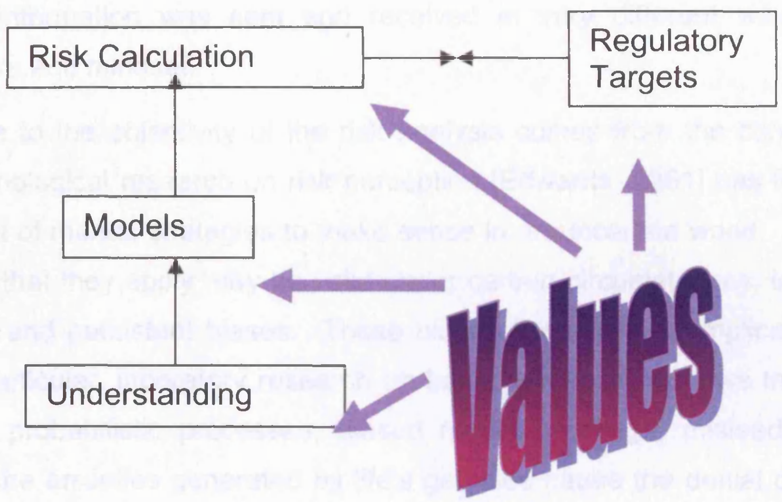
[c] Science covers a range of very different disciplines, knowledge and cultures. As with the term "public", there is more than one science.

since it does have the potential to be addressed by the acquisition of more information – i.e. by observation. "Ignorance" may be reduced as more information becomes available, although Wynne identifies that the reduction of ignorance will inevitably lead to an increase in uncertainty since new causal factors will come into play. "Risk" is culturally understood and therefore different people will make different choices about the significance of the risk. "Indeterminacy" is, by definition, irreducible and so any attempt to deal with these will be educated guesses and will be influenced by personal experience.

The fact that risk is culturally understood means that subjectivity inevitably comes into judgements made at all stages of the risk analysis process. This includes the definition of environmental standards. Value-free information can guide these judgements to a greater or lesser extent (Figure 10).

Figure 10. Risk analysis and values



So if values are influencing the risk analysis process and the process sits in the domain of experts, are the value judgements being made by the experts appropriate? Generally speaking, the expert should apply his/her knowledge in a manner that is as impartial and objective as possible. This is the essence of the scientific method described in Figure 9 and is encapsulated by the notion that scientists are "seekers after the truth". Given this cultural background, the analyst is seeking to be as objective as possible in making a calculation of risk. However, as uncertainty increases, the influence of values becomes stronger and stronger (Figure 3). Whilst the experience and training of the expert gives him/her a certain authority in terms of knowledge, it does not provide him/her with any significant ascendancy in terms of values. So where values become significant, should it be up to any one epistemological group to determine what those values should be? The issue here is whether any group of experts can claim to have objectively considered an uncertain problem.

It is naive for any group to claim complete objectivity. Research into the didactic use of information and discourse analysis demonstrates that experts use information differently in their dialogue. Lawyers will tend to cover over weak points and emphasis strong ones, even when it is the weak ones that are important – scientists emphasise detail – communicators select key points and evidence therefore exercising control over the debate. So inevitably, cultural training will affect the way information is used and discussed. An example of the significance of cultural differences was given by Edward Tufte in his analysis of the 24 hours leading to the Challenger disaster in 1983. [Tufte, 1997]. In this work, Tufte analysed the way scientists presented information on the risk of O-ring failure in cold weather to NASA officials gearing up to authorising a Challenger take off in January. The information was presented with all the detail that a scientist would be expected to provide to demonstrate the rigour of his/her analysis and the message was entirely lost on the NASA officials. Take off was authorised, an O-ring failed and twelve people died. Knowledge and information was sent and received in very different ways due to a difference in culture and mindset.

Another challenge to the objectivity of the risk analysis comes from the consideration of expert bias. Psychological research on risk perception [Edwards, 1961] has indicated that people apply a set of mental strategies to make sense in an uncertain world. Although the mental strategies that they apply may be valid under certain circumstances, in others they can lead to large and persistent biases. These biases have serious implications for risk assessment. In particular, laboratory research on basic perceptions shows that difficulties in understanding probabilistic processes, biased media coverage, misleading personal experiences and the anxieties generated by life's gambles cause the denial of uncertainty and the misjudgement of risks. Expert judgements appear to the prone to many of the same biases, particularly when experts are forced to go beyond the limits of available data and rely on intuition – as is the case for long term environmental risks that may arise in the future.

There has been a lot of work exploring the biases of experts [Kahneman et al, 1982; Schrader-Frechette, 1990a] especially when faced with uncertainty. This work supports the claim that, in the absence of an algorithm completely guaranteeing scientific rationality, experts do not necessarily or always make more correct judgements about the acceptability of technological risk than do lay persons. Kahneman and Tversky [Kahneman et al, 1982] illustrated a number of characteristic biases to which most people fall prey:

- Representativeness: which is when samples are believed to be very similar to one another and to the population from which they are drawn. This ignores the kind of factors often discussed in basic probability and statistical theory (prior probability of outcomes, sample size, predictability, correlated variables and regression towards the mean). Therefore, the bias of representativeness can be reduced by sound training.

- Availability: which is where the frequency of something, or its probability is influenced by the ease with which it can be bought to mind
- Anchoring: which is where estimates are made on the basis of adjusting values to an initial variable. This ignores the likelihood of different starting points yielding different results and that insufficient adjustments can skew the results. Typically, for a complex system, this results in an underestimation of failure.

Where there is a level of complexity about the system being analysed, all these biases may come into play in risk analysis. The concern expressed by many risk commentators is that those undertaking risk analysis may be vulnerable to bias due to their personal perception of the risks they are analysing. This is particularly the case when there is limited information on which to base the risk analysis.

As awareness of these potential bias increases, methods are gradually being introduced to minimise their impact. Nirex's approach of previewing scientific work prior to its undertaking it is one such example. Participatory assessment techniques have been developing rapidly over the past decade (Petts and Leach, 2000). Nevertheless, it is still the expert community that largely determines what ideas about environmental evolution go into a risk analysis. It is also experts who develop the models used to make the risk calculations.

4.3.4 Abstraction and Calculation

The risk analysis itself is done using models of many kinds. Problem definition is developed from the available knowledge (which includes knowledge about uncertainty) to represent the "important" aspects of the system and how it may evolve into the future. Mathematical models are created from these concepts using a series of assumptions about the repository system. Therefore, the development of a risk analysis requires the expert to make an intellectual translation of information into a modelling methodology (Table 7). Since the assumptions are approximated by a numerical representation within the models, this means that the intellectual translation needs to convert essentially descriptive information about system behaviour and uncertainty into numeric and quantitative model input parameters.

Model input is often represented as conceptual assumptions and supporting information. This generally includes a description of the features and processes to be modelled and data on key properties. Sometimes these are called conceptual models[d][Nirex, 1997], especially in the field of hydrogeology which is of great relevance to environmental modelling. Since the information going in to the model determines the robustness of what comes out, these conceptual models and their origin are tremendously important to the risk analysis process.

Table 7: The translation of information into a modelling methodology

Information input	Translated into..
What standards need to be met (generally defined in regulations)	Identification of model output (what the model is to calculate)
How the proposed course of action hopes to meet these standards (the project design)	Model representation
What is known now about environmental conditions, processes and evolution (environmental knowledge)	Conceptual models and algorithms for representing key processes and couplings between processes, input parameters
What potentially could happen in the future	Scenarios of the future
	Groups at risk and their representation in the model
What are the risks?	Ways of judging risk

The conceptual model is a very important component of the modelling process. It captures what is encompassed within the risk models. However, conceptual models are not quantitative. They are descriptive in nature and in the arena of risk analysis have tended to take a subordinate role to the numerical models used for the quantitative treatment of uncertainty to deliver a risk result. This result can be compared with environmental standards and regulations (Figure 10). The level of compliance with regulations informs the decision-making process.

So the derivation of risk results is based on the use of mathematical models used to represent conceptual assumptions and knowledge (both what is known and what is not known). The risks analysis process is therefore only as good as the models used to calculate the results and the models are only as good as the information used in the first place [Ravetz, 1998].

There are a number of problems that arise from this:

[d] The definition of conceptual model used here is *"a brief, clear, simple and unambiguous description of the system. It defines the processes acting within the system, the parameters required to model those processes and the conditions on the boundaries of the system"*.

- A quantitative definition of risk, derived from regulatory science and captured in an environmental standard may not necessarily represent the concerns and values held by all stakeholders. In particular, the quantitative definition of risk derived from the physical sciences is not in accord with that of social scientists whose definition is inherently multidimensional and personalistic [Covello et al, 1988]. Thus results can appear to have little relevance to immediate concerns held by non-experts.
- Probability theory is often used to handle uncertainty within the model. However, probability is not intuitive, data will need to be augmented by expert judgements and the numerical representation of all this can be complex. This tends to focus discussion on the modelling process itself, rather than the underlying scientific assumptions.
- The quantitative presentation of results from a risk analysis is rarely in a form aimed at engaging non-regulatory stakeholders.

These problems arise from the fact that mathematical models approximate reality to a greater or lesser extent. The accuracy of the approximation depends on a great many issues including:

- the degree of realism or conservatism required;
- the quality and comprehensiveness of data used to populate the models and the way in which they are used within the model;
- uncertainty about the conceptual model which the mathematical model is seeking to represent;
- the way in which the mathematical model simplifies and abstracts physical and chemical processes so that they can be represented in equations;
- uncertainty about the future evolution of the system being modelled.

Additionally, the model development process can be involved. This is particularly the case for the assessment of a radioactive waste repository where, for example:

- the wide range of features and processes considered requires that a range of different models needs to be used in a hierarchical manner;
- data processing may be required to develop model input parameters. This data processing often requires the application of expert judgement;
- sophisticated programs are used;
- the models need to handle the changes that may occur over long timescales into the future;

- the system under consideration is heterogeneous, manifested in a high degree of spatial variability. This is particularly the case where the variability is not simple, as is the case with many geological systems.

Because of the emphasis on quantitative output and the sophisticated nature of the models involved there is a temptation to present the models in great detail. They are the key to turning understanding into results. However, a high level of detail about the models may not be of interest to the majority of stakeholders. It is obviously important to establish the validity of information that has gone into the models (data and assumptions) and the confidence with which model output can be used (their strengths and limitations and their ability to reproduce independent data). However, these are generally seen to be one role for expert regulation and peer review to play *on behalf of society*. Stakeholders may not consider they have the competence to pass comment in these areas. However, that does not mean that they are not interested in the ideas and concepts behind the models – concepts that describe expectations about the causes and effects of environmental processes.

A key argument in this thesis is that, out of context, an emphasis on the strengths and weaknesses of the mathematical models may act as a barrier for discussion and dialogue about the causes and effects of environmental processes. Whilst expert regulators may be able to engage with the models, the discussion is kept within an expert (some would say closed) community. The risk models and the results they produce are unlikely to serve as a platform for shared knowledge building since, by their very nature they exclude the non-expert community.

In using the term expert here, I am referring to those with an intimate understanding of the mathematical modelling of risk and uncertainty. There are many examples of (expert) natural scientists, working to provide conceptual models to input to risk models and remaining sceptical about the model output because of the "numerical hoops" through which their input is put. Many instances of this are documented by Nirex in a detailed investigation into allegations of misconduct in the mid-nineties [Nirex 2001b].

Risk workers do not call the output of their models predictions. This is common to many fields of investigation that have to rely heavily on probability theory to deal with long term environmental risks – e.g.climate change, radioactive waste disposal. The models used in these areas of work, which involve considering risks for very long times into the future are highly sophisticated. They are also based on uncertain input information. When faced with such uncertainties the analyst may adopt the principal of "conservatism" – using a model parameter that will tend to increase the risks calculated by the model. Additionally, when faced with multiple futures, the analyst may choose to use a probabilistic approach to the analysis – whereby the model handles the many possible futures and uncertain information by allowing them all to be possible and calculating risks from randomly selected combinations of parameters. If this is done a sufficient number of times, an "expectation value of risk" can be derived which is some average value of risk allowing for all identified future and data uncertainty that is included within the model. However, it is not a prediction of risk. Most analysts would claim that a "prediction" of risk would be lower than an "expectation value" of risk.

The apparent numerical complexity required to handle data uncertainty quantitatively is not easy to assimilate, even by those intimately involved in providing model input information. This raises the question of how to understand the output of the risk calculation. Where models need to place such emphasis on treating uncertainty and where there is such difficulty in comprehending the meaning of the model output, can the risk results be used with any confidence?

4.3.5 Reliability

There is no single answer to the question "how reliable are the models" since the answer is a value judgement in its own right and will be influenced by epistemological uncertainties. There will also be a significant level of debate about what is meant by the term model. Computer codes may be very reliable in some situations and completely unreliable if used inappropriately. Conceptual models may be very robust but their translation into a mathematical model capable of calculating quantitative results may be inappropriate. So despite the rigour going into the calculation of risk, confidence in the results will be determined by other factors.

A fundamental challenge to the application of any risk assessment is that there may be causal relationships that have not yet been experienced. This is particular problem in the environmental arena and has been discussed extensively by Wynne [Wynne,1996]. So how should a risk analysis dealing with future uncertainty be viewed? In part, this comes down to the level of confidence the stakeholder has in models.

However, given that it will never be possible to test the output of the models, it is not possible to rely on scientific methods to wholly "verify" or "validate" the models in the face of continuing future uncertainty. Therefore, confidence in the models that provide an assessment of risk cannot be divorced from the level of trust placed in the institution or individual developing the models. This will lead to questions about the motives and values of those developing the models, and the level of transparency about the assumptions that are used within the models.

In the past, where the risk assessment was used to facilitate discussion between the proponent and the regulator, confidence in the models was established through expert peer review and debate about specialist knowledge and uncertainty. In participatory forms of decision-making, this may not be sufficient. Whilst expert review and comment will remain a significant factor in determining confidence in the risk models, the use of other forms of knowledge may be required for a risk assessment that is robust to review by a wider cross-section of stakeholders. Deciding whether to respond to this wider audience is one of the key challenges for analysts arising from new forms of environmental decision making.

So although there is a general consensus that risk assessment is an essential component of developing a risk management strategy, its limitations need to be appreciated, by both the analysts undertaking the assessment and the decision-maker.

4.3.6 But is it science?

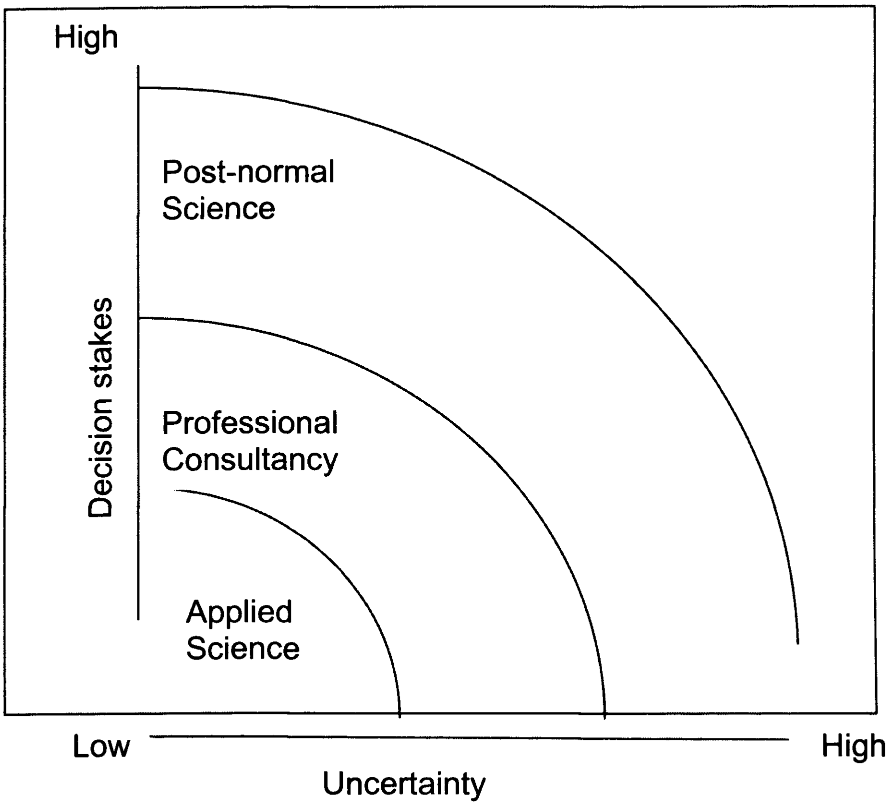
Where there is sparse data, or lack of precedent for a project, some researchers claim that risk analysis (in particular the development of conceptual models and providing the numbers to model it) is an exercise in "disciplined guesswork" [Fischoff, 1995]. This could be reconciled with scientific practice since expert judgement is the basis on which observations are turned into hypotheses (Figure 9) and also the bedrock of peer review. However, other workers have referred to risk analysis as " the technological application of science", which is clearly challenging whether it is science or not [Schrader-Frechette, 1990b]. Aside from some bruised egos, it does not really matter in practice whether risk analysis is or isn't science. However, it is important that the balance of fact, knowledge and judgement going into risk analysis is seen clearly, especially where the analysis is informing a decision-making process. This is a major theme in the work of Wynne – that risk workers should not claim authority and objectivity (and hence executive power) without acknowledging limitations. The reason why this is of such concern is that risk analyses are used in standard setting and policy formulation. These are currently highly dynamic fields and it is surely important that old technology and ideas are not applied inappropriately to new problems.

Funtowicz & Ravetz explore the relationship between science and policy in their work "Uncertainty and Quality in science for policy [Funtowicz and Ravetz, 2001]. They identify the emergence of a new form of 'post-normal' science. The term, 'post-normal' is relative to the idea of 'normal science' which assumes that it is possible to identify a framework for the systematic handling of knowldege. Within such a framework, values tend to be unspoken and assumptions are often implicit rather than explicit. Hence socio-political *problems* tend to be converted into analytical *puzzles* [Kuhn, 1962]. In contrast, Funtowizc and Ravetz claim that post-normal science responds to a decision-making climate where 'facts are uncertain, values in dispute, stakes high and decision urgent' [Funtowicz and Ravetz, 1992]. They suggest that "normal science" struggles to deal with these issues owing to factors such as data inadequacies and poor understanding of complex phenomena. They propose "post normal science" as a new culture or epistemology, developing in response to changes in the decision-making climate in which experts find themselves.

The relationship between post-normal science and normal science is shown in Figure 11, reproduced from Funtowicz and Ravetz's original work [Funtowicz and Ravetz, 1992]. The term "decision stakes" refers to the complexity of the decision - some multiple of cost, benefit, impact and the number of interested and affected parties. Where both uncertainty and the decision stake is low, the model claims we are in the realm of *applied science*, where uncertainties can be dealt with at the t*echnical* level using standard ('normal') techniques. Where decision stakes or uncertainties are 'higher', uncertainties exist involving more complex aspects of information such as reliability or values. Here, judgements are required, and the practice in question is termed a *professional consultancy*, a 'learned art' like medicine or engineering [Funtowicz and Ravetz, 2001]".

According to Funtowicz and Ravetz, the realm of post-normal science exists when either stakes, uncertainties, or both are high (see Figure 11). Uncertainties involving indeterminacy and ignorance become significant and decision stakes reflect conflicting purposes among stakeholders. Uncertainties therefore become "epistemological" (using the NUSAP system) and incorporate issues associated with morals and ethics. As discussed in chapter 2, these are the very issues that fuel environmental debate and make contemporary environmental decision-making so tricky.

Figure 11. Three types of problem-solving strategies (redrawn from Funtowicz and Ravetz 1992)



The idea behind post-normal science is that the quality of the information being used in the decision can no longer be determined solely by expert peer review. This is because there is an extended set of legitimate participants in post-normal science and hence "extended facts" which need to be incorporated into the knowledge base for the decision. These extended facts derive from those with local knowledge and are complementary to knowledge derived from "abstract, generalised conceptions of the genuineness of the problems and the relevance of information".

Whilst the rationale behind the identification of post-normal science is sound – it identifies a realm of understanding where knowledge and values are linked and decision-stakes and uncertainty are high – the concept can be challenged on two counts:

- The notion that science itself is limited by its ability to deal with uncertainty and extended facts;
- The notion that different types of uncertainty can be represented on a linear scale.

If the discipline of science is taken to be the "pursuit of knowledge" [OED], then all types of uncertainty – incompleteness, ignorance, indeterminacy, technical, epistemological, methodological, data, model, future – and all types of knowledge are entirely within its boundaries. However, a particular application of science, or a specific method of dealing with a scientific problem may well be unable to cope with certain types of knowledge or uncertainty. For example, the inability of a risk analysis to deal with ignorance and indeterminacy is discussed above. Post-normal science is a response to the increasingly rigorous quantitative nature of scientific analysis – good for dealing with technical uncertainty. However, this is only a method. In a way, post-normal science appears to be taking methodological uncertainty and using it to define the boundaries of normal science. An alternative view is that an open-minded scientific practitioner thinks beyond the boundaries of any particular method. A good scientist should be able to acknowledge the existence of all types of knowledge and his/her role is to pursue ways of incorporating this knowledge and reducing these uncertainties via systematic structuring of knowledge. This scientific practice remains valid for any position on the diagram reproduced in Figure 11.

One of the reasons for identifying the realm of post-normal science is that it enables values and knowledge to be more firmly linked together than is done in the traditional ("value-free"?) pursuit of science. Deficiencies in recognising the significance of values could be more of a methodological uncertainty (a limitation in past scientific attitudes and applications) than a fundamental boundary to science *per se*. This suggests that there is no need to define a new epistemology <u>outside</u> science (as is done with the definition of post-normal science). Rather there is a need to rethink the role and pursuit of science and its social context within difficult policy areas, and to understand the limitations of the scientific applications currently used.

A related issue is that post-normal science identifies technical, methodological and epistemological uncertainty as a spectrum. Wynne offers comment in this area and identifies that *"risk, uncertainty and indeterminacy are overlaid one on the other, being expressed depending on the scale of social commitments which are bet on the knowledge being correct"* [Wynne, 1994]. If different types of uncertainty are overlaid one on the other, then it may be better to conceive of different epistemic knowledges as onion skins around a central issue. In this way, Wynne's view that more precise scientific knowledge can narrow down uncertainty but will increase ignorance and misrepresent indeterminacy identifies a limit to science. Wynne's challenge is that science expands to fill the void where indeterminacy and ignorance exist, whereas this should more usefully be filled by a discussion of the limitations of science. In my view, it should be a discussion of the limitations of the scientific method being used to deal with uncertainty. I believe we are all in danger of defining and limiting science by the methods used in general scientific practice.

Nevertheless, the upshot of this highly philosophical discussion is that risk analysis is limited in its potential to act as a knowledge base for environmental decision-making. Risk analysis is an analytical method derived for the quantitative and systematic treatment of uncertainty. Funtowizc and Ravetz would probably identify that risk analysis sits in the realm of "normal" science – it is methodological and has been developed in the belief that values and knowledge can be separated and uncertainty can be objectively handled. An ideal vehicle for shared knowledge building for environmental decisions would sit in the realm of postnormal science and acknowledge the interaction between knowledge and values that was discussed earlier.

A quick look at Table 7 shows that the translation of information through the three key stages of risk analysis (understanding, model building and calculation) acts as a focus for both:

- The application of expert knowledge and judgement; and
- Values - influencing choices about what to model and how to model it.

Knowledge and values <u>are</u> therefore intimately intertwined within the risk analysis. Therefore, it may be possible for risk analysis to evolve and hence continue to be a <u>central</u> part of the knowledge platform for environmental decision-making.

4.4 Risk analysis as a vehicle for knowledge building – a summary of issues

There is little argument that science, and in particular scientific knowledge about physical and chemical processes and their effect on the environment is, and will continue to be, a very important source of information for environmental decision-making. Additionally, whilst there is a lot of discussion and debate about understanding and acknowledging the limitations of mathematical treatments of uncertainty in a risk analysis, it seems generally agreed that risk analysis will continue to have a role.

Since risk analysis has been developed as a way of modelling environmental consequences within a regulatory framework, it is reasonable to consider that it provides a means of meeting the requirements of expert regulation. However, it has rarely been used to facilitate social inclusion. Partly this is because of the very systematic nature of the analytical process and the complexity of the models that are used when dealing with environmental risks. This has led to an increase in the development of participatory assessment practices outlined in (for example) Petts and Leach (2000). Undeniably, within these participatory frameworks, the risk analysis is an important input to knowledge building since it provides a means of considering what might happen in the future. However, the work described above suggests a number of limitations in using risk analysis as the platform for shared knowledge building. Essentially these ideas challenge:

- Whether uncertainty is captured comprehensively
- The objectivity of the expert judgements used in the development of a risk analysis

The implication is that a risk analysis undertaken by experts working within their own epistemological community is not a sufficiently broad-based vehicle on which to base a discussion. Hence the results of a risk analysis should not be used without reflection and discussion of who did it, what definition of risk was used, what went in it and what was left out. These issues actually have a very large impact on the analytical process itself and on the people who undertake the analysis. If risk analysis is to be used more effectively in participation, it will be important to understand the practical implications of opening up these issues to scrutiny and debate, both on the practice of risk analysis and on the practitioners.

One practical implication is that the involvement of stakeholders in dialogue about environmental risk should start earlier in the analytical process. Rather than the risk analysis informing the dialogue, there should be opportunities for dialogue to inform the risk analysis. The question is, how can these opportunities be created and how will they affect the analytical process.

At the very least risk analysts will need to reconsider the extent to which their work is value-free and objective. In general terms, it could be claimed that the risk analysis does go some way to integrating knowledge and values via expert judgements, although the analysts are not always aware of this. Hence the values that are incorporated are solely those of a closed and expert community. Going back to Stern and Finebergs criteria for a good analytic deliberative approach, this essentially means that the determination of "the right science" has been left to the analysts.

Many workers are now advocating a new paradigm for risk analyses in support of radioactive waste disposal [Andersson, 2001]. In this new paradigm, values drive the analytical process and are determined in a consultative manner. Inevitably, this proposal leads to the concept of a consultative risk analysis. But is this vision really compatible with the scientific method and with the behaviour and practice of scientists and risk analysts?

This question is very broad and may have a different answer depending on the nature of the environmental-decision being made. In the following chapters, the question is considered by looking generally at the role of science in general and earth science in particular in environmental decision-making.

5 SCIENCE AND EARTH SCIENCE: HOW CAN THEY CONTRIBUTE TO ENVIRONMENTAL DECISION-MAKING?

5.1 The challenges of analytic-deliberative decision-making

There is not much doubt in the literature that science and scientists have a significant and ongoing role to play in environmental decision-making. Three key challenges for scientists arise out of the preceding discussion:

- Scientists no longer have the executive power they enjoyed in the decide-announce-defend model of decision-making, where the risk analysis provided a common platform for discussion and debate between the proponents and the regulators experts. The scientific experts no longer have complete autonomy to determine what is "the right science" to be addressing;
- The significance of value judgements within science has been highlighted – challenging the notion that science is "value free";
- The scientist needs to engage with new audiences without the training and mindset of the scientific peer community. The expert nature of science is not helpful in this respect and demonstration of scientific rigour itself may be a barrier to communication.

Scientists remain important sources of knowledge about:

- the physical and chemical processes and their impact on the environment,
- the management of uncertainty and
- the assessment of risk

I would put it more strongly. Scientists are in a unique position to facilitate knowledge building, provided that the necessary receptiveness to alternative (scientific or lay) opinions can be adopted. What would the implications of this be?

There is a lot of debate about this in the literature. Adams [Adams, 1995], captures views expressed strongly by Beck (a sociologist) and Wildavsky (a political scientist) and concludes that they agree on the significance of culture and society in influencing perspectives on risk perception, and disagree about the magnitude and seriousness of those risks, Nevertheless, they have similar ideas about how to deal with these issues.

The way ahead shared by Beck and Wildavsky is one that sits very comfortably with scientific culture and practice. Beck argues that when scientist is pitted against scientist then arguments become intelligible and self-criticism can act to identify errors and limitations before they become entrenched in action. Wildavsky implies that some perspectives will be more in line with knowledge than others – and hence some people's views should take priority over others [Wildavsky and Dake 1992]. The notion is that *good science* can provide the necessary knowledge. This idea is mirrored in the Royal Society's discussion of risk [Royal Society, 1992].

Adams [1995] challenges these proposals on the basis that this would only be possible where everything is controllable. He states that, as evidenced by the ideas of Einstein, Heisenberg, reflexive modernisation and chaos theory, everything is far from controllable. This prescriptive theme that science cannot provide all the answers is picked up by many recent workers and has been discussed elsewhere (Wynne1996). It is also apparent in Stern and Fineberg's work [1996]. This leads to an important question for this thesis - how is a practising scientist to contribute to the management of risk? How can the individual be:

- authoritative without being authoritarian or arrogant?;
- responsive without abrogating the responsibilities of a specialist knowledge?
- open without being apologetic for his/her expertise?

These questions need to be answered practically rather than philosophically. Douglas and Wildavsky [1982] suggest that the selection/identification of risk is a matter of social organisation and the management of risk is an organisational problem. So the scientist needs to keep in mind the organisational structure and context within which (s)he is working as well as the social values to which (s)he is responding

A number of tools and techniques have been developed in recent years to aid this integration and enable individuals and individual groups to be included in the development of knowledge (social learning). In such participatory processes ideas about risk communication, participatory analysis and the concept of citizen science have their place.

However, there is also a need for consideration of societal issues in a generic or collective sense based on social and behavioural research. Often ideas of collective benefits are wrapped up into regulations and governance. Ideas of group values are therefore important to consider as part of expert regulation, along with the provision of appropriate checks and balances and qualified peer review. The notion of addressing two distinct axes is illustrated in Figure 12.

Figure 12. Axes for the discussion of scientific knowledge in the analytic-deliberative approach to decision-making

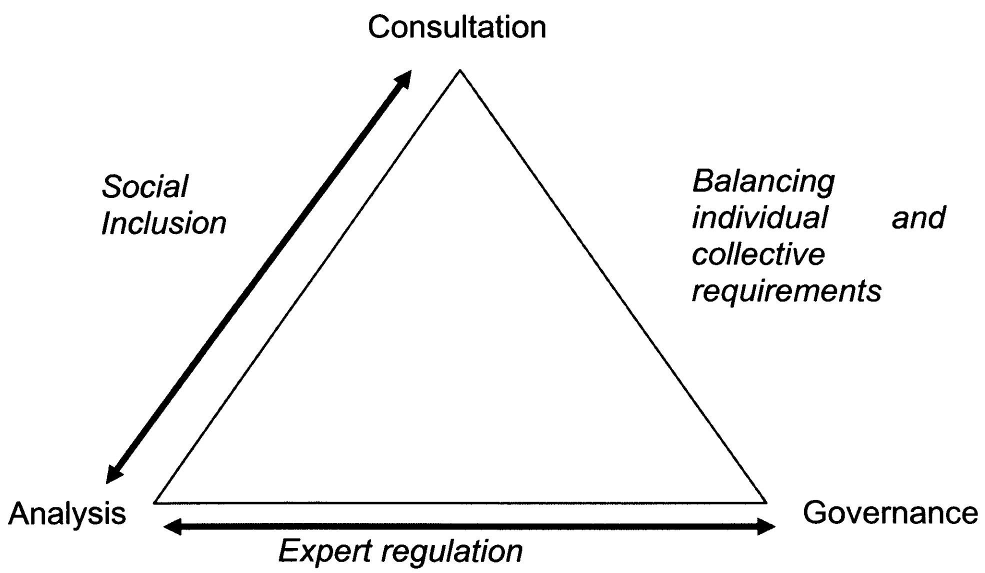


Figure 12 identifies that the scientist (analyst) needs to engage in dialogue with those providing expert regulation of their work and also with those seeking a less expert involvement in response to social inclusion. Past institutional expectation has been that risk analysis should rationally form the basis for discussions and knowledge development about environmental risk (i.e. it should sit in the centre of the triangle in Figure 12). In traditional forms of decision-making this was appropriate and checks and balances to ascertain the quality of the science encompassed in the risk analysis have been set up through legislation, regulation and monitoring organisation (regulators). Because dialogue about environmental risk has been mainly limited to the developer and the regulator, it has been possible for the dialogue to adopt the expert culture and scientific language of risk assessment. The risk analysis has therefore served well in enabling discussion and knowledge building with expert regulators.

However, experience in many sectors is giving rise to questions about whether the risk analysis continues to be an effective vehicle for dialogue and discussion with a broader representation of society. If not, the scientists therefore need to rethink whether or not traditionally structured risk analyses continue to be an appropriate vehicle for discussion and debate if they are to continue with a central role in environmental decision-making.

5.2 Vehicles for debate

Stern and Fineberg [1996] identify the development of an accurate and balanced synthesis as important for an effective analytic deliberative process. In essence, the synthesis is a key goal of the knowledge building process (Figure 5). Taking their work further, this synthesis needs to be informed by "the right science" and "the right participation" so that the decision maker can form a view about the significance of environmental consequences, based on a balanced discussion of the cause and effect of environmental consequences.

This seems to have the makings of something that could act as a vehicle for discussion between both expert and lay communities since it is important to all. Generally speaking, a knowledge platform needs to consider what is known (observational evidence), what is generally accepted (basic principles) and what is not known (conjecture). However, uncertainty is handled differently within different scientific disciplines. Geoscientists deal with uncertainty by seeking to explain it (explanatory rather than reductionist), and this should be a real asset in encouraging a debate about environmental uncertainty [Allaby and Allaby 2003].

Essentially, wider stakeholder participation (deliberation) will be captured in a linguistic form – ideas, comments, arguments developed in writing and rhetoric. The determination of risks (analysis) will be undertaken in a numerical fashion based on mathematically rigorous treatments of uncertainty. Between these two endpoints of the analytic-deliberative approach to decision making, something needs to occur that translates linguistic inputs into numeric information.

This is where an interpretative and heuristic approach to science comes into its own. Earth Science is a descriptive (i.e.linguistically oriented) discipline in which the subject matter is essentially environmental – so much so that in the past the Earth Sciences have been considered a derivative science, based on the application of primary sciences (chemistry and physics) to understanding the environment around us. The central theme of this thesis is therefore to look at the potential for geoscientific knowledge about the physical and chemical processes affecting the environment to focus social negotiation and develop shared knowledge about the significance of environmental consequences.

5.3 The value of Earth Science

"Earth Science" is acquiring currency as an all-embracing term for geology, geography, geodetics, climatology and meteorology, oceanography and the astronomical aspects of the earth-moon system. Encompassed within Earth Science is the term geology which is defined as "the study of the earth as a whole, its origins, structure, composition and history and the nature of the processes that have given rise to its present state" [OED]. This thesis is primarily concerned with the geological context of the Earth Sciences which has provided the biophysical background for my work with Nirex and my involvement in long term risk analyses.

The Earth Sciences, with their emphasis on considering the earth as a natural system and exploring the chemical and physical processes that determine the earth's dynamic evolution help in understanding the cause and effect of environmental change. Earth scientists therefore have a central role to play in environmental policy-making. Historically, the discipline of Earth Science has been descriptive and interpretive. However today, it also includes experimental modelling so that it can be a predictive, as well as interpretive discipline. The work of a geoscientist is to offer explanatory hypotheses in the face of sparse evidence and large uncertainties [Oreskes, 2001]. It is, by nature, an heuristic discipline, which seeks to explain evidence in the present by considering evolutionary history. Time and evolution are constant points of reference for the Earth Sciences. In consequence, it is fundamentally bound up with the consideration of environmental change and, as such, provides a good basis on which to discuss environmental impact.

Whilst the practice of Earth Science uses models to recreate history, test hypotheses and make predictions, it is essentially conceptual, based on the observation of naturally occurring features and processes. So when an oil geologist makes predictions about the extent of oil reserves, (s)he uses a model based on observations from field tests, a hypothesis about the evolution of the site and the disposition of the rocks and an understanding of the physical and chemical processes of hydrocarbon generation (derived from experimentation and observation). A volcanologist will analyse and model the cause and effects of an eruption to make predictions about future hazards from an active volcano.

Additionally, the evidence which the Earth scientist uses are provided by nature – and exhibited as part of the environment in which we live. Earth Science therefore has the potential to be tangible to others, since we are all part of the environment and will see examples of geoscientific evidence as part of our everyday lives – the upwelling of a spring, the drying up of a river, the red brown colour of the soil in Devon.

So, theoretically, there are some key opportunities for the Earth Science community to contribute to environmental decision making. Earth scientists can provide:

- a major contribution to establishing, describing and reviewing the processes that could affect the environment, both now and in the future, and hence give rise to environmental risk [OUP,];
- inputs to the risk analysis process [Stern and Fineberg, 1996] ;

However, if Earth Science is to contribute to evolving methods of environmental decision-making by facilitating the linkage between expert and lay knowledge, then a key question has to be whether it provides a medium for dialogue, for example by enabling/encouraging other stakeholders to engage in dialogue about the cause and effect of environmental risk.

Although there is little documented evidence for Earth Science acting as a vehicle for dialogue, this may be due to the nature of past practice where the focus for most Earth Science contributions to environmental decision making has been via the risk analysis. This focus has emphasised the skills of comprehensiveness, scientific rigour, precision and auditability, all of which are important attributes of any good scientific practice. However, this emphasis has inhibited the application of Earth Science in the other areas, which require a greater level of audience focus and therefore demand clarity of presentation and an ability to engage in dialogue.

The emphasis on the quantitative presentation of information also encourages a view that science provides an impartial, factual answer (however uncertain). Recent work challenges this idea by exploring the scientific practice and the motivational behaviour of scientists working in the face of significant uncertainty [Wynne and Irwin, 1996]. Hutton said that the present is the key to the past. As evidenced by the increasingly predictive nature of Earth Science, contemporary practice is to make the past the key to the future. This is where geoscience has an opportunity to contribute to environmental decision-making.

5.4 Geoscience and prediction

With environmental decision-making, society is still learning about the consequences of actions taken fairly recently and so new information is coming to light all the time. Hence the uncertainty and complexity associated with environmental systems is increasing and it is becoming much more difficult to achieve scientific consensus. This is partly because of the important scientific quality factor of pluralism. As more scientists with different perspectives and fields of expertise become involved, the number of factors to be integrated into a hypothesis about system behaviour increases, and hence the range of viable hypotheses available to explain the uncertain information expands exponentially.

Geologists have been dealing with uncertainty for more than 200 years. It is the essence of the geoscience subjects to take partial information about the disposition of materials and chemicals within the earth and its atmosphere, and speculate about:

- the processes and features that gave rise to them (for example, palaeontology, mineral genesis);
- their current disposition (as exploited by the oil and minerals industry); and
- what they might tell us about the future (for example in volcanology and natural hazard prediction).

These strands of geology all have one thing in common: uncertainty. Uncertainty in what happened in the past, uncertainty about what could happen in the future and also uncertainty arising from incomplete information. However, these uncertainties are essentially different.

What happened in the past is unknowable for sure, but hypotheses about past history can be tested against data and observations made now. This type of uncertainty is amenable to reduction via the scientific method. It is typically explored by physical scientists to develop theories of how the world works, and a general consensus may be achieved after a long process of such testing and peer review. The development of the idea of plate tectonics, and its ascendancy over the concept of continental drift is an example of this type of uncertainty reduction [Press et al, 2003].

Uncertainty due to incomplete information can, in theory, be eliminated by completing the dataset. In practice, this would not be possible. However, with the application of suitable resources, it may be possible to reduce uncertainty to a point where it is not significant. This approach to handling uncertainty is adopted by the engineering sciences, who test materials in order to provide a more complete dataset about their performance. Oil geologists face daily decisions about how much uncertainty they can live with when committing resources to exploration and oil production.

Finally, what may happen in the future will only be known with hindsight. Again, referring to the oil industry, geologists cannot know exactly how long hydrocarbon resources will remain available for exploitation. Power consumption may change, the balance of different energy sources may change, new technologies may make currently unusable hydrocarbon sources viable, new sources may be found. So to handle future uncertainty, analysts turn to models, in which assumptions are made to enable future impacts to be evaluated.

Because geologists have a long history of handling uncertainty, many methods exist for dealing with it. However, these methods have really been developed for application in mineral exploration and oil industry. In a recent submission to a Government review of energy and security of supply [Oil Depletion Analysis Centre, 2001], a range of predictions about "almost certain" near-term hydrocarbon shortages are identified. These predictions are based on models of future hydrocarbon production rates in which assumptions are made to deal with future uncertainty. The claim is that these models are assessed as "adequately accurate and robust". In essence, this type of claim means that model validation processes and peer review have been applied to the issue to build confidence that rigour and good science have been applied in the development of the models. However, as the time horizon being considered extends further into the future, it becomes more and more difficult to answer the question " how good are the models?"

With enough knowledge, and after the event, the models can also be tested by "postdiction". This approach has been adopted in the global climate change arena and the medical health arena. It is also used all the time for business analysis models. However, the business analyst is typically concerned with timescales altogether shorter than the "future generations" identified under the umbrella of sustainable development. Postdiction is not an option for the long term management of environmental impact.

5.5 Summary

The traditional scientific method of hypothesis testing against empirical observation followed by peer review has, in the past, led to a general consensus of scientific opinion about physical theories, this method can only be applied historically. The very nature of the scientific method is about explaining observations – i.e. something that was observed or measured in the past. Which leaves policy-makers and stakeholders concerned about the environment with a problem: "how can I make decisions about what may or may not happen in an uncertain future?".

The previous chapter considered the challenges associated with evolving risk analyses to contribute a broader perspective into the decision-making process by becoming more participatory. The aim would be to encourage greater levels of debate and dialogue over the knowledge and values included in the analysis. The compatibility of dialogue with scientific practice has been considered in this chapter. There are many different scientific cultures. In this chapter, the culture of geoscience has been examined and offered as a potential vehicle for debate since it has strongly descriptive and predictive elements which could be shared with non-experts. In the next section, the robustness of these ideas is explored by looking at the specific case of the deep geological disposal of radioactive wastes.

Section 2

The specific case of radioactive waste management

6 RADIOACTIVE WASTE MANAGEMENT AS A CONTEMPORARY EXAMPLE OF ENVIRONMENTAL DECISION-MAKING

6.1 Introduction

Radioactive waste management is an exemplar of contemporary environmental issues. The solid radioactive wastes produced by the nuclear industry (and others) act as a focus for a wide range of societal debates and economic issues. They are the by-product of an industry which has been, and is, violently opposed by some on ethical and environmental grounds. In many countries, there is a long history of attempts to develop a sustainable means of managing radioactive wastes over the very long timescales for which they pose a hazard. More recently, those involved in the management of radioactive wastes have been seeking to find ways forward that command a measure of public support. Hence, as an industry, there is a lot of valuable case-study material to consider in terms of using deliberation and analysis to find a way forward on behalf of society.

6.2 Background

Radioactive wastes are waste products that contain radionuclides and hence emit radiation in some form or another. Some wastes will remain hazardous for many thousands of years, both by virtue of the radioactivity associated with them and the chemical form of the wastes. Radioactive wastes are generally produced as a by-product of processes involving the use of radioactive sources and nuclear technology, primarily within the nuclear industry but also within the health and education sectors. From 1950 to 2000 there was a world-wide increase in the exploration and the exploitation of nuclear technology. Primarily, nuclear technology was developed for electricity production, but it has also been used for military purposes to develop strategic deterrents. All these activities have created radioactive wastes,

Both solid and liquid radioactive waste can be produced. This thesis is concerned with considering solid radioactive wastes. Different countries classify the waste in different ways according to their characteristics – primarily based on the nature and amount of radioactivity they emit. The UK classification system is presented in Box 5.

Box 5: Categories of solid waste in the UK

UK solid radioactive wastes are categorised into four groups

High-level Waste (HLW)

HLW has the greatest concentration of radioactivity, and generates significant quantities of heat. It occurs in relatively small volumes from the reprocessing of irradiated nuclear fuel and contains about 95% of the radioactivity in all wastes from UK nuclear power generation. It is produced as a solution in nitric acid which, for the most part, is converted into glass and stored in a specially designed facility at Sellafield. In April 1998 there were 1,800 cubic metres of HLW in storage.

Intermediate-level Waste (ILW)

Waste is classified as ILW if its radioactive content exceeds the upper limit for LLW, but its heat output is not so high that special cooling is necessary (as is the case for HLW). Much of the waste comes from materials that have previously been in nuclear reactors e.g. fuel cladding. Many of the wastes are stabilised by mixing them with cement inside a stainless steel drum. In April 1998 there were about 71,000 cubic metres of ILW in storage.

Low-level Waste (LLW)

LLW is waste with a radioactive content which does not exceed 4,000 Bq/g (Becquerels[1] per gram) of alpha or 12,000 Bq/g of beta/gamma activity. Most solid LLW in the UK is disposed of at Drigg after supercompaction and placed into containers that are infilled with a cement grout. The containers are then buried in engineered trenches. Between 1959 and 1998 about one million cubic metres of LLW were disposed of, mostly to Drigg.

Very Low-level Waste (VLLW)

VLLW has a radioactive content that is less than 0.4 Bq/g of alpha or less than 0.4 Bq/g of beta/gamma activity. VLLW may be disposed of without special treatment at landfill sites licensed for domestic and other wastes.

I – a becquerel is the SI unit for radioactivity and equates to one disintegration per second

Whatever the classification, the perception of hazards from radioactive wastes is generally high, principally due to a dread factor (see Chapter 3). Radioactivity is silent, unseen and can cause cancer. To compound the issues, radioactive wastes have connotations with the nuclear weapons industry. Another problem is the extraordinarily long-term health risks arising from the wastes. Society is therefore challenged with finding a way of managing these wastes both now and in the very long-term future

It can be difficult to divorce the issue of radioactive waste management from the processes that produce radioactive wastes. Inevitably there is a link between these wastes and the nuclear industry (and strategic deterrents). Hence the topic of radioactive wastes is rarely discussed in isolation from consideration of the future of nuclear power and the legacy arising from strategic deterrents. Therefore, decisions about what to do with radioactive wastes encompass most of the complex factors that make environmental decision-making such a multifaceted problem.

Ongoing environmental debates focus on issues such as whether the development of a long-term management proposal for radioactive wastes means that the continued production of these wastes is being condoned – therefore assuring the continued survival of the nuclear power industry. Alternatively, it is argued that there is an ethical obligation on this generation to deal with an existing, and hazardous legacy, regardless of decisions about the future of nuclear power production. Either way, it is difficult to decide what is the best way of handling these wastes, now and in a future which is essentially unknowable

Broadly speaking, the development of radioactive waste management policy requires the integration of:

- scientific research (into the environmental behaviour and health impacts of radioactivity);
- technology (to design and build facilities for the containment of the wastes);
- social research (to understand the behavioural, political, ethical and cultural factors that require consideration during the decision-making process; and
- consultation (to establish the key issues of concern and the values to be adopted in developing a management policy).

There are a number of possible options for managing solid radioactive wastes that are under active consideration. Some are considered more viable than others [DEFRA, 2001]. In the eighties and nineties, the options tended to be grouped into one of two broad categories:

- Dilute and disperse
- Concentrate and contain

However, this classification is simplistic when the timescales of concern (millions of years) are taken into account. No containment system can be guaranteed for such timescales and so an idea that has received much international support is the concept of multibarrier containment. In such a system, the wastes are indeed concentrated and contained into a central disposal facility, often conceived of being deep underground. However, the concept assumes that eventually the engineered containment will deteriorate to a point where it no longer serves a containment function. At this point, the natural system in which the disposal facility was built will begin to serve a containment function by retarding, diluting and dispersing the radionuclides within the natural environment.

Radioactive waste management is a problem being faced by many of the developed nations. Approaches vary between nations due to the different national cultures and backgrounds. Within the EC, many countries focus on the idea of building geological disposal facilities to manage their radioactive wastes. However, the details of such repositories can vary markedly. In most countries, there is a history of successful, partially successful and failed attempts to develop and implement different policies for the long-term management of the wastes. There is a lot of scope for comparing these attempts to identify strengths and weaknesses of the decision-making processes adopted

6.3 International Policy Considerations

The amount of waste held by any one country depends upon the history of nuclear exploitation within that country. Some of the oldest wastes relate to extraction of radium from uranium for medical purposes. Early electricity-producing nuclear reactors produced much more waste (per unit of electricity generated) than more recent ones. The volume and the diversity of the wastes in a country's possession therefore depends on past and present policy decisions for energy and defence. Examples of such decisions are the extent to which nuclear power is to be used for electricity production, whether uranium mineral reserves are to be exploited, and whether spent nuclear fuel is to be treated as a waste or as a resource to be exploited through reprocessing. For reasons such as these, different countries face quite different challenges in terms of the quantity and the range of waste types that need to be managed. A summary of management approaches is given in Appendix A.

In accordance with the principles of sustainable development, there is widespread international agreement that, in addition to protecting the current population, these wastes must be managed so as to provide fairness and equity in terms of:

- the risks and burdens placed on future generations (inter-generational equity), and
- resource allocation and decision-making within contemporary generations (intra-generational equity).

With current technology, the storage of these wastes to protect current generations (short-term management) is relatively straightforward. Many waste storage plants already exist. However, they have not been designed as a permanent solution for the management of radioactive wastes. Providing adequate protection to future generations (long-term management) is therefore a different matter.

For some wastes this entails isolation of the wastes and containment of long-lived radionuclides for many thousands of years. On these timescales it cannot be assumed that the infrastructure, resources and technology that are required for storage will continue to be available. Long-term management therefore requires other approaches and different countries are addressing this in different ways.

Broadly speaking, much of the policy-debate about the long-term management of radioactive wastes tends to be focussed on those options which do not contravene international treaties: long term storage and disposal. Ethical arguments citing the principle of intergenerational equity can be advanced for both.

Long term storage involves active management, monitoring and maintenance of a storage facility for hundred of generations. The idea is that this active process extends choice to future generations and gives them the option of applying new technologies in the future. However, in the light of the terrorist attacks on the World Trade Centre on September 11th 2001, some advocates of long term storage (sometimes called guardianship) are including the notion of below-ground storage into their thinking.

Disposal involves the construction of a facility which does not rely on active maintenance to achieve the necessary containment of radioactive wastes – i.e. it relies on the idea of "passive safety". Multibarrier containment is a concept that has been developed to deliver this passive safety and a way of achieving multibarrier containment is to construct a repository for radioactive wastes deep underground – deep geological disposal. However, in view of concerns regarding the performance of such facilities, many advocates of deep geological disposal are now including periods of storage in the repository during which the wastes can be monitored and retrieved into their proposals, prior to final closure.

Given these trends in thinking, the policy issues that separate the ideas of storage and disposal come down to question s such as "how deep?", "how retrievable?" and "for how long?" – once again that type of value-laden ethical questions for which it is very difficult to establish any measure of consensus.

Meanwhile, as the policy debates continue, existing wastes are stored in interim storage facilities which are vulnerable to surface processes and which require increasing levels of active maintenance. Therefore, internationally there is pressure to formulate policies for the long-term management of radioactive wastes [Oxburgh, 2002]. Different countries are developing different approaches [Lidskog and Andersson, 2002]. A comparative study is presented in Appendix A. Countries included in the study are Belgium, Canada, Finland, France, Germany, the Netherlands, Spain, Sweden, Switzerland, Czech Republic, United Kingdom and the United States. Given the wealth of detail associated with various radioactive waste management programmes internationally, this analysis focuses on particular sites and aspects of waste management programmes that provide the most useful lessons with respect to stakeholder dialogue and consultation. The analysis was undertaken in 2001.

6.4 Radioactive waste management in the United Kingdom

As in other countries, the UK has a long history of solid radioactive waste management, and more importantly, a history of persistent attempts to develop a solution for the long-term management of radioactive wastes. Appendix B outlines the history of radioactive waste management in the United Kingdom, leading to the present Government consultation about Managing Radioactive Waste Safely [DEFRA, 2001] and the setting up of an advisory committee on radioactive waste management (CoRWM).

6.4.1 Wastes and disposal options

The UK already has significant quantities of long-lived radioactive wastes. Most of these have arisen in the last 50 years as a result of UK Government decisions on nuclear power production and nuclear defence. Smaller quantities of radioactive waste also arise from medical and industrial uses of radioactive materials. The categories of waste existing in the United Kingdom are given in Box 5. The UK Inventory of Radioactive Wastes [DETR, 1999a] provides a more detailed description.

In the UK, the management of these wastes is being increasingly viewed as an ethical issue relating to inter-generational equity. It is the present generation that has benefited from the technology that produced these wastes. It would be wrong to leave the finding of a solution to future generations, which may have neither the industrial infrastructure nor the resources to do so.

Nevertheless, determining a management strategy for these materials has proved to be a major challenge in the UK, despite 30 years of research. A range of different options for the management of radioactive waste have been discussed. These are illustrated in Figure 13 and have been discussed in more detail in a recent review by Nirex [Nirex, 2002b]. However, only a small subset of these have been actively considered in the past as representing viable options for the management of radioactive waste. These are:

- Sea disposal
- Shallow disposal
- Deep disposal
- storage

These options are discussed in more detail in Box 6 and are illustrated on Figure 13

Box 6: Options for the disposal of radioactive wastes (see Figure13)

Long term surface storage

Long-term surface storage involves specially constructed facilities at the earth's surface. The waste could be monitored and retrieval at any time. Ideas include:

- Conventional stores of the type currently used for interim storage, which would require replacement and repackaging of waste every two hundred years or so:
- Permanent stores that would be expected to remain intact for tens of thousands of years. These structures are often referred to as 'Monolith' stores or 'Mausoleums'.

Both suggestions would require information to be passed on to future generations, leading to the suggestions of whether the stability of future societies could be ensured

Below surface storage

This type of facility usually takes the form of engineered (concrete) vaults constructed at ground level.

Waste containers are placed within the vaults and when full are backfilled. They will eventually be covered and capped with an impermeable membrane and topsoil. These facilities may incorporate some form of drainage and possibly gas venting system. Facilities of this type already exist.

Shallow Disposal

Unlike near surface disposal where the excavations are conducted from the surface, shallow disposal requires underground excavation of caverns but the facility is at a depth of several 10's of metres and accessed through a tunnel (drift). This type of facility is typically used for operational arisings of LLW and short-lived ILW as with the near-surface type. This type of facility already exists.

Deep geological disposal

A deep geological repository usually comprises of a mined tunnels or caverns into which packaged waste is placed. In some cases the waste packages are then surrounded by a material such as cement or clay (i.e. bentonite) to provide another barrier (termed buffer and/or backfill). The choice of waste package materials and design and buffer/backfill material varies depending on the type of waste to be contained and the host geology available.

Disposal in deep boreholes

In a deep borehole concept solid packaged wastes are placed in deep boreholes drilled to depths of several kilometres with diameters of typically less than 1 metre. The waste packages could be separated from each other by a layer of bentonite or cement. The borehole would vertically not be completely filled with wastes. The top 2 kilometres would be sealed with materials such as bentonite, asphalt or concrete

Box 6 (cont)

Rock Melting

The concept of deep rock-melting involves the melting of wastes in the adjacent rock in order to produce a stable immobilised mass encapsulating the waste or incorporating the waste in a diluted form that cannot be leached and transported back to the surface. This technique has been mainly suggested for heat generating wastes such as HLW and host rocks with suitable characteristics to reduce heat dissipation. The HLW in liquid or solid form could be placed in an excavated cavity or a deep borehole. The heat generated by the wastes would then accumulate resulting in temperatures great enough to melt the surrounding rock and dissolve the radionuclides in a growing sphere of molten material. As the rock cools it will crystallise and immobilise the radionuclides in the rock matrix. After complete crystallisation and cooling, it is estimated that the waste would be strongly "diluted" (i.e. dispersed through out a large volume of rock).

Injection into deep rocks

This concept involves the injection of liquid radioactive waste directly into a layer of rock deep underground chosen to have suitable characteristics to trap the waste (i.e. minimise any further movement following injection).

Disposal at Sea

Disposal at sea involves radioactive waste being shipped out to sea, and either released into the water in appropriate packaging, to sink to the seabed, or released directly to the seawater volume, to be dispersed and diluted. Sea disposal was undertaken by the UK and other countries over the period 1946 to 1982 to dispose of low and intermediate level radioactive wastes. It had not been implemented for HLW. The application of the sea disposal of radioactive waste has evolved over time from being a disposal method that was actually undertaken by a number of other countries, to a disposal method that is now banned by international law.

Sub-seabed disposal

The concept of sub seabed disposal differs from disposal at sea in that radioactive waste would be buried in suitable geological media beneath the deep ocean floor. It has been suggested for LLW, ILW and HLW This could be performed by:

- A repository located beneath the seabed. This could be accessed from land or from an offshore structure, and would be a variation on the concept of a repository located under land. Included in these suggestions has been the use of small uninhabited islands
- Burial of waste material in deep ocean sediments. This could be made by two different techniques: penetrators or drilling placement.

Box 6 (cont)

Disposal in subduction zones

Subduction zones form at convergent plate boundaries, where one section of the Earth's crust is moving towards and underneath another lighter section. In principle, wastes disposed in such places would be drawn deep into the Earth As shown in the figure, the movement of one section of the earth crust below another is marked by an offshore trench, and earthquakes occur adjacent to the inclined contact between the two plates. The edge of the overriding plate is crumpled and uplifted to form a mountain chain parallel to the trench. Deep sea sediments may be scraped off the descending slab and incorporated into the adjacent mountains. As the oceanic plate descends into the hot mantle parts of it may begin to melt. The magma thus formed migrates upwards, some of it reaching the surface as lava erupting from volcanic vents.

Disposal in iced sheets

Canisters of heat-generating waste could be placed in stable ice sheets such as those found in Greenland and Antartica. The containers would melt the surrounding ice and be drawn deep into the ice sheet, where the ice would refreeze above the wastes creating a thick barrier.

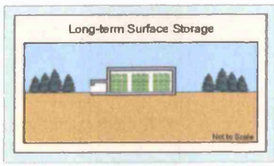
Although disposal in ice sheets could be technically considered for all types of radioactive wastes, it has only been seriously investigated for HLW, where the heat generated by the wastes could be used to advantage to self-bury the wastes within the ice by melting.

Disposal in space

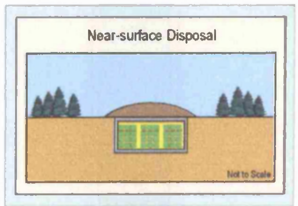
The objective of this option is to remove the radioactive waste from the biosphere permanently, for all time, by ejecting it into outer space. The basic idea would first involve packaging the waste in such a way as to be likely to remain intact under most conceivable accident scenarios. A rocket or space shuttle would be used to launch the packaged waste into space. Placing the waste in space near earth would not be sufficient due to the possibility of waste returning to earth. There are several possible ultimate destinations for the waste in space which have been considered including shooting it into the Sun, leaving it in an orbit around the Sun between Earth and Venus and ejecting it from the solar system altogether.

Figure 13. Options for long-term radioactive waste management

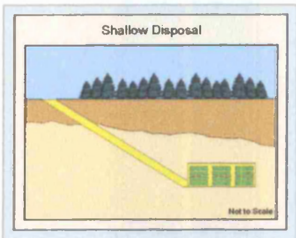
What is the option of "long-term surface storage"?



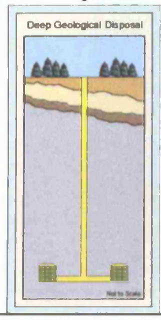
What is the option of "near-surface disposal"?



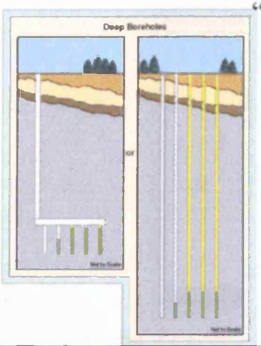
What is the option of "shallow disposal"?



What is the option of "deep geological disposal"?



What is the option of disposing in "deep boreholes"?



What is the option of rock melting"?

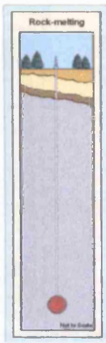
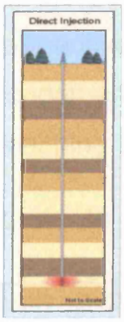


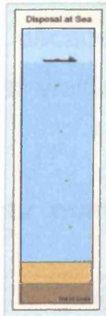
Figure 13 continued overleaf.

Figure 13 cont. Options for long-term radioactive waste management

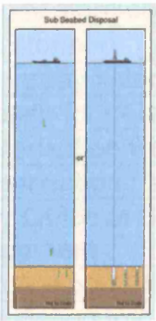
What is the option of "direct injection"?



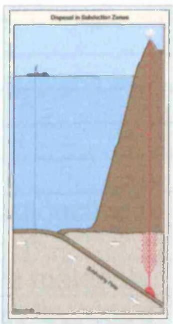
What is the option of "disposal at sea"?



What is the option of "sub-seabed disposal"?



What is the option of "disposal in Subduction zones



What is the option of "disposal in ice sheets"?

What is the option of "disposal in space"?

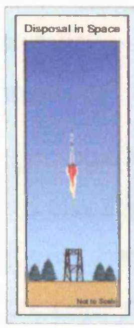


Table 8 reproduces key dates in the history of radioactive waste management in the UK based on a review undertaken by earth scientists who were members of the Radioactive Waste Management Advisory Committee [Kelling and Knill, 1997].

Table 8 shows us that there has been a history of policy changes and failures relating to the management of radioactive waste. The sequence of events, decade after decade, suggests something fundamentally wrong in the way the nuclear waste management system has been approaching the issue of radioactive waste.

Table 8: Key points in the history of radioactive waste management in the United Kingdom

1976	Flowers report - a UK strategy for solid radioactive waste management
1978	Radioactive Waste Management Advisory Committee established
1981	HLW drilling stopped
1982	Nirex established
1983	Sea dumping stopped
1985	Billingham study stopped
1987	Shallow sites stopped
1989	Sellafield/Dounreay selected
1991	Sellafield chosen for detailed studies
1995-6	Rock Characterisation Facility Planning Inquiry
1997	Rock Characterisation Facility stopped
1997	Parliamentary Office of Science and Technology report on radioactive waste management
1998	House of Lords report - the future management of radioactive materials
2001	DEFRA consultation into Managing Radioactive Waste Safely launched

This thesis will focus on only one of these decision points in detail. Context will be drawn from other experiences and from the international context.

6.4.2 The Nirex Rock Characterisation Facility Public Inquiry – a defining moment in radioactive waste management in the United Kingdom

In the nineties, Nirex focussed an extensive programme of geological investigations on the Sellafield site. Twenty-nine deep boreholes were drilled to investigate the properties of the geology around the site, and considerable modelling work carried out to assess the suitability of the site for a repository based on the concept of deep geological disposal. In 1992, a need for a Rock Characterisation Facility (RCF), an underground laboratory was identified. The purpose of the RCF was to investigate further the detailed properties of the potential host rock. Nirex applied for planning permission to build the RCF in June 1994. Cumbria County Council rejected the application in December 1994.

Nirex appealed against the decision and this resulted in a public inquiry that took place between October 1995 and February 1996.

The result of the public inquiry was that the rejection of planning permission for the RCF was upheld. The Secretary of State for the Environment announced on 17th March 1997 that he supported the decision not to allow the construction of the RCF and consequently Nirex terminated its work at Sellafield.

The RCF decision ended serious pursuit of any specific long-term management option for solid ILW radioactive wastes. In a report summarising the national situation with regard to radioactive waste management [Parliamentary Office of Science and Technology, 2000], the Parliamentary Office of Science and Technology identified that:

"While site characteristics and the way in which Nirex was perceived to operate no doubt contributed to the particular problems, the experience does throw up many serious questions over the mechanism for determining the appropriate approach to what would have to be a unique and national facility."

The report was the first in a series of comments about the future of radioactive waste management in the United Kingdom from influential organisations. Following the RCF Public Inquiry decision and the election of a new party into government in May 1997, the House of Lords' Select Committee on Science and Technology launched an enquiry into the management of nuclear waste, inviting evidence from a wide range of experts and stakeholders. Their report, *The Management of Nuclear Waste* [HoL, 1999] was published in March 1999. They concluded that the future policy for nuclear waste management would require public acceptance based on widespread public consultation before a policy is settled by Government and presented to Parliament for endorsement.

6.4.3 Current situation

The Government has responded to this situation on a number of fronts. Radioactive wastes exist now and will continue to arise over the foreseeable future. Those who produce them at many different locations around the United Kingdom currently look after these wastes (Figure 14).

Figure 14: Current locations of radioactive wastes

The existing wastes, their current storage and the ageing facilities that produced them are commonly termed the UK's "nuclear liabilities". For many years the responsibility for these liabilities has rested with the nuclear operators – BNFL, UKAEA and British Energy. Recently the Government's Department of Trade and Industry (DTI), who effectively sponsors these nuclear operators has announced the inception of a single "Liabilities Management Authority" to take over and unify the currently fragmented management arrangements [HM Government, 2002].

To address the issue of how to manage the wastes for generations of generations, the Government's Department of the Environment, Food and Rural Affairs (DEFRA), together with the devolved administrations in Scotland and Northern Ireland published a consultation document entitled "Managing Radioactive Waste Safely" [DEFRA, 2001]. This consultation process has led to the formation of a Committee on Radioactive Waste management (CORWM) whose remit is to develop and coordinate a process that will lead towards new government policy on managing radioactive wastes within the next 5 years.

So DEFRA and the devolved administrations are embarked on a process of developing future policy for long-term radioactive waste management and DTI is working towards the establishment of a centralised authority for the present-day management of nuclear liabilities. These two initiatives, and the relationship between them will shape the future of all stakeholders involved in the management of the UK's solid radioactive wastes.

The DEFRA policy development process will take many years to complete, not least because the Government is sensitive to the fact that non-inclusive approaches to radioactive waste management were adopted in the past which has left a legacy of disaffected stakeholders. However, concerns have been expressed that the time required to develop a legitimately inclusive policy consultation process is too long, given the present hazards associated with leaving radioactive wastes in current storage facilities. The concern is that the wastes present a very immediate risk to society and if a long term management strategy for these risks is not quickly forthcoming then an interim solution may be required [Oxburgh, 2002].

Meanwhile, the wastes need to be packaged and stored safely, until such time as a long-term management solution has been developed. In partnership with the Department of the Environment, Food and Rural Affairs (DEFRA), Nirex (an organisation with a long history of experience in the management of radioactive wastes) produces an inventory of radioactive wastes in the United Kingdom [DETR, 1999a]. This inventory is updated periodically and contains information on the volumes and characteristics of all the wastes produced by organisations such as BNFL, UKAEA, the Ministry of Defence and British Energy. Based on this knowledge, expert advice on the packaging of the wastes – the immobilisation of raw waste into an appropriate form and container - is provided by Nirex to the waste producers. This advice needs to be given against a background of generalised and specific knowledge about options for the long-term management of radioactive wastes in order to ensure that the packages are safe for both interim storage and for subsequent management in the long-term.

Currently, Nirex give their advice about packaging against a long-term management concept based on multibarrier containment in a deep geological repository for which there is a protracted (100s of years) period of monitoring and retrievability prior to final closure. This concept (the Nirex Phased Disposal Concept) is discussed in more detail in Chapter 10.

6.5 Analysis - what lessons does history teach us?

Both International and UK history of Radioactive Waste Management demonstrate the complex characteristics of environmental decision making described in the earlier chapters. Generally speaking, management strategies in all nuclear countries have evolved towards new, more consultative framework for radioactive waste management. This provides the opportunity to juxtapose technocratic and deliberative approaches and consider their implications for organisational and individual behaviour, and in particular, for the role of scientific knowledge in the decision-making process.

Because of cultural differences and differences in the nature of the radioactive wastes in different countries, there are limitations to any analysis of past and current approaches to radioactive waste management in different countries. Nevertheless, generalised comments can be made about the importance of a few key factors.

6.5.1 The role of consultation

There is increasing international consensus that consultation and dialogue have to form part of the process of making decision about radioactive waste. This is clearly manifested in the international approaches studied in Appendix A. Clearly this is in line with the general trends in the risk management research arena, as described earlier. With regard to radioactive waste management, this trend is reflected in the exponentially increasing literature on public participation, consultation and stakeholder engagement arising from organisations involved in making decisions about radioactive waste management.

Appendix A provides an empirical summary analysis (by this author) of information about how various countries have consulted about radioactive waste management by the year 2001. Consideration of the Appendix indicates that there is no explicit international consensus regarding which consultation principles and processes are the most effective. This is to be expected given the cultural differences between the countries tackling the issue of radioactive waste management. Nevertheless, some common trends are identifiable:

- There is evidence of continuing innovation in the methods of dialogue and engagement with stakeholders on radioactive waste management. On the basis of meetings such as the Forum for Stakeholder Confidence organised by the NEA, and European funded projects such as RISCOM and COWAM, there is evidence that these innovations are welcomed by politicians and public alike.

- Public and stakeholder involvement in determining the guiding principles for radioactive waste management policy is increasingly identified as essential for establishing the legitimacy of the overall management process since it provides the opportunity to identify the societal values that need to lie behind radioactive waste management solutions. Hence the idea of front end consultation is gaining ground in organisations involved in radioactive waste management organisations.
- Longer timescales for public discussion and debate are now accepted as both inevitable and important, reflecting increased social awareness and concern for issues of intergenerational equity and environmental sustainability.
- The Environmental Impact Assessment (EIA) procedure (and potentially Strategic Environmental Assessment [SEA]) are playing increasingly significant roles in site selection processes. However, the effectiveness of EIA is determined by country specific guidelines for EIA design and implementation. Countries that have drawn societal values into the process through forms of dialogue and community involvement, such as Finland and Sweden, appear to have made more consistent progress, although in the US significant progress has been made at WIPP and at Yucca Mountain with a very technocratic and legislative approach. Nevertheless, the adoption of inclusive processes does not mean that the project will be accepted, as evidenced by experiences in Canada.
- Site selection processes need to be specifically tailored to meet the socio-political history, culture, and needs and expectations of the communities involved. Volunteer processes and the use of a local veto seem to contribute to having an effective siting process, but they must be seen to be part of a wider package addressing the national need.
- Stakeholders, including the public, have brought valuable information, opinions and guidance to the dialogue. They are capable of tackling complex technical issues. Important methods have been developed to increase the transparency and accessibility of technical reports and other material so that it can be fully tested and "stretched" in this way.

In the United Kingdom, Nirex have recently published a report on the role that stakeholder consultation plays in their current programme (Nirex, 2004).

6.5.2 Science is no longer sufficient

Internationally scientific argument alone is no longer regarded as sufficient to justify a democratic decision, particularly where objective scientific proof may be impossible and effective risk management involves managing the doubts caused by uncertainty. A wider interpretation of risk is required, as risks will be perceived differently by different individuals and also for different projects. For risk management decisions to be supported by society, societal debate is needed in the early stages and throughout the decision-making process. Although agencies in the US have been successful in developing an implementing a disposal facility for military wastes in New Mexico (the Waste Isolation Pilot Plant or WIPP) using a fairly technocratic approach, this has generated a lot of discontent in local communities and is unlikely to offer a practicable model for more densely populated countries in Europe.

In the United Kingdom, past approaches have been very technocratic, with experts and decision- makers working together to determine and distinguish options. Generally speaking, these options are developed with the best of intentions, by committed scientists seeking to address the technical problem (what to do with the wastes) with a technically viable solution. However, time after time, these technically developed options have been rejected on behalf of society in general.

6.5.3 Sustainable development

Many of the principles of sustainable development are directly applicable to radioactive waste management. However, there is a lot of ambiguity over the interpretation of sustainable development and what it might mean in practice. Therefore, although some countries have carefully considered the principles of sustainable development and how they influence proposals for radioactive waste management, the impact has not been significant. Much of what has been done in the name of sustainable development would have been done anyway in the interests of legitimate and inclusive decision-making.

In the United Kingdom, most options considered in the past have been looking at providing a final solution based on the concept of passive safety, whether considering deep or shallow systems. This does not extend choice to future generations. However, it is very consistent with an interpretation of the precautionary principle that we should not burden future generations with the consequences of the current generation's activities. Nevertheless, until now there has been no significant dialogue about whether it is more appropriate to extend choice (long-term storage/guardianship) or to adopt a final solution (disposal).

6.5.4 Regulations

The nature of the regulations governing the management of radioactive wastes has a fundamental impact on the development of options. For example, in Finland, regulations place a requirement to contain radioactive for the first few thousand years. This has led to a design that uses barriers around the wastes that are designed to remain intact for very long timescales. In Finland (as in Sweden) wastes are to be encased in copper canisters which will be protected by a bentonite clay surround. In the United Kingdom, regulations place a quantitative requirement that the risks to an individual should not exceed 1 in a million at any point in the future. Since no man-made material can be guaranteed for that length of time, greater emphasis is placed on selecting a natural environment around the waste that will limit the chances of releases to the accessible environment.

In the United Kingdom, regulations under the Radioactive Waste Management Act [EA, 1997] would govern the final authorisation of a facility to dispose of radioactive wastes. Hence, these regulations have governed all past approaches to radioactive waste management in the UK. However, in the early stages of development, proposals to research particular sites is generally legislated under the Town and Country Planning act. In consequence, the environmental regulator has had no official role in option proposals and planning. As pointed out by the House of Lords [HoL, 1999] and others, the regulatory environment for the development of proposals has been fragmented.

6.5.5 Trust in the nuclear waste management system

In Sweden, there seems to be a measure of trust that the nuclear waste management system has an appropriate level of in-built checks and balances. Both the regulator(s) Ski/SSi and the government advisory group KASAM are active within the nuclear debate. Early siting studies in the north of Sweden, undertaken by SKB, the waste disposal agency, met with strong local opposition. At that time, Ski was not actively involved in monitoring the siting activities of SKB and so there was no obvious "public champion"- a phrase that has been used about Ski during later siting studies. Although Ski work closely with SKB to develop appropriate processes for moving the debate forward, they are careful to maintain distance from SKB [Andersson et al, 1998] – even to the point of setting up public hearings independent of SKB during the recent siting process in Sweden. In Sweden they also have the special adviser on radioactive waste management issues who provides a further source of independent expertise - expertise that is made available to the local communities (municipalities) who may be considered for hosting radioactive waste.

Culture is an important factor here. In Finland, the culture is much more consensual than in the UK, and hence there is less tendency to challenge. In Sweden, the long history of transparent government similarly tends towards a less hostile decision-making environment.

Trust in the United Kingdom is generally low following the Windscale fire, Chernobyl and more recent allegations of inappropriate behaviour on behalf of BNFL. The close association of the nuclear industry with the UK's nuclear weapons programme and a legacy of low levels of information about nuclear power does not helping this regard. More recently, the economic failure of British Energy has not helped engender an environment where the major organisations identified with radioactive wastes are trusted.

6.5.6 Involvement of local communities

Once again, looking to Sweden and Finland there are strong indications that a close and early involvement of local communities can enhance progress towards a common understanding of issues and hence an improved knowledge base for decisions. In Sweden, the local municipal councillors are allocated funds – to be used at the Municipality's discretion for commissioning independent studies of any sort. The Municipality can (and does) choose to use some of the fund to support local opposition groups. In Finland, arguably further down the decision-making process than other European countries, the radioactive waste management agency POSIVA Oy has relocated its offices to the community of Olkiluoto. Posiva have just received a decision-in-principle to construct a facility at Olkiluoto subject to a successful ten year programme of underground research. This follows an extensive and very transparent programme of site investigation, selection and the production of a detailed Environmental Impact Assessment for the Olkiluoto site. By moving base to Olkiluoto, Posiva are publicly declaring support for the local community in a very practical manner – one that makes a big difference in sparsely populated rural Finand.

By contrast, the local communities of New Mexico (which hosts the Waste Incapsulation Pilot Plant for military wastes) and Nevada (which plays hosts to an extensive site investigation programme investigating the suitability of Yucca Mountain as a host for high level wastes are very antagonistic towards the authorities developing and operating the facilities at these sites – even to the point that Nevada is bringing a court case against President Bush for endorsing a recommendation that investigations at Yucca Mountain proceed. In both cases, the sites were chosen for their strategic locations, coupled with suitable geology.

Until recently, local communities have not been involved in any form of site selection process in the United Kingdom. Generally they have only been consulted by the authorities and institutions once a site has been identified. There has been little national debate about the siting of radioactive waste management facilities and the conditions and provisions that should go with it. In the UK, the distinction between planning gain and bribery is a very fine line and hence organisations have shied away from any open discussion of what is owed to a community who takes on the burden of a national facility. Although public relations programmes have been considerable, they have been typified by information provision and one-way communication.

6.5.7 Relationship between legislation and decision-making

There needs to be an obvious link between the decision-making processes for nuclear waste and any legislation governing its long-term management. In Finland, this has recently been quite successfully achieved by adopting an Environmental Impact Assessment approach to siting decisions, and then adopting a decision-in–principle approach to proceeding with detailed investigations at the preferred site. This decision-in-principle is made by the Finnish Government against legislation covering all nuclear activities and then ratified by Parliament.

As evidenced by the discussion of regulations given above, these relationships are very unclear in the United Kingdom.

6.5.8 The importance of siting

The process of siting appears to be crucial to the management of radioactive wastes. It is the point at which a national (and dispersed) problem, becomes a local (and concentrated) issue with direct and tangible impacts on the local population. The manner in which decisions about what is owed to the local community for taking on board a national problem is critical. It is also nation-dependent.

In France, dependency on nuclear power production is high, as are the planning benefits provided by the Government for communities hosting a nuclear facility. In Sweden, discussions with potential host communities have been extensive and ongoing. This has led to a considerable degree of engagement with nuclear waste issue on the part of the local municipalities – typified by the "Oskarshamn model" of decision-making [Andresson et al, 1999]. The Oskarshamn model is also interesting since it suggests that the amount of control on the decision-making process devolved to the local community has a significant impact on their willingness to engage.

Nevertheless, it is important not to confuse engagement in decision-making with acceptance. In Canada, an EIA approach to siting was adopted which ended in a rejection of proposals to site a facility at Deep River.

In the United Kingdom, siting has been undertaken "behind closed doors" and only a very small number of people know the names of sites which have been on shortlists in the past. Indeed, the selection of a site has been a matter for the implementing agency alone, with no overseeing framework and little in the form of checks and balances.

6.5.9 Sites before options or options before sites?

A key issue appears to be how far a technical option for the long-term management of radioactive wastes should be worked up before identifying a site. In Belgium, for low level waste disposal, the concept of partnerships with the local community has been developed and implemented. In this model, the local community is involved in developing a technically feasible option for the particular locality. In this way, the local community can be engaged with the technical work before it has developed too far, and site specific criteria can be adopted in the technical design. This way of working is one response to the fact that the identification of a site for the management of radioactive wastes is one of the most difficult and critical steps in the process and that the technical work can follow. It is a far cry from developing a national policy for waste management and then finding somewhere to implement that policy.

In the UK, the option for radioactive waste management has been inscribed in policy before any siting work has been undertaken. Whilst this makes sense in terms of being able to identify option-specific criteria for siting, it can reduce the ability of development proposals to respond to the concerns of the local community.

6.5.10 Demonstration of feasibility

Many countries identify demonstration of feasibility as a central part of building public confidence in a proposed management option. Hence there are a number of underground research facilities that combine meeting scientific research needs with demonstrating technology. The Aspo facility in Sweden, Grimsel in Switzerland, Mont Teri and Mol in Belgium are visited by both researchers and interested decision-makers and opinion-formers from all over Europe.

There has been no significant attempt to demonstrate feasibility in the UK although influential stakeholders are sometimes taken to overseas facilities.

6.5.11 Conclusions

Those countries which have had most success in progressing a radioactive waste management solution have sought to apply legitimate procedures to policy development rather than legitimising procedures for consultation purposes. Those that have recognised the importance of 'social values' are now beginning to shift dialogue about radioactive waste management away from discussion about what *should* (not) have been done in the past, to a more constructive debate about what *could* happen in the future.

As with many other environmental problems for which there is little past precedent and long term future risks (hazards associated with adopting genetically modified organisms, human health hazards from food processing), the problems seem to turn on the clarity, transparency and inclusiveness of decision making processes. Hence, developing and implementing inclusive and transparent decision-making processes is now a major goal of those organisations most closely associated with radioactive waste management over the past few years.

6.6 The move towards step-wise decision making

In pursuit of transparency and inclusion, there is currently a major change occurring in the way that issues associated with radioactive wastes are being discussed and debated. Those organisations most affected are radically changing their approach and the relationships between those organisations are being redefined.

For example, since the late 1990's, Nirex has been working to re-establish itself as a credible and knowledgeable organisation, accountable to the public for the long-term management of radioactive materials. As well as the continued retention of its technical expertise and competence, Nirex has identified a number of practical ways for instilling a culture within the organisation that will enable it to operate in the inclusive and democratic climate of participatory decision-making. This has a required some radical rethinking, both by the organisation and by the individuals working within the organisation. Nirex is actively pursuing independence from the Nuclear Industry so that it can provide expertise on long-term waste management that is not linked to the economics of nuclear power production.

Similarly, the work of DEFRA [DEFRA, 2001] and the DTI [HM Government, 2002], and the response to DEFRAs consultation document [DEFRA, 2002b] reflect ideas about new and radical ways of working to develop solutions for radioactive waste management. Most of these ideas are based on the notion of a stepwise and inclusive process of decision-making. Such a process should enable the issues and concerns of society to be articulated early, and confidence in each step to be generated before a subsequent step is taken.

Figure 15 reproduces the Nirex view of what such a stepwise process should look like [Atherton and Poole, 2002]. Clearly, having such a long personal association with Nirex makes it impossible for me to comment objectively on the value of the process.

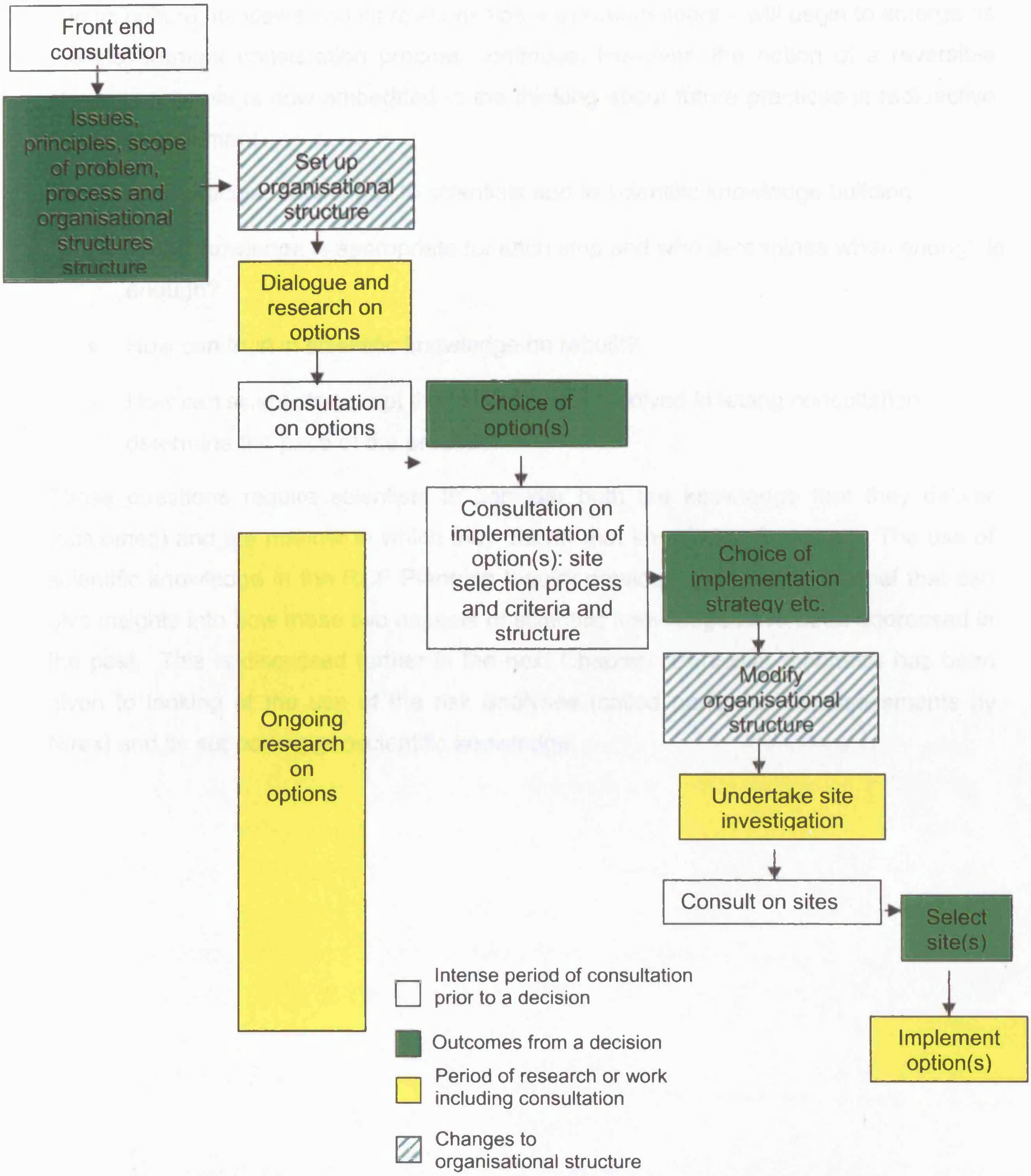
However, the intention has been to develop a process that provides the opportunity for a number of the lessons learned from history to be addressed. Table 9 shows my view of how the key factors identified above could be addressed within the framework of a stepwise process.

Table 9: How could a stepwise process help address some of the issues identified from international and UK history?

Sustainable development	Provides the opportunity to debate principles and ethics early on, prior to identification of options
Regulations	Front end consultation could help identify what an integrated regulatory framework would look like and how the organisations involved would relate to each other and to legislation
Trust in nuclear waste management system	Provides time and opportunity for relationships to develop between stakeholders and the public
Involvement of local communities	A range of opportunities for local communities to express views, both before and after sites are identified
Relationship between decision-making and legislation	Can be discussed as part of a front end consultation
The importance of siting	Enables a national debate about siting, and about what is owed to a local community should they accept a national burden "on their doorstep"
Sites before options or options before sites	Early involvement of local communities extends some level of influence over options

Whilst Table 9 highlights the manner in which a stepwise process can theoretically encourage transparency and inclusion, there are a number of practical issues that require consideration before a truly stepwise process can be delivered for a specific project.

Figure 15: The Nirex Stepwise Process.



6.7 Concluding Remarks

In a particular context, participatory decision-making has very real and practical implications on the work of organisations involved in contemporary environmental issues and on the work of individuals within those organisations. In the radioactive waste management arena, there are many lessons to be learned from history and from other countries. The effectiveness of the changes that Nirex has made over the last five years – in its culture, its views and its relationships with stakeholders – will begin to emerge as the Government consultation process continues. However, the notion of a reversible stepwise process is now embedded in the thinking about future practices in radioactive waste management.

This brings particular challenges to scientists and to scientific knowledge building:

- What knowledge is appropriate for each step and who determines when enough is enough?
- How can trust in scientific knowledge be rebuilt?
- How can scientists accept the loss of power involved in letting consultation determine the pace of the process?

These questions require scientists to consider both the knowledge that they deliver (outcomes) and the manner in which they deliver that knowledge (process). The use of scientific knowledge in the RCF Planning Inquiry provides case study material that can give insights into how these two aspects of scientific knowledge have been addressed in the past. This is discussed further in the next Chapter. Particular emphasis has been given to looking at the use of the risk analyses (called performance assessments by Nirex) and its supporting geoscientific knowledge.

7 THE USE OF SCIENTIFIC KNOWLEDGE IN MAKING DECISIONS ABOUT THE DEEP DISPOSAL OF THE UK'S RADIOACTIVE WASTE.

At a Public Inquiry into proposals to further investigate the Sellafield site for deep disposal, the available scientific knowledge about a repository at the site was actively explored. The manner in which information about long term risks was put to the Inquiry and subsequently explored at the Inquiry is outlined below. The representation below reflects my personal experience and it must be stated that I had a high level of ownership of much of the geoscientific information under discussion. Hence this account will inevitably reflect my own values and my own belief in the benefits of pursuing deep geological disposal as a management solution for the problem of radioactive wastes. Nevertheless, whatever the perspective, the RCF Inquiry experience can help to explore the nature of dialogue about risks and radioactive waste management that can be expected in the future. Hence we can use it to guide ideas about building a more participatory knowledge platform for future decisions.

7.1 Background

7.1.1 Context

In the nineties, Nirex proposed to construct an underground "Rock Characterisation Facility" (RCF) in order to carry out further research into the suitability of a site near Sellafield (Longlands Farm) to host a deep waste repository. The RCF Public Inquiry, was an inquiry into whether or not Nirex should be allowed to develop the RCF. Prior to the inquiry, Nirex had applied to Cumbria County Council for planning permission for the RCF, an application that was rejected. Nirex appealed against this decision, which led to the Secretary of State to convene a planning inquiry under the Town and Country Planning Act. Following the planning inquiry, the then Secretary of State for the Environment upheld the refusal of planning permission, and investigations into the suitability of the Longlands farm site were effectively terminated.

The refusal of planning permission for the RCF had a major affect on the scientific and research communities involved in radioactive waste management. In particular, the earth science community was hard hit, having been intimately involved in the Sellafield investigation programme - one of the largest site investigation programmes to be undertaken within the United Kingdom and representing a commitment of some £200 million. The manner in which the results of this research programme were presented to the RCF Public Inquiry is the subject of this chapter.

There is almost unanimous agreement that history teaches us the importance of following a transparent and inclusive programme of decision-making. This was discussed earlier in Chapter 6. The question being addressed in this chapter is what we can learn from past experience in terms of the use of scientific knowledge in making decisions where the decision stakes are high. To explore this, information about the RCF Inquiry has been analysed, primarily using the sources presented in the footnote[a].

7.1.2 The Nirex proposals at the time of the RCF Public Inquiry

The Sellafield repository concept was based on the idea of deep geological disposal, and multibarrier containment. This concept, in which natural and engineered barriers work together to contain radioactive materials and limit radionuclide migration (Figure16) is discussed extensively elsewhere [Savage, 1994; NEA, 1999a; Nirex, 2001a; Bailey and Littleboy, 2000]. As discussed in Chapter 5, the idea is that the performance if the repository does not rely on the performance of a single barrier.

The Sellafield proposal was based on four phases of operation: waste packaging; transportation to the repository; emplacement in the repository; backfilling; closure. The Sellafield proposals were therefore different to more recent proposals embedded in the Nirex phased disposal concept which includes an explicit phase of monitoring and retrievability. These ideas formed the basis for a detailed design for an underground repository.

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[a] The report of the Inquiry submitted by the Planning Inspector to the then Secretary of State on 21 November 1996. This provides a comprehensive record of the discussion at the Inquiry and the Inspector's conclusions, recorded in the Inspector's words;

Haszeldine R.S and Smythe D.K (Eds). *Radioactive Waste Disposal at Sellafield: site selection, geological and engineering problems.* University of Glasgow publication 1996a; This report draws together various Proofs of Evidence from organisations (Cumbria County Council, Friends of the Earth and Greenpeace) opposed to Nirex' proposals;

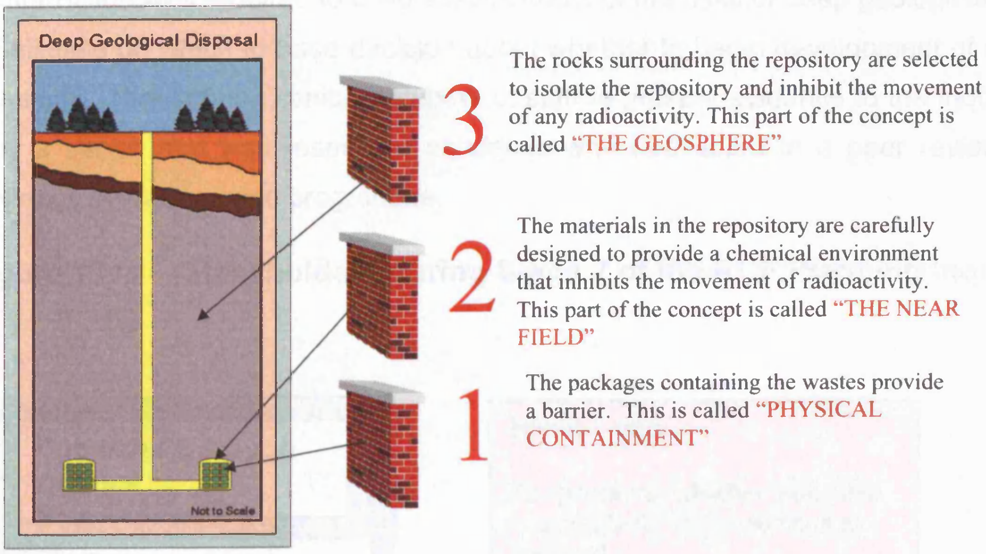
Nirex Proofs of Evidence which are available from Nirex via its website www.nirex.co.uk;

A report from the Parliamentary Office of Science and Technology *Radioactive Waste – Where Next.* This report was publlished in 1997 and provides an independent analysis of the Sellafield project, including the matters discussed at the RCF Public Inquiry.

Haszeldine R.S and Smythe,D.K *Why was Sellafield rejected as a disposal site for radioactive waste?* In Geoscientist, vol 7,No 7,pp 18 – 20a This presents an interpretation of the Inspector's report from the point of view of those involved in opposing Nirex' proposals at the Inquiry;

Observations and conclusions from attending the Inquiry during the examination of evidence about the site investigations and safety analysis [Personal experience].

Figure 16: Deep geological disposal, as considered at the Sellafield site



7.1.3 Stakes at the RCF Inquiry

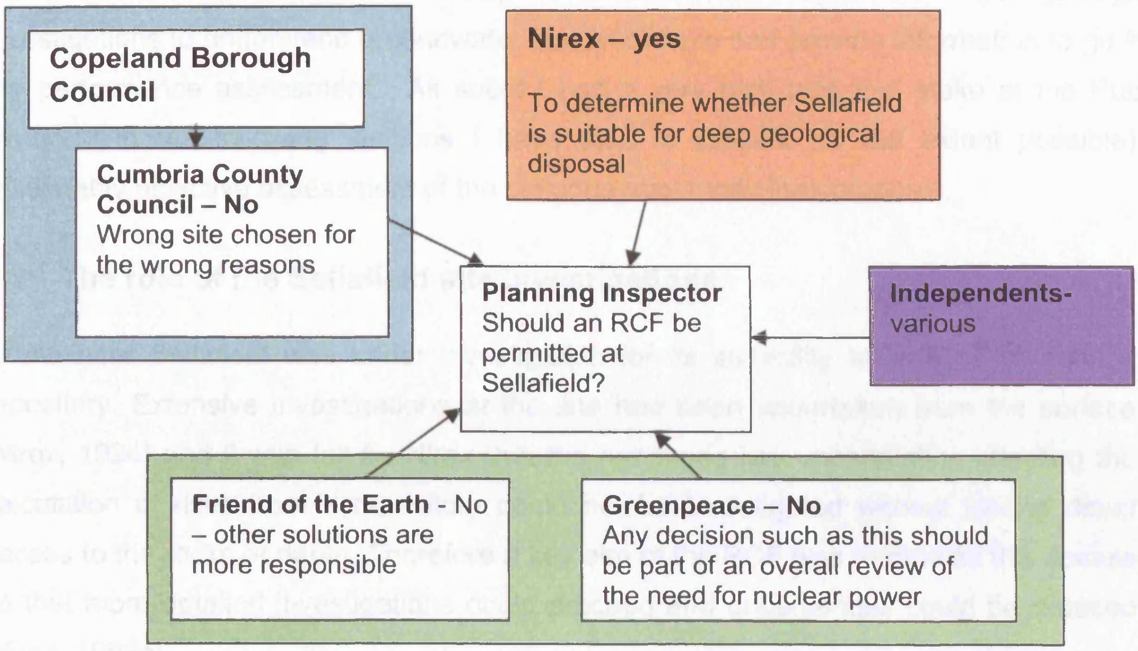
A number of stakeholders contributed evidence to Stage 2 of the RCF Public Inquiry. The procedure was overseen by a Senior Planning Inspector, who was supported by another planning inspector and by a Scientific Advisor. The Inspector chose to undertake the Inquiry in two stages. The first stage considered the typical planning issues associated with the project. The second stage focussed on the level of scientific understanding that Nirex had at the time, and the implications of the uncertainty remaining in Nirex's understanding of the long-term risks associated with deep geological disposal. This thesis is solely concerned with the second stage and the debate that ensued about the scientific knowledge available to make the RCF decision.

Below, an outline of the stakes present at the second stage of the Inquiry is given. This is primarily drawn from personal experience and will inevitably be biased by my own stake in the outcome of the Inquiry. However, I have tried to link the stakes discussed below back to the Proof's of Evidence provided to the Inquiry and the unfolding of the procedure. Figure 17 provides a schematic illustration.

The Inspector's responsibility was to make recommendations to the Secretary of State for the Environment about whether Nirex should be permitted to build a Rock Characterisation Facility near Sellafield.

Nirex was requesting approval to build the RCF in order to provide scientific information that was not obtainable from surface-based information. They (we) believed that this information was required to build assessments of the risks of deep geological disposal near Sellafield on which to base decision about whether to begin development of a repository at the site. Nirex chose senior members of staff to present evidence to the Inquiry, supported by a senior and well respected academic who had acted in a peer review capacity on Nirex's overall science programme.

Figure 17: Stakeholders during Stage 2 of the RCF Planning Inquiry



Cumbria County Council were the regional council to whom the application to construct the RCF had previously been made. They had refused permission, and presented their reasons for this at the RCF Inquiry. In this refusal, they were supported by Copeland Borough Council, the local council in whose borough the investigations were happening. Cumbria County Council appointed Environmental Management Resources (ERM) to support them in presenting evidence to the Inquiry. ERM used academic experts for this.

The national bodies of Friends of the Earth and Greenpeace also provided evidence to the Inquiry. Both organisations were opposed to the RCF development but for slightly different reasons. They pooled resources, and marshalled a range of academic experts to give evidence on their behalf at the Inquiry regarding the scientific advisability of various aspects of the Nirex proposals. The evidence of these experts has been collated into a permanent record (Hazeldine and Smythe, 1998).

There were also a number of independent stakeholders who presented evidence to the Inquiry regarding specific aspects of the science of radioactive waste management and deep geological disposal.

For all stakeholders, a key topic for debate was the level of geoscientific understanding of the site and the way uncertainty in this understanding could affect potential long term consequences as a result of a deep repository. Hence a large number of geoscientific expert evidence was presented to the Inquiry, and a key topic for debate was how geoscientific understanding and uncertainty were represented in assessments of long term performance.

My role within Nirex had been to develop and coordinate the programme of hydrogeological investigations to understand groundwater flow at the site and provide information to go into the performance assessment. As such, I had a very high personal stake at the Public Inquiry. In the following sections I have tried to present (to the extent possible) a reasonably objective assessment of the dialogue about the Nirex proposal.

7.2 The role of the Sellafield site investigations

A site near Sellafield was under investigation for its suitability as a host for such a repository. Extensive investigations at the site had been undertaken from the surface [Nirex, 1994] and it was felt by Nirex that the remaining key uncertainties affecting the calculation of risks from a repository could not be investigated without having direct access to the rocks at depth. Therefore a key aim of the RCF was to provide this access so that more detailed investigations could proceed and uncertainties could be reduced [Nirex, 1995a].

One of the main sources of actual risk is if radionuclides within the repository come into contact with groundwater, become entrained in the groundwater and subsequently move through the rock mass. This is called the "groundwater pathway" and is central to most past risk analyses undertaken by Nirex, and all the post-closure risk analyses of the Sellafield site [Bailey and Littleboy, 2000].

Therefore, a focus of the investigations was on understanding and modelling groundwater flow at Sellafield so that this information could be used to calculate how the geosphere would behave and the chance and extent of radionuclide migration in groundwater back to the biosphere. Whilst there are other important elements to site investigations for a deep repository (geotechnical stability, gas, likelihood of natural hazards and disruptive events, factors that might result in human intrusion into the rock mass) this thesis focusses on understanding groundwater flow. However, this does not mean that the discussion is a purely hydrogeological one. Developing a credible understanding of groundwater flow is a truly multidisciplinary exercise that requires the close integration of geological, hydrogeological geochemical and hydrochemical studies [Nirex, 1998a].

Generally speaking, the performance assessment assumes that it is necessary to understand a range of factors in order to understand groundwater flow. The Sellafield investigations considered issues such as:

- What are the rock types that occur at the site?
- How do they relate to each other?
- What properties do they have, in particular properties that will affect the movement of groundwater (the nature of void spaces through which groundwater might move, the chemistry and physical properties of rock surfaces with which groundwater might come into contact)
- What processes have affected the rock mass in the past?
- What are the current driving forces for groundwater movement?
- What is the evidence for groundwater movement now and in the past (chemical evidence, mineralogy, measurements)?

Answers to these questions, developed through a linked programme of data acquisition, interpretation and modelling provided one of the foundations for analysing the potential risks arising from a radioactive waste repository [Nirex, 1998a, Nirex, 1995b]·

In order to analyse these risks, the knowledge gained through the Sellafield site investigations was captured by conceptual modelling [Nirex, 1998a, Nirex, 1995b]. Conceptual models of groundwater flow were therefore the vehicle for building the geological and hydrogeological understanding of the site into the risk analysis process [Littleboy et al, 1998]· These analyses were called "performance assessments" by Nirex, and were a means of assessing whether the site was likely to meet the risk target laid down in legislation [Nirex, 1995a]

7.2.1 Performance assessments[b] of the groundwater flow path at Sellafield

In the nineties, the overall objective of the science programme undertaken by Nirex was to develop a progressively more confident analysis of the risks associated with a repository located at the Longlands Farm site near Sellafield. As part of this programme,

[b] In Nirex at the time, the process of analysing the long term risks from the repository was (and still is) called performance assessment.

performance assessments were periodically undertaken to determine whether or not the site continued to show promise of meeting the regulatory risk target [EA, 1997]. Assessments of risks arising from the operations of a repository and from the transport of wastes to the repository were (and still are) also undertaken. However, the long-term risks were (and still are) evaluated for a period following the closure of the repository extending for at least one million years into the future – post-closure performance. A key performance requirement was that the radiological risk to individuals of cancer or a serious hereditary defect should be less than a value of 10^{-6} per year [DETR, 2000].

In general terms, post-closure performance assessment evaluates the ability of a repository to protect people and the environment in the very long term after closure. It represents the repository system and includes features, events and processes which may affect the repository system over long times (typically of order 1 million years) into the future. Mathematical models are used to represent these features, events and processes and to estimate radiological risk. The modelling process can be complex and may use probabilistic mathematical modelling techniques. In consequence, post-closure performance assessment reports are commonly written with a highly technical audience (such as the regulators) in mind.

As the project developed, Nirex sought to maintain a contemporary view on the continued suitability of the site. Therefore successive performance assessments were undertaken as new information became available from research programmes. The series of performance assessments of the Sellafield site are given in Table 10. Each assessment built on the experience and insights obtained from the previous assessments and incorporated new data and understanding emerging from research programmes.

Table 10: Nirex performance assessments of a repository at the Sellafield site

Year	Assessment	Reported in…
1987/88	CASCADE (or stage 1) (DSAT A301-A304)	
1989	PERA/PSR	Nirex Report 71
1991-92	Stage 2 assessment	Nirex report 337
1993	Stage 2 update assessment	
1994	Nirex assessment 94	
1995	Nirex 95	Nirex Science Report S/95/012
1996	Nirex assessment 96	
1997	Nirex 97	Nirex Science Report S/97/012

As the site investigations at Sellafield progressed, the performance assessments became increasingly related to the geological and hydrogeological knowledge of the Sellafield site. The information sources used in successive performance assessments are shown in Table 11 and give a sense of the progressive nature of the scientific research and analysis of the site.

Nirex 95: A preliminary assessment of the groundwater pathway at Sellafield [Nirex, 1995b] was the document submitted to the RCF Inquiry. The RCF Inquiry was ongoing whilst the information used in support of Nirex 97 [Nirex, 1997] was being acquired and analysed.

Table 11: Relationship of assessments to data.

Assessment report	Additional Site Characterisation data
PERA/PSR(1989)	Desk study comparing different environments
Internal report (1991)	Regional mapping and geophysics 3 boreholes Hydrology Desk Studies
Nirex Report 525	More geophysics 2 more boreholes Surface hydrology studies
Nirex 95 (Nirex Science report S/95/012)	7 more boreholes Long term hydraulic monitoring Selected pump testing Fracture Mapping
Nirex 97 (Nirex Science Report S/97/012)	8 more boreholes Quaternary studies Stream and spring gauging Long term hydraulic monitoring Various hydraulic interference tests

7.2.2 The representation of earth science in the Sellafield assessments

The Sellafield performance assessments integrated multiple lines of evidence – many of them geoscientific – and a great many sources of uncertainty into an assessment model. Experts involved in the site investigations were involved in two key activities which underpinned the assessment models:

- A number of linked models were established, for example representing different parts of the repository system or different scales at which radionuclide migration processes might operate. These linked models underpinned the main risk model by taking data and understanding and producing output that was used to parameterise the risk model.

- Where data were sparse and uncertainty high, a process called data elicitation was used to supplement measurement. Data elicitation is a process by which expert judgement is used to derive information to supplement measurements.

These activities had a particularly high profile for groundwater flow information where most of the input parameters to the risk model were "derived parameters". Figure 18 indicates the hierarchy of models which actually underpinned the risk model used for assessments of the groundwater pathway at Sellafield and Figure 19 indicates the process used to develop input parameters for the calculation of risk.

Figure 18: Groundwater model hierarchy

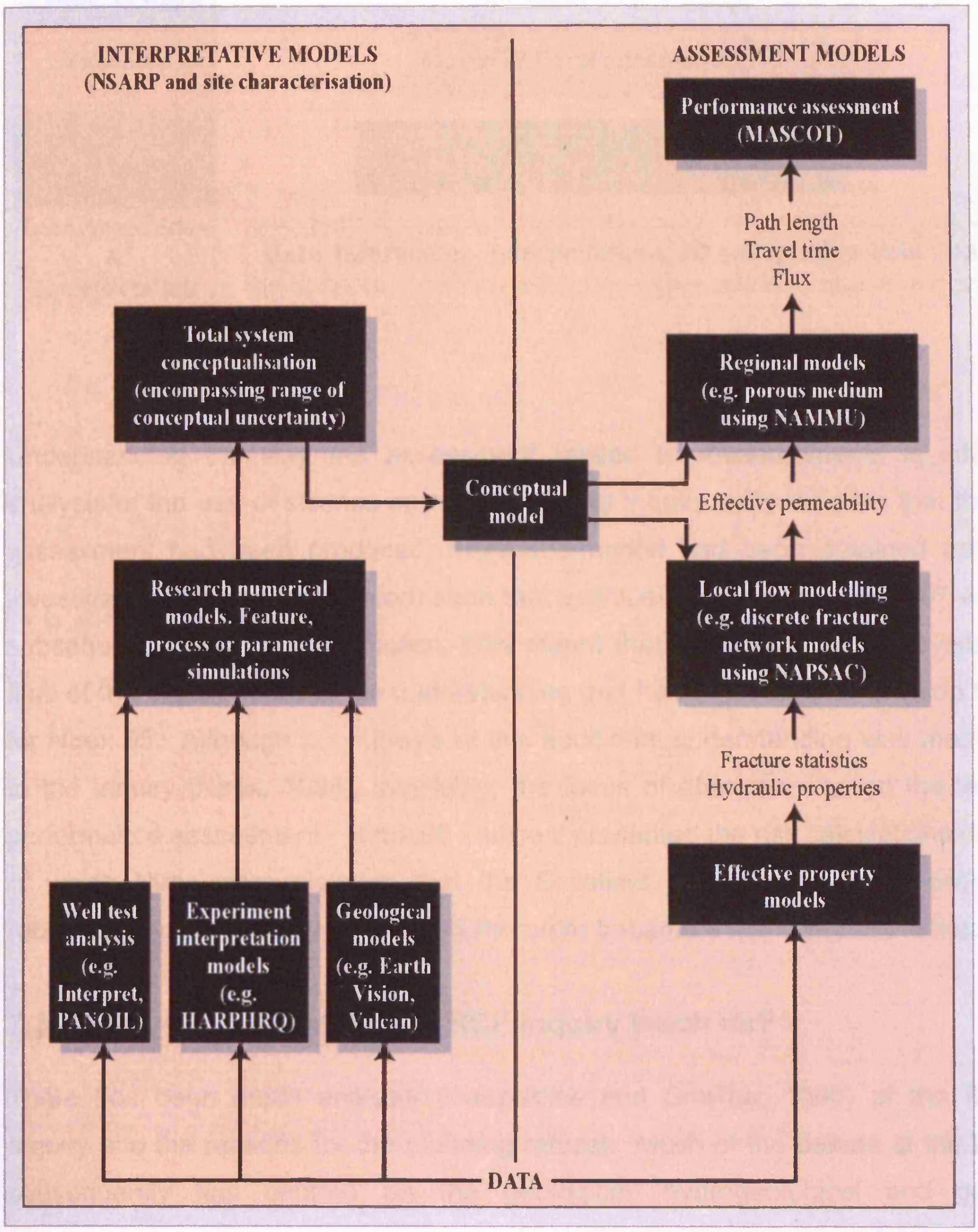
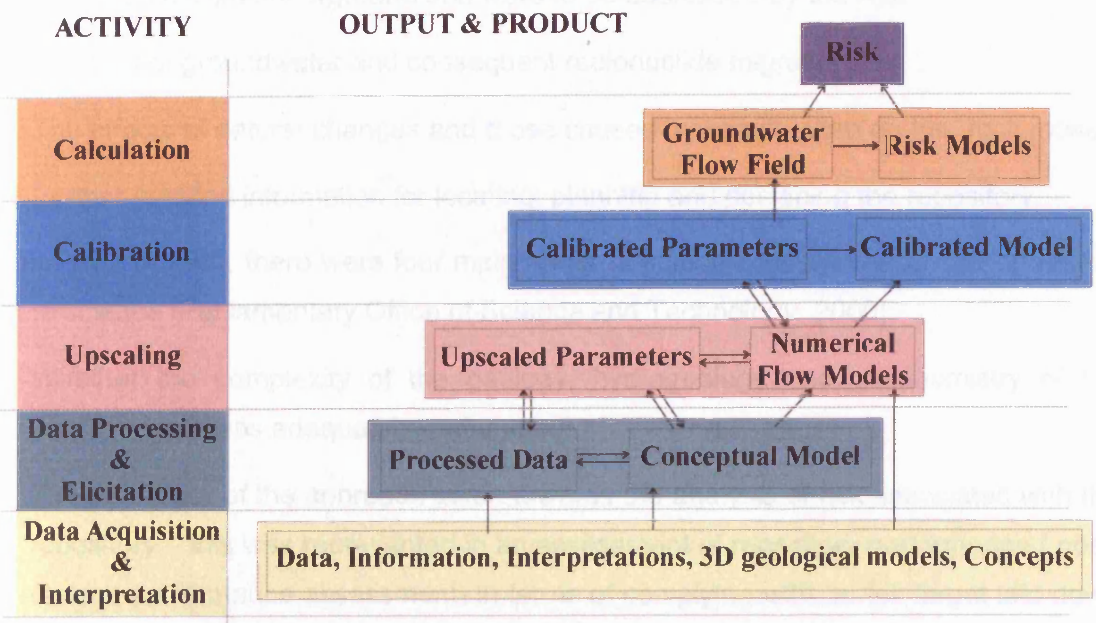


Figure 19: Calculating risks from the groundwater pathway



Understanding the way the assessment related to measurements is critical to an analysis of the use of science in the RCF Public Inquiry. By the time that the Nirex 95 assessment had been produced, more information had been obtained from the site investigation programme. – information that eventually fed into the Nirex 97 assessment subsequent to the Inquiry process. This meant that the understanding available at the time of the Inquiry was not the understanding that had been used to develop the models for Nirex 95. Although a synthesis of this additional understanding was made available to the Inquiry [Nirex, 1996], inevitably, the focus of attention was on the then current performance assessment - Nirex 95 - since it presented the risk calculations on the basis of which Nirex were claiming that the Sellafield site "showed good promise". The robustness and credibility of Nirex 95 therefore became a key issue at the Inquiry.

7.3 Analysis - what does the RCF Inquiry teach us?

There has been much analysis (Haszeldine and Smythe, 1996) of the RCF Public Inquiry and the reasons for the planning refusal. Much of the debate at the Inquiry and subsequently has centred on the geological, hydrogeological and geochemical understanding of the site (gained from the prior surface-based investigations) and whether or not it was sufficient to support a decision to go underground for further work. By definition, Nirex considered that the understanding was adequate to warrant further investigations. In its "Statement of Case [Nirex, 1995a]" Nirex identified three key areas of continued uncertainty about the suitability of the Longlands farm site that could *only* be investigated from underground and were to be addressed by the RCF:

- The flow of groundwater and consequent radionuclide migration;
- The effects of natural changes and those caused by construction on the rock mass;
- Further detailed information for locating, planning and designing the repository.

At the Inquiry itself, there were four main areas of scientific debate about the adequacy of the science [Parliamentary Office of Science and Technology, 2000]:

- Whether the complexity of the geology, hydrogeology and geochemistry of the proposed site was adequately understood;
- The adequacy of the approach taken towards the analysis of risk associated with the repository – this was represented in an assessment of repository performance (post-closure performance assessment) in terms of complying with a risk target laid down in regulatory guidance.
- The validity of the mathematical models used;
- The adequacy of the RCF proposals to resolve the identified uncertainties.

In addition, evidence was presented regarding the site selection process used by Nirex to justify the selection of the Longlands Farm site for detailed investigations, and also on land-use and planning matters.

There was much that came out of the inquiry and the debate surrounding the Inquiry that challenged the use of geological and hydrogeological information within the decisions made by Nirex. Specifically, it has been claimed that [Haszeldine and Smythe, 1996]:

- the geological and hydrogeological information indicated that the Sellafield site would not meet the safety standards laid down in regulations; and
- assessments of the suitability of the site did not accurately reflect those geological and hydrogeological research findings.

These claims challenge the manner in which Nirex linked together the site investigation work and its representation in the Nirex 95 performance assessment. As such, they go right to the heart of how scientific knowledge was being translated into calculations of risk and used in decision-making. A key question is whether stakeholders without vested interests or preconceived views were able to make sense of the arguments and develop their own view about the level of knowledge that existed, what that knowledge suggested and whether/what further knowledge was required. The experience of the RCF Public Inquiry suggests a number of important influences on this.

7.3.1 Developing a shared view about the scope of the dialogue

The Planning Inspector for the Public Inquiry into the Rock Characterisation Facility (RCF) at Sellafield states in his Inquiry report [McDonald, 1997] that one of the reasons for recommending the refusal of planning permission was the (lack of) maturity of the science presented at the Inquiry. And yet Nirex, an organisation with considerable expertise and experience had clearly considered that Sellafield "showed good promise" on the basis of its scientific knowledge and was willing to commit significant amounts of resource and expenditure to pursuing investigations from underground. This difference of opinion about the adequacy of the science bears further analysis.

At the RCF Inquiry, Nirex presented material they considered adequate to support an application for further research (the RCF) [Nirex, 1996]. From their point of view, the decision to investigate Sellafield had already been taken, but the level of knowledge was not yet such as to warrant an application to develop a repository. However, the link between site selection, the RCF and a potential subsequent repository was such that the Inquiry discussed both the process of selecting Sellafield in the first place, and also the suitability of the site for disposal in some depth. Both these issues are cited in the Inspectors report as reasons for recommending refusal of the RCF. So on face value, it appears that Nirex 's understanding of the scope of the Inquiry was much more limited than that which the Inspector chose to allow. Earlier chapters have already highlighted the importance of ensuring that those involved in the dialogue process are clear about what is being discussed, and that the process by which controversial projects are developed is transparent. For science to be used effectively in decision making, the decision being made must be clear to all parties.

7.3.2 The importance of the regulator as an expert reviewer/witness

In the United Kingdom, emissions arising from the disposal of radioactive wastes are regulated by the Environment Agency of England and Wales (EA) or by the Scottish Environmental Protection Agency or the Northern Ireland Department of the Environment. The operation of nuclear licensed site which a waste repository would be) is regulated under the Health and Safety Executive (HSE) by the Nuclear Installations Inspectorate (NII). For the purposes of developing ideas about the suitability of a site near Sellafield to host a deep geological repository, the Environment Agency was therefore a key player.

In the years leading up to the RCF Public Inquiry, Nirex made many important decisions, sometimes by advising the Government and sometimes as part of developing its own programme of work. Examples of such decision are:

- The abandonment of shallow site investigations;
- The decisions to explore Sellafield and Dounreay;
- The decision to investigate Sellafield as a "preferred site";
- The decision to apply for planning permission to go underground by constructing a rock characterisation facility.

The common factor in all these decisions is that they were essentially made using a decide-announce defend" approach. For the majority of stakeholders there was very little clarity about the information going into these decisions, the basis on which they were made, the individuals or groups who were involved in the decision making process and their motivations. The criticism is that Nirex used a closed process whose pace was driven by pre-determined deadlines and not by the needs of stakeholders or orderly scientific research [Nirex, 2001b].

For all the decisions mentioned above, there was no requirement in legislation to involve the Environment Agency, since at no stage was an application being made for a disposal facility. The regulator was only minimally involved in evaluating any of the performance assessments which informed the decisions, and, although the regulator appeared at the Inquiry, it was not to give evidence in any formal capacity. So although Nirex approached the RCF Public Inquiry assuming an actor-based (decide-announce-defend) form of decision making, one of the key actors identified in Figure 4 had no formal role in the process.

Speculation about the direction of discussions at the Inquiry had the regulator been present is not useful. However, as discussed earlier, the performance assessment methods adopted by Nirex were driven by a need to consider levels of consistency with a regulatory target. The process involved in achieving this is complex – as indicated by the model hierarchy and calculation processes shown in Figures 13 and 14. Enabling effective discussion and critical comment on these complex processes is difficult to achieve in an adversarial situation, in particular when no independent source of expertise is available to impartial stakeholders.

Although there was no obvious expert regulation on the work undertaken by Nirex, there had been an independent review of its work undertaken by a Royal Society Study Group in 1995 [Royal Society, 1994]. Such "independent" work enables stakeholders to appreciate the breadth of thought and opinion being applied to the decision. It can be particularly important where a high level of science and technology is being applied to a project.

Since the RCF Inquiry, reports seeking to move the debate about radioactive waste management forwards (from the House of Lords Select Committee on Science and Technology [HoL, 1999] and within Government [DEFRA, 2001]) anticipate the need for body to oversee implementation of the process. A key issue to address as policy formulation proceeds will be the relationship between this overseeing body, the regulator(s) and the developer.

7.3.3 The significance of the siting decision

Whatever options are chosen for long-term waste management, a site selection process will be required. At this point, the national need (to manage radioactive wastes safely) becomes a local problem ("not in my back yard"). Site selection needs to take account of the scientific and technical criteria required to develop "safe" options. The rationale behind the decision to undertake scientific research at Sellafield became a major subject for debate at the RCF Inquiry, even though it was a decision taken many years previously.

At the RCF Inquiry, Cumbria County Council gave evidence to the effect that the Sellafield site was "the wrong site chosen for the wrong reasons" [Cumbria County Council, 1995]. On this basis, the Inspector took evidence about the site selection process used to identify Sellafield as a preferred site [Nirex, 1996]. Nirex had not anticipated that the siting decisions would be up for discussion since, in their view, they had met all the necessary criteria for the siting decision several years earlier. However, no information about the siting decision had been published and it was essentially made "behind closed doors" using a limited group of participants.

There is a large body of research that identifies that a technical approach to siting is not sufficient on its own to justify the selection of a site. Social and ethical issues become essential points for consideration, for example:

- what is an acceptable burden to place on a community?
- what rights does the community have? and
- what constitutes sufficient recompensation?

Such consideration can only be legitimate if it is done in consultation with stakeholders. Hence the siting issue acts as a very tangible focus for scientific and technical research, social and behavioural research and consultation.

In the event, Nirex did provide evidence to the Public Inquiry about the multi-attribute-decision analysis process used to identify the Sellafield site (amongst others). The decision to focus research on Sellafield was made by Nirex, and endorsed by Government on the basis that many of the wastes already exist near the site and the transportation issues are significant if another site is considered. However, the fact that it became a primary issue at the RCF Inquiry tells us that there were a lot of stakeholders (including the local Government) who felt the decision had not had sufficient consultation. This tells us that there is a much wider group of audiences for information about a proposed course of action than acknowledged in the decide-announce-defend model illustrated in Figure 4.

7.3.4 The need to understand the audiences for analysis

Most stakeholder groups will agree that scientific work is an essential component of any decision-making process about solving the problem of radioactive waste. Analysis of the events that transpired at the RCF Inquiry suggests that Nirex relied on providing information of relevance to the regulator. In the end, much of the scientific debate focussed on the results of the Nirex 95 performance assessment. The primary audience for post-closure performance assessments produced by Nirex was the regulators, with secondary audiences being other international waste management organisations, consultancies and technical advisors to the Government. The performance assessments underpinning the key decisions of the nineties aimed to evaluate the performance of a repository should it be sited near Sellafield as a means of evaluating the *technical* viability of the Nirex proposals, based on compliance with regulatory requirements.

It is therefore highly significant that the regulator had no role at the RCF Inquiry to provide independent and authoritative comment on the adequacy of Nirex's analysis in terms of complying with regulations.

7.3.5 The difficulty of debating uncertain scientific knowledge

The decisions Nirex made about how to present its scientific information to the Inquiry influenced the nature of the debate about scientific understanding. The first detailed scientific evidence presented by Nirex was on the most up-to date information arising from the ongoing site investigations. This was considered the paramount evidence in defending the Nirex proposals and its decision to apply for planning permission and then appeal against Cumbria County Council's refusal. Nirex 95 as offered as the most recent assessment of performance.

However, a great deal of focus at the Inquiry was placed on the calculations contained within Nirex 95 and whether they justified further investigations at Sellafield. The performance assessment became a focus for a great deal of debate. However, the performance assessment process itself creates problems for a discussion of the more general understanding of the geology and hydrogeological knowledge of the site. Although this understanding has to be captured (in conceptual models) to identify what to model, (see Chapter 9 for more detail), the significance of uncertainties in the general understanding are not always easy to draw out and appreciate.

For example, it was known that the groundwater flow models used to develop the Nirex 95 performance assessment were not able to reproduce measurements of groundwater pressure made at the site. Hence there was an uncertainty at the heart of the models on which the risk calculations were founded. Although Nirex 95 did indeed suggest that under most circumstances the Sellafield site would not exceed the regulatory risk target, opposition witnesses were able to challenge the validity of the results by highlighting uncertainties in the information, understanding and models on which the results were based.

There are many examples in the documentation of the inquiry where Nirex' response to these challenges was to state that the uncertainties to which opposition witnesses referred had been taken into account in the modelling methods used to develop Nirex 95. A probabilistic approach was adopted in an attempt to be very specific and systematic about the propogation of uncertainty through the model hierarchy (Figure 13) into the calculation of risk. When questioned about areas of conceptual uncertainty, as was done extensively in evidence submitted by Friends of the Earth, Greenpeace and Cumbria County Council, direct answers were rarely given. Nirex response was often that this uncertainty in conceptual understanding had been allowed for in the treatment of uncertainty within the model – for example by the adoption of conservative assumptions in the risk models. Essentially, the Inquiry was being asked to believe that the Nirex method of handling uncertainty was adequate.

This type of response led towards fairly expert discussions about the treatment of uncertainty. The risk calculations became, de facto, the province of detailed discussion between experts who understood probabilistic modelling. However, the treatment of uncertainty is a tremendously dynamic area of academic research and debate involving scientists from all disciplines and social scientists as well. Hence it is impossible to identify any "best practice" approach. Therefore, such discussions inevitably lead towards a discussion/disagreement between experts about method and process, rather than the uncertainties themselves.

In consequence, many conceptual questions were not directly answered. And yet, a key value of performance assessment lies in the manner in which information, understanding and uncertainty is synthesised to develop a view on performance. So, answers to the questions could presumably have been provided by delving a little deeper into the assumptions and information underlying the performance assessment itself.

7.4 Conclusions

An analysis of the records and remembrances of the process suggests that:

- There was no obvious independent expert involved in the decision making process since the regulator was not involved;
- There was a lack of understanding of the scope of the decision and the material being discussed;
- There was a notable absence of true dialogue since there was a tendency to focus on the treatment of uncertainty rather than the evidence for and against certain assumptions.
- The inclusion of the issues and concerns of others formed no part of the assessment itself, which was developed purely to respond to regulatory requirements and a technocratic approach to uncertainty.

Whilst this does not necessarily mean that the RCF decision would have been any different, it can give us pointers for how to improve the use of science in public decisions making in the future. The RCF Inquiry suggested to me that the analytical methods themselves acted as a barrier for dialogue and discussion. Discussion about Nirex 95, a sophisticated performance assessment designed to meet the particular requirements of a regulatory audience, strongly influenced the nature of the discussion at the Inquiry and may not have met the needs of the other audiences present.

In the next section, performance assessments are analysed to look at their potential to serve a debate about science better in the future.

8 WIDENING STAKEHOLDER INVOLVEMENT IN PERFORMANCE ASSESSMENT –WHAT ARE THE ISSUES?

Section 1 explores the possibilities for using risk analyses generally as vehicles for debate. The aim for this debate would be to develop a shared knowledge platform that meets the requirements of expert regulation and is based on social inclusion. Experience at the RCF Inquiry (preceding chapter) has provided insights about the use of the Nirex performance assessments as a vehicle for debate and their ability at the time to meet the needs of different stakeholders involved in the decision-making process. In this chapter, the performance assessment process is examined in more detail to identify aspects that need to be addressed if an organisation such as Nirex desires to make the performance assessment process more participatory.

In order to examine the assessment process in detail, I wanted to consider a specific example and because of my familiarity with the work of Nirex, I have based much of the discussion below on post-closure assessments of the Nirex Phased Disposal Concept [Nirex, 2000a]. Appendix C presents the conceptual basis for anaysing the risks associated with this concept in some detail. To provide context for the analysis, Appendix D presents a short summary of a range of performance assessments developed internationally.

8.1 A way of thinking about performance assessments

Performance assessments have played a major part in decisions about radioactive waste management internationally for many decades. The scope and content of the performance assessments has received much attention over that time, generally from the expert community and from the point of view that a set of objective assumptions can be developed and used in models designed to calculate risk in a quantitative manner. However, Chapter 4 identifies that the ability to treat uncertainty quantitatively and the claims of objectiveness are under challenge. The rather general nature of this challenge makes it difficult to move forwards in terms of evolving practice. It is therefore tempting to ignore the challenges as not being relevant to a practising scientist or to a specific performance assessment, not least because performance assessments have been developed to a point where they are seen as "best practice" within the specialist and regulatory communities.

However, a consequence of this approach could be the marginalisation of performance assessment and the scientific expertise that goes into it because of the perception of elitism. Therefore, the purpose of this work is to explore the content of performance assessments used to support ideas about the disposal of radioactive wastes from a new perspective. The hope is that viewing performance assessment in a different way may help rise to the challenges raised in the previous chapters and hence identify practical (evolutionary rather than revolutionary) ways forward for building knowledge about the environment in the context of radioactive waste management.

In analysing performance assessments, attention is often focussed on the modelling process. This is understandable, given the history of risk analysis as a means of capturing and quantifying uncertainty for discussion in the specialist domain. The primary purpose of the performance assessment is, after all, to quantify levels of safety for a system whose long-term evolution is bound to be subject to uncertainties. However, the approach adopted below is to move away from a strong focus on the modelling process and consider the inputs to a performance assessment in a more qualitative and subjective manner.

In Appendix C, the Nirex performance assessment is described in terms of a series of questions which the performance assessment seeks to answer. These are:

- What standards need to be met (generally defined in regulations)
- How the proposed course of action hopes to meet these standards (the project design)
- What is known now about environmental conditions, processes and evolution
- What potentially could happen in the future
- What are the risks?.

The exploration of these questions has identified a series of issues which will determine whether or not there is value in seeking to evolve the performance assessment process and widen participation in the assessment process.

Table 12 identifies some key issues for consideration. They are discussed in turn below.

Table 12: Key issues to consider for evolving the role of performance assessment in decision-making

What knowledge requirements does the decision-making process place on the performance assessment?
What are the value judgements inherent in the performance assessment?
Are there cultural barriers to widening stakeholder participation in the performance assessment?
How can opportunities for wider participation be created?
Can stakeholder inclusion and expert regulation be reconciled?

8.2 Knowledge requirements for different stages of decision-making.

Any vehicle that captures knowledge (such as a performance assessment) must be "fit for purpose". Assuming that this purpose is defined by the decision-context, then the relationship between the performance assessment and the decision-making process must be explicit. Where a stepwise decision-process is being adopted, this relationship will be step-dependant and will change as the process is followed. There can be no simple formula for determining what should go into the performance assessment because different issues and concerns come into focus at different stages.

These ideas are not new. Experiences to widen deliberation and dialogue about environmental risk assessments in general and radioactive waste management in particular highlight the importance of context [Hunt and Simmons, 2001]. In a recent review of post-closure performance assessments worldwide [NEA, 1997], guidelines for the content of a performance assessment were identified (Table 13). These guidelines identify the need for clarity in terms of:

- stakeholder input;
- the context for the performance assessment; and
- the relationship between the performance assessment and a wider development process.

In response to these ideas, a report on developing and communicating confidence in the long term safety of deep geological repositories, the Nuclear Energy Agency (NEA) [OECD/NEA, 1999b] recommends that context forms part of the "assessment basis", which should be described as an integral component of the performance assessment

The idea that the performance assessment and its role in the decision-making process evolves through the process bears further consideration if practice is to evolve so that performance assessments (and risk analyses more generally) can act as vehicles for shared knowledge building. In particular:

- How does the decision-context affect the performance assessment? This question relates to the **process** of environmental decision-making and the role of analysis within that process.
- What constitutes a sufficient assessment of performance? This question relates to the **content** of the assessment and the knowledge platform available to inform the analysis.

Table 13: Information desired in a performance assessment (after [OECD/NEA, 1999b])

Information required	Key questions
The context of the performance assessment.	-What is the purpose of the performance assessment?
A description of the disposal concept, the conditions at closure and the prediction or predictions of its possible evolution (scenarios) that are considered in the assessment.	- What assumptions are made (and why) about: • The physical and chemical processes that will affect the repository? • Different "scenarios" about how the repository will evolve over time? - Why does the performance assessment focus on some scenarios and not others?
A description of the models used to estimate risks.	- What physical and chemical processes are represented in the models and what is their scientific basis? - What data are used in the models, how representative are they and have they been used directly? - What judgements were made during the development of the models? - How confidently can the models be used? - Where are the uncertainties in the models and data?
The results of the performance assessment including an analysis of the results within the context of the performance assessment.	- Are any caveats on the results and conclusions stated? - Has the potential impact on results of any limited scope been described explicitly?
A statement about the level of confidence in the scientific and engineered elements of a waste management system demonstrated by the performance assessment.	- What are the unresolved issues - Could these be resolved and if so, how? - If unresolved, how significant? - What stakeholder input has there been into the performance assessment, for example by suggesting which scenarios should be considered? - Is the performance assessment clearly related to a process addressing the ethical, economic and political aspects of waste management?

8.2.1 How does decision-context affect performance assessment?

A quick look at Appendix D highlights considerable variation in assessment approaches internationally. Some have used highly complex mathematical models to compute a quantitative risk value (e.g. Nirex performance assessments, the Japanese H12 assessment). Others present indicative calculations using much simpler mathematical representations of the future (TILA 99 from Finland and the Swedish SR97). Very few have explicitly incorporated dialogue in their construction, although many acknowledge that dialogue and consultation are potential end uses of the assessments. The difference between the assessments is a reflection of the fact that knowledge requirements will vary for different programmes, different stages in the programme, different repository concepts and different performance assessment methods. Knowledge requirements and hence performance assessments do not, therefore, lend themselves to standardisation.

In order to identify ideas about the relationships between performance assessment and decision-making, the contemporary performance assessments described in Appendix were classified in terms of decision context [after Bailey, 2003]. Decision context was defined using the stages identified in the Nirex Stepwise process (Figure 15). Obviously this process is specific to one organisation with a specific agenda, but it serves the purpose of enabling a comparison of the nature of a performance assessment required for the different stages of a generic decision making. Table 14 presents these assessments in terms of their essential components. Obviously such a categorisation is not rigorous, since different countries have different approaches.

Appendix C highlights the controlling influence of environmental standards on performance assessment practice in the UK. In practice, this leads to a tendency in the UK for performance assessments to be undertaken using a systematic, "tried and tested" (within the peer community) approach. Although there are inevitably some variations for different sites and situations, the tried and tested approach tends to be based on seeking to determine levels of compliance with standards, regardless of the decision-stage. Whether this is an appropriate objective is not always considered and the relationships between performance assessments and wider decision-making is not always clear.

Table 14: Classification of international performance assessments based on their decision- context (after [Bailey, 2003])

Stage in Stepwise Programme	PA Reference	Disposal Concept
Issue, principles,scope	H-12, NUMO, formerly JNC, Japan (disposal agency) [JNC, 2000a]	Vitrified HLW encapsulated in thick steel overpack, surrounded by highly compacted bentonite mixed with quartz sand at depth in a stable generic geological environment
Dialogue and research on options	GPA, Nirex, UK (disposal agency) [Nirex, 2000a]	ILW and long-lived LLW in stainless steel or concrete containers, eventually surrounded by cement backfill in vaults at several 100's metres depth in stable generic geological environment
	SAFIR 2, ONDRAF/NIRAS, Belgium (disposal agency) [ONDRAF/NIRAS, 2001b]	Vitrified HLW and spent fuel in water-tight stainless steel containers with stainless steel overpack and bentonite/sand/graphite backfill, co-disposed with long-lived ILW in clay host rock with overlying aquifer
Choice of option		
Implementation strategy	SR 97, SKB, Sweden (disposal agency) [SKB, 1999]	Spent fuel in copper canisters with high-strength cast iron inserts, surrounded by bentonite in individual deposition holes at a depth of 500m in granitic bedrock (the 'KBS-3 concept'), using data from 3 different sites, none of which is a potential repository location
	SITE-94, SKI, Sweden (regulator) [SKI, 1996]	The 'KBS-3 concept' as above. An assessment of a hypothetical repository at a real site (Äspö)
Site investigations	Kristallin-I, Nagra, Switzerland (disposal agency) [Nagra, 1994]	Vitrified HLW in massive steel canisters surrounded by compacted bentonite in tunnels at around 1,000m depth in crystalline basement rock of Northern Switzerland (two regions considered)
	TILA-99, Posiva, Finland (disposal agency) [Vieno and Nordmann, 1999]	Spent fuel in copper-iron canisters with bentonite buffer at depth in crystalline bedrock (similar to the KBS-3 concept), compares performance of 4 named sites
	Nirex-97, Nirex, UK (disposal agency) [Nirex, 1997]	ILW and long-lived LLW in stainless steel or concrete canisters, surrounded by cement backfill in vaults at around 700m depth in fractured hard basement rock (Sellafield site)
	Yucca Mountain Viability Assessment, USDoE, US (agency) [USDoE, 1998]	Spent fuel and HLW in massive carbon steel packages with corrosion-resistant inner layer of high-nickel alloy, placed in tunnels 300m below surface but 300m above water table in unsaturated zone of volcanic Tuff rock in desert environment (Yucca Mountain, Nevada)
Site selection		
Implementation	WIPP Compliance Certification Application, USDoE, US (agency) [USDoE, 1996]	Long-lived transuranic (ILW) waste in mild steel drums and waste boxes, with added magnesium oxide, at 655m depth in bedded salt rock (Carlsbad, New Mexico)

In a world dominated by a decide-announce-defend approach to decision-making, this lack of clarity was not so relevant or significant as with contemporary decision making. Primarily, this was because the scientific knowledge captured in the performance assessment was originated and discussed within a defined group of actors with expert knowledge and understanding. Within this epistemological community, issues such as the evolutionary nature of performance assessment were implicitly, rather than explicitly acknowledged. Many documents describing performance assessments in the 90's discuss the iterative and evolutionary nature of assessments, and Nirex went so far as to adopt the concept of assessment cycles to frame its work at Sellafield [Bailey and Littleboy, 2001; Littleboy, 1995]. However, the relationship of these assessment cycles to the decisions that were required was only just being made explicit outside Nirex when the Sellafield investigations were terminated.

It is possible to identify commonalities between different performance assessment within the same category. This suggests some guidelines for good practice in developing context-specific performance assessments which are outlined Table 15. The stages illustrated in the Nirex stepwise process introduced in Chapter 7 (Figure 15) are used to reflect the development of the decision-making process.

Table 15 implies that performance assessments vary significantly depending on the decision-stage which they support. The idea is that the performance assessment should evolve as the state of knowledge evolved and a less sophisticated exercise would be required in the early stages where the levels of knowledge to inform the assessment were lower.

Table 15: Commonalities between international performance assessment developed for similar decision-contexts

Step in process	Focus	Approach	Output
Issues principles, scope of problem, process	Developing concepts	Mostly qualitative understanding of processes and scientific/technical principles	Estimates of hazard/risk/consequences (e.g. peak doses, impacts on health and the environment)
Dialogue and research on options	Development and comparison of options	Identification of features, events and processes (FEPs) and potential impact	Fluxes, doses, conditional risks, environmental concentrations, comparisons with natural and anthropogenic analogues
Choice of option			
Implementation strategy	Developing methods and assessment criteria, SEA assessment of options	Generic scenarios and "what if" calculations for specific timeframes	Environmental impacts and long term dose/risk impacts
Site investigations	Evaluation of sites	Increasingly detailed calculations in iterative assessment cycles	Environmental impact and long term dose/risk calculations
Selection of site			
Implementation	Licensing submission, demonstration of compliance with regulations	Rigorous quantitative analysis, full scenario analysis with weightings	Environmental statement, risk to potentially exposed groups and evaluation against other regulatory requirements

If the inputs and outputs vary for each stage of the process, then the information required at each stage of the process will vary. Equally, it is likely that the stakeholders who need to be involved in considering the performance assessment will vary for different stages.

The RCF Inquiry discussed in Chapter 7 was when the decision was at the stage of site investigations. The evidence presented by the stakeholders involved at the RCF Inquiry (Figure 17) would suggest a need for them to be involved at:

- Issues stage (Greenpeace campaign strongly on the issue of nuclear power in general)
- Choice of option stage (FoE believe that long term storage is a better option)
- Site selection stage (CCC identified that Sellafield was the "wrong site for the wrong reason")

So the concepts of front end consultation and stakeholder engagement from the earliest opportunity manifest themselves for the specific case of radioactive waste disposal.

Table 16 postulates the nature of knowledge required for each stage. The knowledge requirements at each stage can be (and are) informed by performance assessments. However, it is only at the implementation stage that performance criteria (i.e. standards to be met) are really being established. Therefore, prior to that point, the assessment should be considered to be indicative only, and is not a sound basis for societal decisions.

Table 16: The nature of knowledge required for different stages of a stepwise process of decision-making

Stepwise process for long term waste management illustrated in Figure 11.	Nature of knowledge
Issues principles, scope of problem, process and organisational structure	Generic knowledge contributing to policy development
Dialogue and research on options	Knowledge about different waste management options
Choice of option	Generic knowledge about relative strengths and weaknesses
Implementation strategy	Knowledge about preferred outcomes to be translated into performance criteria
Site investigations	Increasingly detailed and site specific knowledge about environmental behaviour and outcomes
Selection of site	Site specific knowledge
Implementation	Observed knowledge about outcomes

So the decision context is extremely important in defining the scope of the performance assessment. If this point is accepted, then it suggests that the assessment methodology is not time invariant, nor should it be solely defined by considerations of best technological practice in risk analysis. This is fairly intuitive and is in keeping with the notion of producing assessments that are "fit for purpose". However, determining what is a *sufficient* level of knowledge for each decision-stage, and therefore what constitutes a *sufficient* performance assessment is an extremely difficult question.

8.2.2 What constitutes sufficient information for a performance assessment?

Even if the relationships between performance assessment and decision-stage are clear, a question in the minds of all stakeholders will be "have we dealt with uncertainty sufficiently to move to the next stage?" The content and outcomes of the performance assessment is traditionally used to inform opinion on this, and to identify continuing uncertainties. Therefore, the performance assessment needs to contain the necessary knowledge.

The influence of environmental standards on the knowledge requirements for a performance assessment cannot be underestimated. If regulations are the sole driver for performance assessment, then the necessary knowledge is that required to enable the performance assessment to be undertaken. The modelling methods identify input parameters and a research programme can be put in place to provide those inputs. Deciding when "sufficient" knowledge is available can be based on a consideration of confidence in the performance assessment process, the results and the level of compliance with standards.

In this case, one can identify further research on the basis of residual uncertainties that have a significant impact on the results of the performance assessment. This is an attractive idea. It offers the potential of being able to identify when to stop acquiring knowledge (based on peer review, residual uncertainties and levels of compliance with risk targets). However, there is a top-down aspect to this which leads some workers to claim that the analysts can become "blind slaves" to the regulations [Adams, 1995].

The idea of driving the performance assessment totally by a need to determine compliance no longer sits comfortably in our knowledge –based society. It is regulation-driven rather than knowledge driven. What about knowledge held by others which does not necessarily fit into the performance assessment method being used (for example, "lay knowledge". extended facts or minority theories)?

In a knowledge-<u>driven</u> process, rather than seeking and obtaining scientific knowledge in order to undertake a performance assessment, the performance assessment should respond to the level of available scientific knowledge. The performance assessment becomes a servant of available knowledge. This would be a requirement if the performance assessment was expected to act as *the* vehicle for shared knowledge building. However, in this case, there is a problem in determining whether sufficient knowledge has been gained to inform the decision-context. Fundamentally, this becomes the biggest value judgement of all.

The analysis of the RCF Inquiry in Chapter 7 demonstrates that the key issues aired at the Inquiry centred around this very point – did Nirex, or did it not have sufficient scientific knowledge to justify going underground and an even greater financial commitment to pursuing deep disposal at Sellafield? This question was further clouded by the lack of context for the Nirex 95 performance assessment presented to the Inquiry. Was the Inquiry about:

- site selection (why are you at Sellafield?);
- about building confidence in the Sellafield site by further research (why do you want to go underground?); or
- about the suitability of the Sellafield site for a deep disposal facility (should we or should we not build a repository in this local environment?)

Nirex 95 was designed to inform the context of why Nirex should be allowed to go underground. It was neither sufficiently generic for site selection nor sufficiently robust for determining the suitability of Sellafield. Used inappropriately, the performance assessment was not fit for purpose and confused dialogue about alternative contextual situations.

The above discussion highlights two very practical difficulties in developing performance assessments that are "fit for purpose". These issues centre around the issue of ***what*** constitutes "fit for purpose" in different decision-contexts. This question will need to be understood in terms of what other assessment tools are being used to support the decision-making process. For example, if environmental impact assessment is to be used to guide the knowledge building for a decision, then the relationships between the performance assessment and the EIA needs to be clearly understood before either is embarked upon.

8.3 Participatory performance assessments - Is the relationship between values and knowledge well enough understood?

Values are discussed in Chapter 2. Judgements based on experience, data and constraints imposed by technology will all influence the rationale and conceptual assumptions and most people will agree that these judgements should lie in the expert domain. However, it is where value judgements make a significant contribution to the assumption that challenges creep in[c]. A value judgement is a view that is influenced by a range of subjective factors. These factors can be highly personalised and include worldview, past experiences, priorities, moral principles and ethics. So understanding something of where value judgements are significant is helpful in determining where other knowledge and extended facts may be appropriate. Therefore, a classification of value judgements made within the performance assessments is offered below.

8.3.1 A classification of value judgements in performance assessments

A number of judgements are being made as part of the performance assessment process. In the past, experts have made these judgements as necessary to complete the assessment process. In many instances, this may be entirely appropriate. Specialists have sought to act in good faith by making sound and logical judgements, based on scientific rationality and ethical concepts of societal good. However, there may also be instances where judgements are made that are not firmly based in scientific knowledge, but draw more heavily on assumptions about the relative importance of different issues. These assumptions are essentially "value systems" and the judgements that arise are often called "value judgements".

However, value systems can vary for different individuals and groups. In consequence, where value judgements (for example, judgements about defining the future or futures, or deciding what constitutes a risk) are made by one stakeholder group the legitimacy of these value judgements is called into question. This has given rise to a debate about whether there should be more consultation during the performance assessment process. The debate centres around two questions.

- If the judgements underpinning the performance assessment are subjective, is it right that they are controlled by a single stakeholder group (technical specialists)? Hence
- In an increasingly consultative world, shouldn't such judgements be opened up to the wider stakeholder community?

In theory, it is very easy to say that "all stakeholders should have a say in value judgements". In practice, it may be that most stakeholders are happy to let the specialists get on with it, given certain guidelines and transparency of process. Understanding the nature of the value judgements made within a performance assessment may go someway to turning theory into practice by enhancing the transparency of assumptions underpinning

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[c] As defined in Chapter 2, a value judgement is a subjective judgement informed by a specific set of

performance assessments and determining whether wider participation is possible in the performance assessment process

Four performance assessment specialists[d] were interviewed to identify where they considered subjectivity could be a factor in the assessment processes used for the Nirex 97 and GPA performance assessments. Broadly speaking, three overall types of value judgements were identified in both Nirex 97 and in the GPA [Littleboy, 2002].

- judgements that determine the scope of the performance assessment and provide the background
- judgements that determine how performance will be assessed which therefore set the end points of the assessment process – for example what criteria will be used to judge performance, determine compliance and evaluate confidence[e], how will adequacy be determined?.
- judgements that determine the content of the performance assessment – for example what's in it, what isn't, what methods will be adopted for the performance assessment process – for example, what models will be used, how will uncertainty be handled, what input parameters should be adopted, who will conduct the performance assessment?

Together, these judgements capture the main elements of an "assessment basis" – which has been described in a recent report by the NEA [OECD/NEA, 1999b] about building confidence in long term safety. The relationship between these value judgements and the performance assessment questions identified in Table 9 are shown in Table 17.

Table 17: A general relationship between value judgements and the performance assessment process

Judgement involves....	Key issue	Performance assessment question
Value s about how to judge performance	What are we concerned about and why?	What standards need to be met (generally defined in regulations)
Value judgements affecting the scope of the assessment	What are we trying to do about it and what do we need to take into account?	How the proposed course of action hopes to meet these standards (the project design)
Values about the content of the performance assessment	What factors are sufficiently important to go into the models and how should it go in?	What is known now about environmental conditions, processes and evolution (environmental knowledge) What potentially could happen in the future

[d] my thanks to Mike Poole and Lucy Bailey (Nirex) and David Hodgkinson (Quintessa UK)
[e] Using the NEA definition, these are the key aims of Safety Assessment.

Examples of these value judgements for both the Nirex 97 and the GPA performance assessments are given below.

8.3.2 Judgements determining the scope of the PA

The scope of the Nirex97 and GPA performance assessments was defined by :

- the design of the facility to be assessed (based on the concept of deep geological disposal);
- the wastes that will be placed within the facility (based on information held in the relevant version of the National Inventory [DETR, 1999a];) and
- the site at which the facility may be located.

In a recent report from the NEA [OECD/NEA, 1999b], these are fundamental components of a performance assessment that are referred to as the "system concept". There are a number of judgements at this point that define the system concept to be modelled. Essentially, the idea of multibarrier containment defines the project. The selection of multibarrier containment is an important decision in its own right since it identifies deep geological disposal as the preferred option for radioactive waste management – i.e. the one that best protects the things that society values most. Additionally, another defining decision is the one about what wastes will go to the repository. These are major societal decisions that have direct impacts on stakeholder groups[f]. However, to specialists developing the generic performance assessment, these are "givens" and were generally not considered to be part of the performance assessment itself.

8.3.3 Judgements about evaluating performance

Assessing performance requires a clear view of how to measure and evaluate results. These are another form of value judgement. For example, the performance of a long-distance runner can be assessed by considering: whether (s)he wins (if the assessor values first place); whether (s)he has beaten her previous time (if the assessor values improvement); or the number of calories burned (if the assessor values effort). Similarly, ideas about what is important will determine the way the performance of a radioactive waste management option is evaluated.

For Nirex 97 and the GPA, performance measures have been derived from the interpretation of regulatory guidelines [EA, 1997], which themselves include a value judgement about using risk as the measure of performance. These judgements about performance criteria (or evaluation measures as they are sometimes called) determine the outputs required from the performance assessment process so that levels of compliance with acceptance guidelines can be considered and confidence in the results can be evaluated. This has been called the "safety strategy" [OECD/NEA, 1999b]

Judgements about how to measure performance are highly significant. These judgements set the scene for the content and focus of the performance assessment and hence influence the actions of all those involved in the assessment process – whether this be as a researcher, communicator, reviewer or analyst.

Table 18 indicates the value judgements about performance criteria adopted in Nirex 97 and the GPA. It shows that different judgements were made for Nirex 97 and for the GPA, and indicates a much broader interpretation of the regulatory guidance for the later performance assessment.

Table 18: Value judgements about performance criteria

Value judgement	Used in Nirex 97	Used in GPA
What timescales?	Up to 10^8 years	Up to 10^6 years
Passive safety when?	300 years following backfilling and closure	Immediately following backfilling and closure, which is after 300 years extended monitoring period
What indicators of safety are used?	Compliance with a 10^{-6} risk target	10^{-6} in any year at any time, flux out of the repository, flu to the biosphere, fraction decayed in different parts of the system plus a range of other performance indicators in supporting reports [Miller, 2000] looking at effects on the natural environment.
Who/what is at risk?	Representative individual members of a "potentially exposed group" (PEGs) which makes many assumptions regarding collective averaging	PEGs but also supporting work on impact on non-human species [IAEA, 1999]
How will adequacy be determined?	Robustness to interrogation and critical analysis (the precursor to Nirex 97 was a key piece of scientific evidence at a Public Inquiry)	Sufficiency to support advice about how to package wastes and examine sensitivity of the system to different conditions

8.3.4 Judgements about the content of the performance assessment

Finally, there are value judgements involved in determining what will go in to the performance assessment. These value judgements are essentially about deciding what is sufficiently important to be included within the performance assessment. This is identified

[f] For this reason, the current situation in the UK is one of Government consultation about options for

as the "assessment capability" by the NEA [OECD/NEA, 1999b]. A range of such judgements are made within Nirex 97 and the GPA:

- Decisions about which features of the facility and the site will affect its post closure performance. Both performance assessments adopt a similar approach to this, based on years of scientific research and modelling.
- Careful consideration of how the facility will evolve in the future, and what processes will affect it. There are a range of possible futures, so assumptions of which are the important ones are obviously value judgements themselves.
- Decisions about what methods to adopt, in particular to deal with uncertainty in data and models. The uncertainties exist because of the difficulties of using data from short term observations and/or experiments to predictions of behaviour over very long timescales. The choice of methods for modelling complex information is also an expert judgement. It is rather fundamental to the performance assessment process since it leads to an identification of the information required as input to the performance assessment.
- Decisions about particular input parameters. Where data is sparse, expert judgement is used to supplement the available information.

Table 19 identifies the value judgements of this type used in Nirex 97 and in the GPA.

Table 19: Value judgements about what's in the performance assessment

Value judgement	Used in Nirex 97	Used in GPA
What are the main pathways back to the surface?	Groundwater movement Gas discharge	Groundwater movement Gas discharge Inadvertent Human intrusion
What future evolutions are considered?	A "base scenario" (including features and processes deemed likely to happen) and some selected variant calculations	A "base scenario" (including features and processes deemed likely to happen) and some selected variant calculations
What are the main components of the system and how are they represented?	Source term (homogenised representation of the repository at closure) Site specific geosphere (represented by path length, travel time and flux) derived from support modelling) Biosphere (represented as conversion factors derived from support modelling)	Source term (homogenised representation of the repository at closure) Generic geosphere (represented by travel time, dilution factor and flux) Biosphere (represented as conversion factors derived from support modelling)

radioactive waste management.

What modelling methods are adopted?	Probabilistic	Probabilistic with some representative sensitivity analyses
What are the data inputs?	Derived through a hierarchical model development process based on experimental data and field information from the Sellafield site	Factors representing the geosphere were derived from expert judgement to be representative for UK geology.

8.3.5 Balancing technical knowledge and values

The work above distinguishes between different types of value judgement within performance assessment. One of the reasons for this distinction is that the relative balance between technical input and input from wider stakeholder consultation and deliberation is likely to vary. It will vary because the level of detailed technical knowledge required to form a judgement and the level of interest from the wider community will vary for the three different types of value judgement.

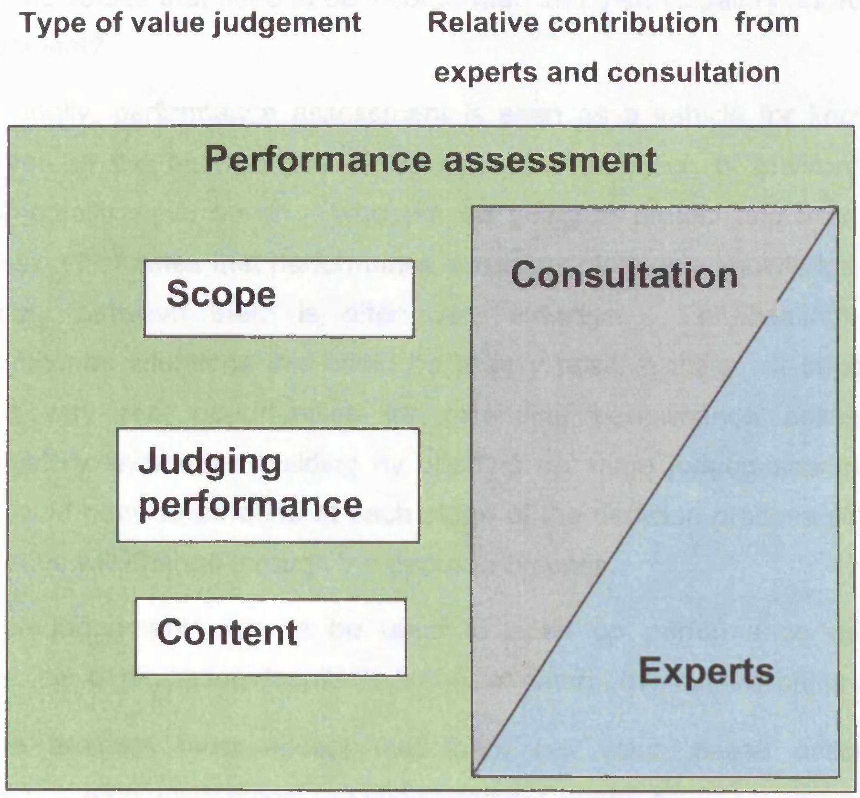
Consultation work into concerns about radioactive waste management has already been undertaken. Strongly value-laden issues emerged from the dialogue processes. The value judgements identified by exploring past performance assessments were compared with these issues [Hunt and Simmons, 2001] and findings are discussed below.

Those judgements of immediate concern to stakeholders are those that determine the scope of the performance assessment assessment rather than those that are used within the performance assessment process itself. As such they invite themselves for much wider consultation and are indeed the subject of current and widespread consultation by the UK Government. However, to specialists, these judgements are not considered to be part of the performance assessment process. Work by EDF [EDF, 2002] showed that non-specialists do not make distinctions about what is, and what isn't part of the performance assessment in the same way as the analysts. This is consistent with broader research on public deliberation that indicates that stakeholders will seek to explore context that is far broader than the issue in hand. This suggests that it would be naïve to exclude issues about management options and wastes from a discussion of the science of radioactive waste management and performance assessment just because the scientists consider them to be defined by someone else.

At the other end of the spectrum, value judgements about the content of the performance assessment require a fairly high level of technical expertise and experience. Nevertheless, judgements that deal with uncertainty about the repository's evolution lend themselves to wider consultation since they explore the future. Increasingly technical judgements that deal with data and model uncertainty require expert input and peer review and the opportunities for significantly wider stakeholder input are more limited. For example, both Nirex 97 and the GPA adopt a "probabilistic" approach to dealing with uncertainty. Others may choose to use "deterministic" methods. The distinction between these methods do not need to be articulated within this report – they are both valid options for performance assessment modelling [NEA, 1997]. The legitimacy of the modelling is generally determined by verification, validation and peer review.

This indicates that there will be a spectrum of interests into performance assessment from very high level inputs to highly detailed inputs. Therefore a balance needs to be struck between the relative inputs of lay and expert stakeholders. This is illustrated in Figure 20.

Figure 20: Relative balance between expert judgement and wider consultation for different types of value judgement.



It is reasonable to expect that as the decision process proceeds and a site or a few sites have been identified, the focus will slide down the scale of value judgements shown in Figure 20 towards those related to the content of the performance assessment. This was illustrated by the evolution of two successive performance assessments of the Sellafield site - from Nirex 95 [Nirex, 1995b] to Nirex 97[Nirex, 1997]. As information from the site increased, the performance assessment models became more firmly founded in data. This did not mean that there was less inclusion. Indeed, once a site has been identified, a much greater level of interest in the content of the performance assessment could be expected, which may be a partial explanation for the emphasis on the Nirex 95 performance assessment at a Public Inquiry (see Chapter 7).

8.3.6 Balancing expert judgement and values

Many of the challenges to risk analysis discussed in Chapter 4 arise from the way in which uncertainty is treated. It is suggested that assumptions and judgements made in the face of uncertainty are influenced by subjectivity and personal value systems. A greater level of participation in establishing these judgements could increase the perceived legitimacy of the performance assessment to a wider range of stakeholders. This requires sharing ideas about the values that need to be incorporated into a participatory approach to performance assessment?

Traditionally, performance assessment is seen as a vehicle for knowledge, not values. However, at the heart of the assessment, the definition of environmental standards is fundamentally value driven – who are we going to protect and from what? The above discussion illustrates that performance assessments juggle knowledge and values and the boundary between them is often very indistinct. For dealing with contemporary environmental situations this could be a very positive thing. It suggests that there are indeed very real opportunities for extending performance assessment to facilitate participatory knowledge building by opening up value judgements to wider deliberation. This would need to be done at each stage of the decision process since both values and knowledge will change through the decision-process.

If value judgements are to be used to open up performance assessment to wider stakeholder participation despite its technical nature, two cultural shifts must occur:

- The analysts must accept that there are value based assumptions within the performance assessment (as suggested in Chapter 5);
- The broader stakeholder communities must accept that their opinion is legitimate, despite lower levels of specific technical knowledge about performance assessments;

If these shifts occur, a simplistic view of a participatory performance assessment could be one that brings together values, via deliberation and consultation, and knowledge, as a response to those values. However, this is not really knowledge sharing. It perpetuates a simplistic distinction between axiological (value-based) and epistemological (knowledge-driven) information. It also makes the mistake of assuming that experts deal exclusively in knowledge and the lay public in values.

In reality, as shown by many workers in many different academic and practical fields, a much more complex relationship exists between values and knowledge, and the relationship is different for different stakeholder groups and different for different stages of a decision-making process. If performance assessment is to be the vehicle for shared knowledge building, then a shared perspective of what the assessment is trying to achieve will be required. However, to develop that shared perspective, the issues and concerns held by all stakeholders will need to be explored in an inclusive and iterative manner. This is one of the purposes of the overall decision-making process, rather than one of its constituent parts.

If this is so, it suggests that seeking to widen participation in performance assessment could confuse the relationship between performance assessment and the decision-making process – hence re-establishing difficulties of context discussed above. At one extreme, it could lead to a conclusion that the performance assessment should provide the overall decision-making framework. At the other, it could suggest that there is no need for a performance assessment since the decision-making process will explore all the necessary issues and integrate them into a course of action.

Whatever the relationship between the decision-making process and the performance assessment, the difficulties of incorporating the multiple perspectives of a wide range of stakeholders points towards very real cultural barriers in developing truly participatory performance assessments. These are discussed below.

8.4 Cultural barriers to widening stakeholder participation in performance assessment

8.4.1 Cultural attitudes

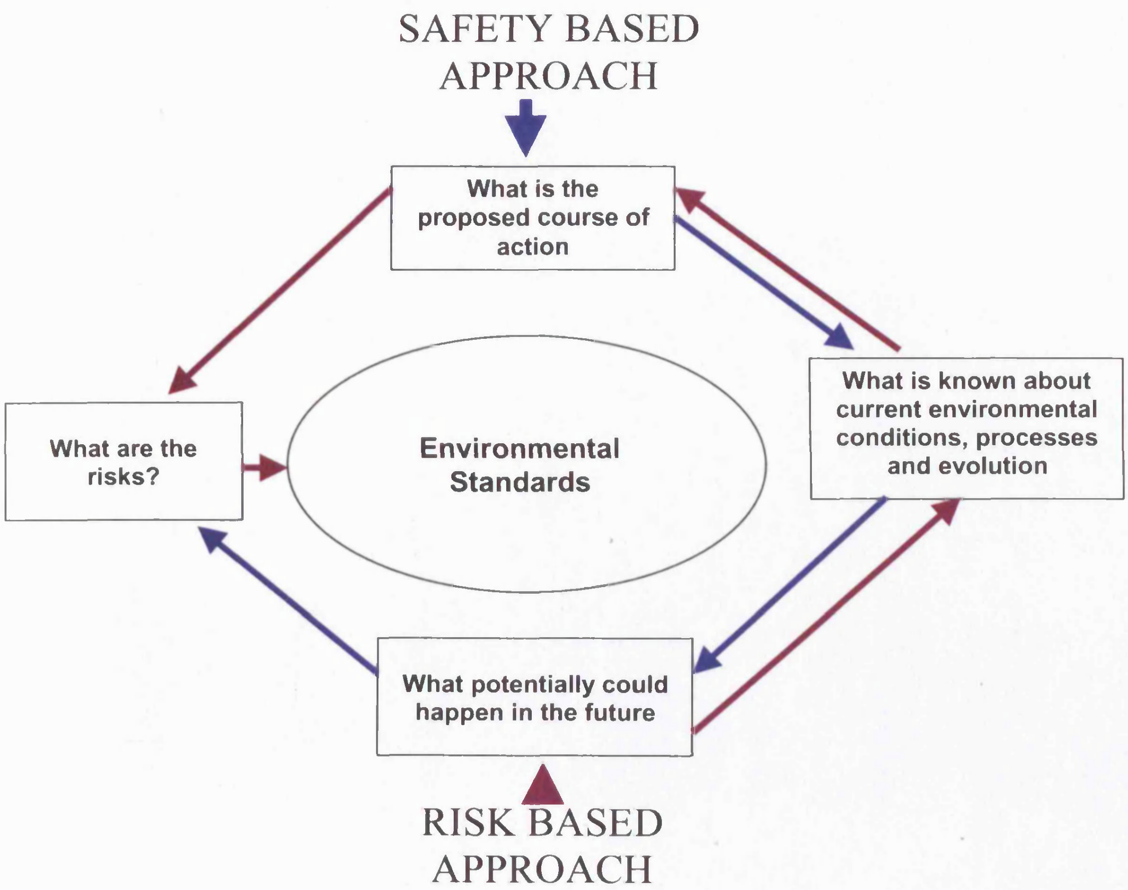
The notion of performance assessment as a series of questions derived from Table 9 was discussed with a twelve experts from different disciplines working in the field. All these experts worked for Nirex. Interestingly, those working with the design and engineering of a repository were happy with the ordering of the questions but those working most closely with evaluating performance wanted to re-order the questions. The different perspectives seem to reflect two different cultural approaches:

- An approach that emphasises what contributes to safety (a safety –based approach);

- An approach that emphasises what could go wrong and hence what could give rise to risk (a risk based approach);

Figure 21 illustrates these different perspectives in terms of the questions posed in Table 9

Figure 21: Integrating key questions in a performance assessment



As can be seen from Figure 21 these two approaches are compatible and are primarily distinguished by where the performance assessment process is considered to start. In both cases, the experts are confident that the performance assessment is an appropriate vehicle for dealing with uncertainty. Indeed, many performance assessment documents claim that the process provides a "systematic" way of dealing with uncertainty.

Table 20 explores this claim by considering:

- the uncertainty issues to be addressed at each stage of the assessment
- the approach adopted by the analysts for dealing with these issues; and

- the challenges to this approach that arise from the academic literature.

Table 20: Treatment of uncertainty in the performance assessment process

Performance assessment question	Issue	Approach	Challenge
What standards are we trying to meet?	Need to demonstrate compliance with a regulatory risk target	Calculating a risk value	Who decides who we are trying to protect from what
What is the proposed course of action?	Need to ensure containment for very long periods	Deep disposal and multibarrier containment	Do we know enough?
What do we know about current environmental processes and conditions?	Lack of data (incompleteness) Variability (temporal and spatial)	Develop knowledge using site investigations and R&D Supplement by expert judgement Combine to develop probability distribution functions of potential property variation	Causal effects may not be known (ignorance) Local and lay knowledge may not be adequately incorporated (extended facts) "Guessing"
What could happen in the future?	There are complex interelationships between FEPs What does the future hold?	FEP analysis and scenario development Conservative consideration of potentially exposed groups. Reference biospheres	Causal effects may not be known (ignorance) Relevant societal behaviour may not yet have been experienced (indeterminacy)
What are the risks?	Need to derive a meaningful number for comparison with standards	Probabilistic modelling supported by sensitivity studies to derive expectation values of risk	Expectation value of risks masks "latent fragility of understanding" Different ethics may highlight the importance of individual or worst case risks rather than collective dose Who decides what risks are important

Table 16 was compiled from the theoretical issues identified earlier (Chapters 3 and 4) and also on discussions with two individuals managing major elements of performance assessment development at Nirex. Also, informal requests for comment were made to individual representatives of the academic social science community a nuclear researcher from Friends of the Earth[9].

Table 13 challenges whether the performance assessment really does provide a systematic treatment of uncertainty. To a certain extent, this depends on the definition of uncertainty. Once the more holistic definitions discussed in Chapter 9 are considered then it becomes apparent that the performance assessment does not deal with:

- Ignorance [Wynne, 1994];
- Indeterminacy [Funtowicz and Ravetz, 1992]; or
- Epistemological uncertainty [Funtowicz and Ravetz, 1992].

However, most performance assessment workers will claim that it was never intended to address these forms of uncertainty, but rather to provide a systematic treatment of data, model and future uncertainty (technical uncertainty in the terminology of Funtowizc and Ravetz [Funtowicz and Ravetz, 1992]). The potential for cultural misunderstanding here is great. The misunderstanding opens up possibilities for criticism that are not about the quality of the scientific knowledge, but are about the definition of uncertainty and the application of knowledge within performance assessment methods. Whilst these are legitimate (but generally expert) areas for debate and discussion, the overall effect is to raise questions about the scientific knowledge and the trustworthiness of those offering it that may be unfounded.

The idea of using performance assessments as a platform for shared knowledge building requires the drawing together of different epistemological communities. These different communities will have their own expertise and, inevitably, preconceptions. Such preconceptions will have been built both from individual experience and cultural history and may act as barriers to widening participation in performance assessment for three key reasons:

- Different views about what a performance assessment is and who it is for;
- The difficulties of drawing together different ways of conceiving and articulating concerns about the environment from different stakeholder groups; and

[9] My thanks to Lucy Bailey, Brendan Breen, Jane Hunt Juhani Vera and Rachel Western

- The threatening nature of increased participation for many scientists and analysts since it requires an extension of thought outside the culturally understood boundaries of the scientific community.

8.4.2 Who are performance assessments for?

As discussed in above, for experts in performance assessment, its boundaries are clear and define its potential role in debate on the long-term safety of radioactive waste disposal facilities. It has been primarily a tool for experts involved developing technical evaluations and scientific research programmes focussed on key uncertainties. A key channel of communication served by performance assessment has been the regulator-operator relationship and therefore the performance assessment has tended to be focussed towards expert regulators.

This practice is evidenced by the performance assessments presented in Appendix D (after [Bailey, 2003]) where an overriding commonality is that they are aimed at specialist audiences. The preface to SR97 states that parts of it are expected to be of interest to non-specialists. TILA-99 and the Yucca Mountain Viability Assessment aim to make the assessment accessible to wider audiences by emphasising, in particular, transparency of data and models and diagrammatic presentations respectively. Recognising that the main body of the performance assessment is therefore unsuitable for non-specialists, many of the assessments have summary documents. These include H-12, SAFIR 2, SR 97, SITE-94, Kristallin-1, Nirex-97, Yucca Mountain Viability Assessment and the WIPP CCA. However, these summaries vary in content and style. Some are simply technical overviews of the main report (H-12, SR 97, SITE-94 and Nirex-97), others have been written with wider, less-specialist audiences in mind (Kristallin-1, SAFIR 2, Yucca Mountain) or specifically to encourage non-specialists to participate in the decision-making process (WIPP CCA).

The analysts are clearly of the view that the primary audience for performance assessment is a specialist one. Summary documents and visual representations are used as a means enhancing accessibility, but even so this seems to be in a fairly one-way sense of communication. Hence, even though the WIPP CCA summary is aimed at encouraging non-specialist input, this input is being requested right at the very end of a licensing procedure and decision-making process.

The implication is that the analysts themselves do not view performance assessment as a useful vehicle for dialogue with non-specialists or do not see how non-specialist views can add value to the assessment. This is probably due to the highly technical nature of a performance assessment and the rigour that is required to produce an assessment that will stand up to the scrutiny of technical peer review and regulatory requirements,

However, it may also be a result of the analytical focus towards determining compliance with the highly quantitative environmental standards to which the performance assessment is responding. Hence the mathematical and statistical solutions developed to handle uncertainty quantitatively and hence the need for specialist knowledge to appreciate the results of the analysis.

This definition of performance assessment is too narrow to fulfil a useful role in promoting dialogue along the other axis shown in Figure 12 - that of social inclusion. It doesn't necessarily address the questions that are of most concern to other stakeholders, notably the public. As discussed above, the need to determine compliance with a long-term risk target reduces the ability of a performance assessment to respond to different decision-stages. Consequentially, this will reduce the flexibility of performance assessment to act as a vehicle for dialogue with those who have values that are not reflected by the risk target.

However, a concern about increasing non-specialist participation in performance assessment is that its rigorous analytical nature will be diluted in the interests of developing a more widespread appeal. A "logical" conclusion from this statement is that the performance should remain a vehicle for debate and discussion between experts that enables performance to be measured systematically against defined regulatory criteria or environmental standards.

This attitude may appear to be contrary to the ideals of an analytic-deliberative approach to decision-making. However, this need not be so as long as the analysis contained within the performance assessment does not *exclude* or *supersede* other knowledge platforms or deliberative knowledge building. Indeed, there are component parts of the performance assessment process that can benefit from such deliberation and that lend themselves to broader discussion in a way that the overall complex performance assessment process does not.

8.4.3 Reconciling stakeholder attitudes and concerns

Table 21 identifies some of the difficulties of incorporating stakeholder values into performance assessment by comparing the issues of concern to the public (derived from [Hunt and Simmons, 2001]) with the factors on which expert performance assessment methods have tended to focus (based on the UK approach to performance assessment).

Table 21: Comparison of public concerns with expert methods

People are concerned about….	Expert methods within Nirex have tended to focus upon…
Tangible impacts on quality of life	Quantitative risk targets at long times into the future
Worst case scenarios	"Probabilistic" modelling approach where model inputs are sufficiently broad to cover all eventualities
Individual dose (maximum?)	Representative individual members of a "potentially exposed group" (PEGs), which makes many assumptions based on collective averaging
Spectacular future events	Base scenarios (to date) although 'what if' calculations are being developed via the use of variant scenarios

Table 21 gives a flavour of the cultural difficulties of drawing together performance assessment specialists with a broader stakeholder community. A significant (if unconscious) barrier is provided by the specialists themselves who have been developing the performance assessment process over the last twenty years into a sophisticated exercise that adopts state of the art modelling and knowledge management methods within a structured environment. Other stakeholders do not articulate their concerns in a manner that is readily incorporated into this framework.

Equally, the wider stakeholder community is not constrained by the niceties of where performance assessment begins and ends. Hence, discussion and debate about policy matters and regulations become intertwined into their considerations but tend to remain outside the domain of the specialists consideration.

8.4.4 Cultural attitudes on behalf of the scientists

As discussed in Chapter 5, the scientific method is ingrained in the trained scientific professional, as is the need to undertake research and analysis meticulously and in a manner that will have to be subjected to peer review. The notion that subjectivity (in the form of value judgements) may be influencing their work is threatening and may incur a defensive response. Additionally, following years of training and specialisation, the idea that non-specialists have something to offer is very difficult to grasp. It requires a re-assessment of the relevance of information lying beyond the traditional boundaries of science. This requires courage, and may incur the sceptism of the traditional peer scientific community. Reconciling these issues can be very difficult and is generally achieved by the personal attributes of the scientists in question, rather than by the adoption of any particular practice.

If participatory performance assessment is to be an effective tool for *shared* knowledge, then this complex relationship needs unravelling for every decision-context. It may be that the relationship is too complex to be unravelled in a reductionist manner. Attempts to do so may end up diluting the performance assessment so that it contains a hybrid knowledge base that is owned by no stakeholder group.

8.5 Can stakeholder inclusion and expert regulation be reconciled in a participatory performance assessment?

Expert regulation has driven the development of performance assessments and risk analysis to date. Environmental standards provide the backdrop for most risk analysis practice. Determining compliance with these standards has been the primary purpose of performance assessments since the fifties. Environmental standards seek to encapsulate the concerns of society. However, these are notoriously difficult to standardise and stakeholders with different forms of knowledge and value systems will have different concerns. The risk target given in regulatory guidance for radioactive waste management in the UK is a technocratic attempt to integrate all these issues into a common, and measurable factor. However, it does not assist more qualitative dialogue and discussion about environmental concerns. Additionally, the risk target does not acknowledge the likely evolving nature of issues and concerns as a stepwise decision-process is followed.

However, the prospect of *not* using a quantitative environmental standard seems equally unrealistic since it removes the opportunity for an independent expert authority (the regulator) to develop a reasonably objective view about the validity of the proposals in question. This suggests that evolving the performance assessment so that it enables more qualitative dialogue and promotes social inclusion may undermine its ability to inform expert regulators. Philosophically, this should raise questions about the nature of the regulations. Realistically, it represents the difficulties of capturing technically specialist but uncertain knowledge in a rigorous manner. Practically, it means that performance assessment for post-closure risks from a radioactive waste repository are unlikely to act as vehicles for dialogue in their own right since the two objectives of social inclusion and expert regulation may work against each other. In view of the fact that the performance assessment has been developed for a specialist audience, it can be concluded that this should remain the prime focus.

Nevertheless, some components of the performance assessment process are seen to be amenable to wider participation – most notably the development of scenarios about the future and choices about how to deal with uncertainty. However, offering the performance assessment process up for wider participation in these areas brings very significant cultural challenges. With variations in both the nature of the judgements being made and the level of interest from the wider stakeholder community, how is an appropriate balance between specialist and lay knowledge to be struck? Also, how is the right balance to be struck between values and knowledge?

This question goes right to the heart of modern scientific behaviour. How is a scientist to be both authoritative (because of his/her specialists knowledge and training) and responsive (because his/her value system has no ascendancy over others)?

This brings us back to the issue of whether a common platform for shared knowledge can be identified, which can encompass both expert and lay knowledges and provide the foundations for differing stakeholder groups to service their own specific decision-needs. The quantitative nature of the performance assessment and its focus on evaluating risks against environmental standards acts as a barrier to dialogue. Because of the very real practical issues raised above, I would suggest that it is not possible to reconcile the needs of social inclusion and expert regulation by adapting performance assessments without major cultural shifts in the attitudes of scientists and analysts. This shift needs to give conceptual and qualitative debate a higher profile in the performance assessment process.

8.6 Widening stakeholder participation – Summary of issues

8.6.1 Performance assessment and decision-context

Fundamentally, where an uncertain future is involved, there appears to be a conflict between the idea that a performance assessment helps determine compliance with a quantitative environmental standard (or standards) which are fixed in regulations, and the need to evolve for different decision contexts. Until this conflict can be resolved, how can performance assessment be used confidently in support of a stepwise decision-process. At each stage of the process, questions must be considered such as:

- Is it helpful to determine compliance with the environmental standard at this stage of the process?
- Is it meaningful to determine compliance with the environmental standard given the current level of knowledge?
- What level of compliance with the environmental standard is acceptable to move to the next stage?
- Is it meaningful and helpful to consider these sorts of questions at this stage of the process?

Another big issue underlying the above questions is the issue of whether enough information is available to support the performance assessment and to support the decision in hand.

8.6.2 Performance assessment, knowledge and values

Performance assessments juggle knowledge and values implicitly. The environmental standards to which they respond contain value judgements about who/what requires protection, from what. Although their cultural nature suggests that the value judgements in performance assessment could provide the means of opening up the assessment process to wider stakeholder participation, their subjectivity means that each stakeholder will be coming to the performance assessment with differing perspectives of

- what the performance assessment is, or should be, trying to assess ; and
- how performance should be judged;
- whether values have any place in a traditionally technocratic, analytical process;
- who has a legitimate voice in a traditionally technocratic, analytical process.

Rationalising these different perspectives will be extremely difficult and will explore stakeholder issues and concerns more properly discussed as part of the wider decision-making process.

8.6.3 Cultural barriers

There are some real difficulties in using performance assessment as a platform for shared knowledge building arising from the drawing together of different epistemological communities, with different culture, language and expertise. These are, generally speaking:

- Difficulties of knowing who the performance assessment is for and why it is relevant to those outside the traditional performance assessment community;
- Difficulties in developing a shared language for articulating and discussing environmental concerns;

Pushing the scientific community outside its “comfort zone”, potentially leading to defensive and non-constructive attitudes

8.6.4 Conclusions

There are real practical challenges to the use of performance assessments as they are currently conceived as a vehicle for dialogue and shared knowledge building. However, some of the qualitative content of the experiences, questions and theory encapsulated in the performance assessment is reflected in the questions and issues raised by stakeholders during consultations [Hunt and Simmons, 2001; EDF, 2002]. This suggests an interest outside the scientific community in the subject matter of the assessment. So even if the analysis is not the best vehicle for dialogue and shared knowledge building, it may be worth exploring the effectiveness of finding another vehicle for the dialogue required for analytic-deliberative decision-making. The next section explores whether the conceptual and qualitative understanding of environmental processes, causes and effects can stimulate debate amongst non-scientific stakeholders, and simultaneously enable the development of a quantitative risk analysis that continues to satisfy regulations.

Section 3

Towards an analytic-deliberative assessment of long-term risks for deep geological disposal

9 CONCEPTUAL MODELS – A PLATFORM FOR SHARED KNOWLEDGE BUILDING?

The research in this thesis is looking for vehicles to enable broad ranging debate about environmental issues and platforms on which to develop shared knowledge. Section 1 identified the changing contexts for the use of risk analyses and scientific knowledge in environmental decision making. In Section 2, the performance assessments developed by Nirex to examine the risks of deep geological disposal at Sellafield have been examined. Conclusions are:

- That it is important to have a vehicle whereby knowledge about environmental consequences can be shared between experts and lay communities;
- That the process used to build that knowledge, and the relationships that develop between participants can have a dramatic effect on the manner in which the scientific knowledge is ultimately used;
- That a vehicle for building a shared knowledge base of potential concerns about the environment on which to conduct a quantitative risk analysis would be a valuable contribution to a participatory decision making.
- That science and risk analyses will always need to be robust to expert peer review, but a focus solely on that objective can act as a barrier to the participation of other communities, which will undermine the value of that scientific knowledge in the decision-making process. This has (in my subjective opinion) been demonstrated by the use of highly complex risk analyses in decisions about the Nirex RCF;
- That scientists will have to develop their work in conjunction with other communities holding different types of expertise. Dialogue should commence as early as possible;
- That the translation between conceptual descriptions of what could happen, to numerical representations of quantitative risk is a major barrier to communication and dialogue.
- That the heuristic and descriptive nature of the earth sciences, and the fact that they deal with environmental processes and outcomes means that the discipline is well placed to bridge the gap between qualitative concepts and quantitative analyses.

This chapter explores the potential for conceptual understandings to act as a vehicle for dialogue and to build a shared knowledge platform on which to base risk analyses.

9.1 Elements of a shared knowledge platform

Dialogue with a socially inclusive range of stakeholders will need to address conceptual understandings and different perceptions of what constitutes a hazard. This can lead towards ethical discussions about who is likely to be harmed and who needs to be protected. Dialogue to enable expert regulation is centred on assessments of compliance with environmental standards and regulatory targets. This can lead to further discussion about what the risk results mean, the level of compliance indicated by the assessment and discussion about whether the environmental standards and regulatory targets are appropriate.

These two, apparently different, interests are not so far apart. The challenging of environmental standards can go back to debate about what who needs to be protected from what hazard. A common thread is an overriding concern with hazards and risks to the environment. The question is whether we can break into the circular process of discussion and define a platform that can:

- grow and evolve as the recursive discussion continues; and
- remain relevant to both axes for the discussion of scientific knowledge.

9.2 Encouraging engagement

A desire for stakeholder involvement in the development of knowledge implies a willingness to listen. Dialogue undertaken on behalf of Nirex has identified a number of issues which stakeholders feel should be addressed by scientists working in radioactive waste management [Hunt and Simmons, 2001]. An analysis of this work suggests that stakeholders engage better if they have:

- The means to reassure themselves about the integrity of the scientific work (in particular the risk analysis or performance assessment) and its results.
- The opportunity to help influence and comment on the work

Figure 22 draws together these ideas into a framework for encouraging stakeholder involvement.

Figure 22. Engaging the public in scientific work

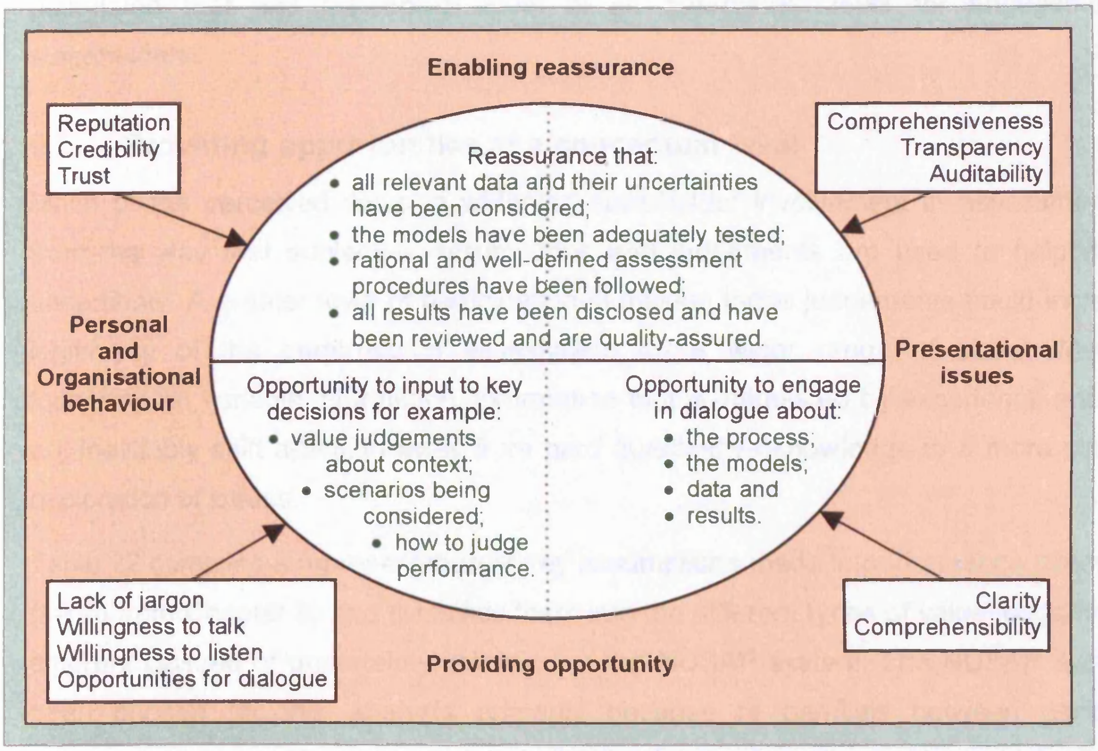


Figure 22 identifies a range of factors that combine to enable stakeholder involvement. Each of these factors is necessary, but not sufficient for the building of shared knowledge about the environment. The presentation of scientific work is one part of the picture – hence the many initiatives on developing the public understanding of science and the focus of the research presented here. Other factors are the development of trust and the provision of opportunities for dialogue. These social and organisational factors have been discussed in earlier sections and are the subject of extensive academic study.

Figure 22 also implies requirements for clear recording of the decisions and assumptions used to develop the analysis. The ideal of transparency has therefore become central to the behaviour of many organisations seeking to be socially responsible and is an increasingly common value in organisational behaviour. This includes auditable records of all the models and data sets used in any calculations and a transparent, comprehensive presentation of the facts and value judgements used in developing proposals. However, the need for comprehensiveness and auditability should not be allowed to undermine comprehensibility.

The problem is that in the scientific arena there is not a straight dividing line between facts and value judgements. Rather there is a spectrum, which has a lot to do with how much trust and confidence a person has in a particular piece of 'evidence'. This evidence is interpreted at the conceptual level, inevitably against a set of values. Therefore, it can be postulated that this conceptual level is an appropriate level for engagement with stakeholders.

9.3 Providing opportunities at a conceptual level

Much of the perceived value in widening stakeholder involvement in assessment arises from the way that subjective assumptions and judgements are used to help deal with uncertainty. A greater level of participation in making these judgements could increase the legitimacy of the performance assessment for a wider range of stakeholders. This focussing on variable information, information that is influenced by experience and values, will inevitably shift attention away from hard quantitative knowledge to a more conceptual exploration of issues.

Table 22 compiles a representation of key assumptions made in performance assessments (taken from Chapter 8) and classifies them into the different types of value judgements and different classes of uncertainty identified in the NUSAP system. The NUSAP system has been chosen for this analysis primarily because of parallels between performance assessment and evaluations of global climate change (long timescales, widely distributed risks and major future uncertainties.

Generally speaking, Table 22 shows that the assumptions dealing with:

- Technical uncertainties: tend to be those based on an understanding of existing conditions or well established knowledge of environmental processes
- Methodological uncertainties: tend to be about the extrapolation of current knowledge.
- Epistemological uncertainties: are those to do with deciding what is important – how performance is to be judged – and also the more sweeping assertions that define the content of the performance assessment – for example that the future can be extrapolated from the present (nature/society preconceptions [Stirling 1999]).

Table 22: Analysis of key assumptions against the NUSAP classification of uncertainty.

	Assumption	Classification	Type of value judgement
Assumptions about What standards need to be met	Radiological risk is what matters;	epistemological	Judging performance
	Because of potential harm to human health;	epistemological	Judging performance
	At any point and with equal importance over an indeterminate period into the future that will span many many generations	epistemological	Judging performance
How to meet those standards	that it will not be possible to contain radionuclides within a repository for the timescales identified (or rather not identified!) in regulations;	methodological	scope
	that it is possible to capture the main risks from a repository by considering three pathways back to the surface: groundwater flow leading to natural disharge; Gas migration; and human intrusion.	methodological	Content
	that the physical and chemical processes occurring within the engineered barrier and the geosphere will mean that the concentration of radionuclides reaching the biosphere will be significantly less than the concentration leaving the repository;	technical	Content
	that knowledge of radionuclide transfer processes and dosimetry means that it is possible to convert dose to a radiological risk;	technical	Content
	that the groundwater pathway can be represented by considering containment, dispersion, spreading and decay;	methodological	Content
	about the nature and quantity of wastes that will be disposed of;	technical	Scope
	about the way the repository will be built and the amount of backfill required	technical	Scope
	about how the repository will evolve prior to closure	epistemological	Content
Environmental Processes	that the groundwater path can be represented by four parameters: travel time, path length, a retardation factor and dispersion;	methodological	Content
	that these parameters can be investigated by site investigation and interpretation;	methodological	Content
	that an understanding of the current groundwater flow system can be extrapolated and used as the basis for deriving these parameters into the future;	methodological	Content
What could happen in the future?	That it is possible to capture future uncertainty within a range of scenarios	methodological	Content
	That some scenarios can be "subsumed" because their effects are less significant;	methodological	Content
	That the future can be represented by scenarios linking features, events and processes;	epistemological	Content
	That current knowledge can be used as the basis of developing scenarios for the future	epistemological	Content
Current conditions Wh[illegible]	determined by investigation, data and expert judgement	technical	Content
	can use a representative individual of a potentially exposzed group	epistemological	Judging performance
	biosphere factor can be derived by considering exposure routes and dose/risk conversion factors	methodological	Content
	future human behaviour can be represented based on current knowledge	epistemological	Judging performance
	future climate states can be predicted	epistemological	Content

The work of Funtowizc and Ravetz [2001] suggests that the assumptions made to handle technical uncertainties can legitimately remain within the scientific domain. Therefore, the analysis given in Table 22 suggests three areas for wider participation, all sitting within the domain of methodological and epistemological uncertainty. These are: the identification of environmental standards; consideration of how to judge performance; and the identification of future scenarios.

9.3.1 Setting standards

The difficulty of standardising the concerns of society should not be underestimated. It is at the point of setting standards that the incorporation of values is most important and most tricky. This has been discussed extensively by the Royal Commission on Environmental Pollution [RCEP, 1998] and will not be repeated here.

9.3.2 Criteria for judging performance

In terms of a more participatory approach to determining how to judge performance, regulatory and specialist guidance documentation is increasingly identifying confidence building measures and multiple lines of reasoning as necessary safety arguments [EA, 1997; OECD/NEA, 1999b]. This allows for much broader evaluation criteria to be identified. It opens up significant scope for wider participation in advance of the performance assessment itself. However, the need to respond to even one quantitative measure laid down in regulation still tends to be a dominant focus for the analysis.

9.3.3 Identifying future scenarios

A quick look at the performance assessments described in Appendix C shows assumptions about future scenarios are very important to the development of a performance assessment and therefore the legitimacy of those assumptions needs to be closely examined. There is general agreement that scenario development (identifying the potential future evolution of the repository), which is a fundamental component of performance assessment, has the potential for consultation. Indeed, a decade ago it was noted that:

"The partly speculative nature of scenarios, and the relative ease with which they can be described, can provide a rich and accessible means for public involvement".

Scenario development has been identified in various sections of this thesis as a point at which uncertainties, value judgements and analytical methods come together. Different combinations can lead to alternative concepts and alternative possible futures (scenarios).

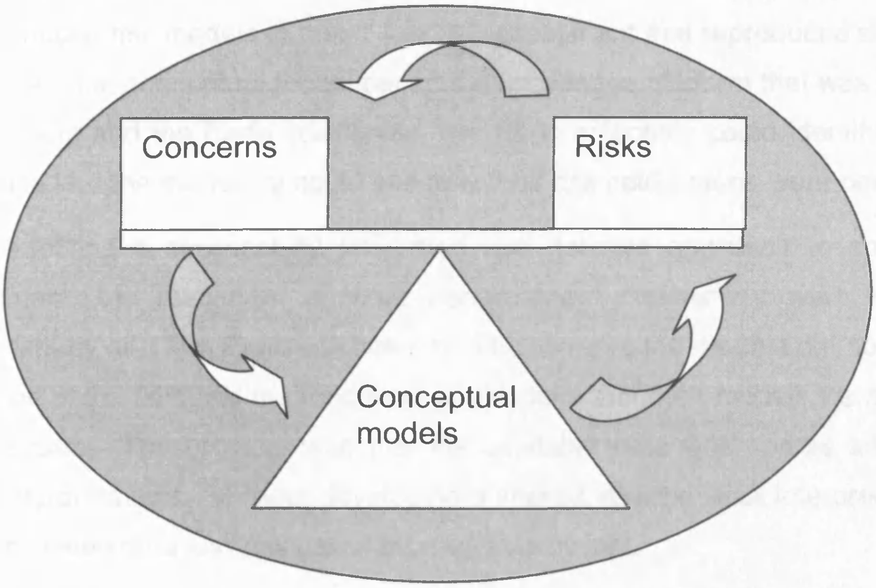
9.4 Conceptual models as a means of building a shared foundation for performance assessment

I am going to use the term "conceptual models" to describe the input to the risk analysis, where the definition of a conceptual model is, loosely:

"*a brief, clear, simple and unambiguous description of the system. It defines the processes acting within the system, the parameters required to model those processes and the conditions on the boundaries of the system*" [Nirex 1995b].

As discussed in Chapter 4, conceptual models are developed as part of the risk analysis process. Conceptual models effectively capture the general understanding of the system and its evolution that underpins the risk analysis process (see Figure 8). Development of this conceptual model or models which will underpin a risk analysis involves considering and collating the available data and describing and justifying the physical and chemical processes which the model will seek to represent. The development of conceptual models for a risk analysis is, to my mind, the fundamental step in the analytical process. Everything else in the analytical process will stem from choices about the conceptual model – the data required, the sources to use, the algorithms in the model. The conceptual model itself stems from identifying the things you are concerned about and therefore it sits at the fulcrum of the scientific knowledge used to analyse risks (Figure 23).

Figure 23. A simplified representation of the scientific knowledge base for risk analysis



Conceptual models are essentially descriptive. They therefore provide powerful tools for capturing the many types of uncertainty that affect the environment and the assumptions (both implicit and explicit) that are made to handle some of these uncertainties. Conceptual models do not seek to capture all uncertainty. In developing a conceptual model, no claim about comprehensiveness is being made – it is a possible state of the system, now, in the future or in dynamic transition between them. Hence the conceptual model does not exclude ignorance or indeterminacy. Transparency about what is going into the risk assessment is thus helped tremendously by a well-presented set of conceptual models.

Conceptual models are not quantitative. They are descriptive in nature, and in the arena of risk analysis have tended to take a subordinate role to the numerical methods used for the quantitative treatment of uncertainty and risk. Nevertheless, they are the point at which various scientific disciplines come together to inform the risk analysis process, before the problem is handed over to the mathematicians and modeller. As such, they are tremendously vibrant areas of dialogue between those involved, even peripherally in the risk process. This is evidenced in the climate modelling arena where the high profile debate centres around the cause and effect of global warming (what to model) rather than the relative values derived from the model.

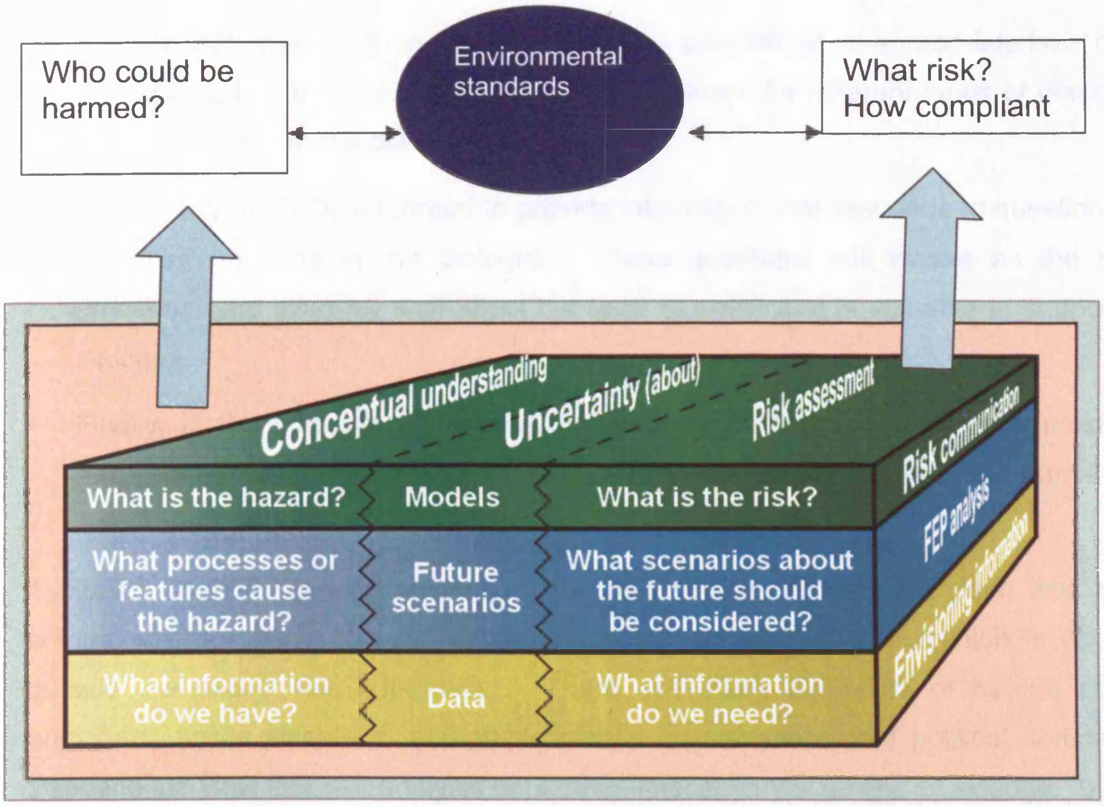
I observed the power and use of conceptual models for knowledge building during investigations into the suitability of a site near Sellafield in Cumbria for the disposal of radioactive wastes. This experience has been described elsewhere [Littleboy, 1997], but essentially it was only when the conceptual model was used as a platform for iterative dialogue between the risk modellers and the Earth scientists investigating the site that Nirex produced risk models in their Nirex 97 assessment that reproduced site observations. At that point, the conceptual model became a knowledge platform that was shared between the modellers and the Earth scientists. The Earth scientists could identify how their work led up to it, and the modellers could see how their risk calculations were derived from it.

Before adopting a successfully integrated and iterative approach to conceptual model development, the results of a Nirex performance assessment were vulnerable to a disownment by all. The Earth scientists could claim that the models did not represent their knowledge of the field and the modellers could claim that their models were as good as the available data. The problem was that the available data was sparse and open to non-unique interpretations. Without developing a shared view on what interpretations to adopt, the link between data and risk calculation was easily lost.

In theory, this experience of encouraging shared knowledge building between field scientists and modellers could be extended outside the scientific community. Given its descriptive nature, it seems entirely possible to consider extending the scope of conceptual models to encompass issues raised outside the expert risk community. Using the conceptual model avoids the confusion and obfuscation of the detailed mathematical structures used to calculate risk and the challenges of post-normal science.

Figure 24 gives an indication of what this shared knowledge platform might look like. More importantly, it shows how specific areas of academic research can contribute to the knowledge building process when integrated into this common platform.

Figure 24. Knowledge platform in support of an analytic-deliberative approach to decision-making



The shared knowledge base proposed in Figure 24 recognises a number of key factors in the effective development of an analytic-deliberative approach:

- the continued importance of the regulator as an expert commentator on environmental risk and management;
- the need to be responsive to the issues and concerns of a wider cross-section of society;
- the continued relevance of scientific analysis, expertise and training to the knowledge development process;

So, in response to the question raised at the beginning of this thesis:

"how can we get the right science in an appropriate social context to build an effective knowledge base for decision-making?"

I am proposing that conceptual models of the cause and effect of environmental impact be used as a common platform for debate and discussion. These conceptual models can be developed in a participatory fashion. The conceptual models can then be used to develop quantitative analyses in order to determine compliance with regulations. To do this, a number of factors need to be taken into account:

- The conceptual description should capture the scientific at an appropriate level of detail. The appropriate level of detail may well be different for different types of dialogue and different players in the dialogue process.
- Additionally, it will be important to provide information that responds to questions raised by those engaged in the dialogue. These questions will evolve as the dialogue proceeds, and this may well affect the level of detail that is valuable in support of the dialogue.
- Finally, in the interests of openness, this common frame of reference must openly acknowledge scientific uncertainty so that those with differing values can form their own judgements about risk.

Typically, scientific experts working in the field of risk analysis will claim that all these criteria are met within the risk analysis process. However, this opinion is not shared outside the expert risk community. There are many examples of natural scientists, engineers, social scientists, non-governmental organisations and political commentaters disputing the view that risk analysis captures all necessary scientific knowledge. It appears that the risk analysis process can obfuscate the contributions made by others so that they become unrecognisable in the output.

9.5 The relevance of Earth Science

The idea presented in Figure 24 is to develop a common knowledge platform based on conceptual models. The relevance of Earth Science to environmental decision-making has been discussed in Chapter 5. Earth scientists need to emphasise their role in providing expert knowledge about the physical and chemical processes affecting the environment. This knowledge includes facts, speculation and uncertainty, all of which become tied together into a conceptual understanding of environmental behaviour. Earth Science therefore has the potential to contribute significantly to an analytic-deliberative approach to environmental decision-making. The knowledge of the Earth Science community could be a valuable starting point for iterative knowledge development, both with experts and with a wider cross-section of interested stakeholders.

Earth Science has always been important for risk analyses in waste disposal. Chapters 5 and 8 describe the need for Earth Science information to underpin risk analyses and performance assessments and identifies that the knowledge of Earth Scientists tends to be translated into the mathematical risk analysis via the conceptual model. The conceptual model and Earth Scientists are therefore fundamental to effecting the intellectual transformations described in Table 9 – turning knowledge into model into parameters via the application of expert judgement. Since there will always be incomplete knowledge about natural systems, there will always be the need for such intellectual transformations. Conceptual models offer a vehicle for capturing this intellectual transformation and for discussing the judgements that are used with peers and expert audiences such as the regulator.

On the more inclusive axes for dialogue Earth scientists can contribute to dialogue about environmental concerns for a number of reasons, all of which tend to be captured within conceptual models:

- As discussed earlier, the Earth Sciences are essentially about understanding the Earth as a dynamic system. Many of the (both expert and lay) concerns about environmental hazard and the causes of environmental harm stem from Earth Science research and Earth resource exploitation.
- Earth Science interprets environmental conditions in terms of sequences of events that have developed over long time periods. It has also developed into a predictve science, with uncertainty being an implicit part of any Earth science training. The timescales involved and the non-uniqueness of Earth Science theories make it well suited to considering and debating the potential for environmental harm in the future.
- The Earth Sciences covers a range of very different scientific disciplines and mindsets, from those working on the micro-scale to those working on a global (even an astronomical scale), from integrationists (lumpers) and reductionists (splitters), from theorists (modellers) to activists (field geologists).As a discipline, Earth Science is well used to debating issues in a descriptive and heuristic manner.

Hence, an increased focus on conceptual models within environmental decision making is likely to have repercussions for the role of Earth scientists within the decision-making process.

9.6 Testing the hypothesis that conceptual models can promote debate and hence iterative knowledge building.

Taking all these things together, the hypothesis becomes that clear and understandable conceptual models may be helpful as a vehicle for debate. The intended outcome is a common platform of knowledge on which to based risk analyses can be developed. Moreover, it is hoped that earth scientists will confidently claim a central role in the development and evolution of these conceptual models. This hypothesis is tested in the sections that follow for the issue of radioactive waste management. As with the previous section, the reasons for this concentration on one example of an environmental problem is my familiarity with the subject. However, in the concluding chapters I consider the lessons learned from this exemplar in a broader context.

More specifically, the focus of the work is on two particular aspects of radioactive waste management – the role of rocks in deep geological disposal and the post-closure performance assessment. The reasons for this specificity (apart from an ongoing familiarity with the subjects) is to test the assumption underlying this thesis that Earth science is highly relevant to environmental decisions because of its descriptive and interpretative nature and its ability to deal with long timescales.

The studies described in the succeeding chapters were initiated using a public dialogue process to explore issues and concerns with deep geological disposal. This was, in effect, a front end consultation for the research and is described in the following chapter.

10 DEEP GEOLOGICAL DISPOSAL– DIALOGUE ABOUT ENVIRONMENTAL IMPACT

10.1 Introduction

The preceding analysis identifies early, broad stakeholder involvement as an important component of an analytic-deliberative approach to decision making. That idea is followed in this chapter in order to provide input to more detailed studies about using conceptual models to build knowledge for decision about radioactive waste management.

An opportunity to design and develop a public dialogue study for Nirex was used to explore issues and concerns about the deep geological disposal of radioactive waste. Whilst it was not possible to completely structure the study to the ideal needs of this research, it was possible to work with others to develop a study with aims that met Nirex's immediate needs and also amounted to a "front end" dialogue for this research. As well as the information from the dialogue providing valuable material for the direction of this research, the dialogue design process itself provided a valuable opportunity for reflective practice in terms of engaging in dialogue about deep geological disposal. The study is outlined first and then reflections on its progress are presented.

10.2 Aims of the dialogue

An independent facilitator (The Future Foundation) was engaged to run the study, which had the following aims:

- To articulate succinctly the concerns and risk perceptions of the general public resulting from a discussion of the phased disposal concept
- To provide guidelines as to how Nirex can better communicate complex issues and provide readily understandable information to the public
- To inform the technical process with suggestions for the kind of assessment work required to address public fears that may arise
- To assess the effectiveness of the research process as a means of public engagement and to suggest improvements

Additionally, subsidiary aims were identified that were specific to exploring the hypothesis set out in this these – that conceptual models can act as a vehicle for dialogue about the risks involved in deep geological disposal of radioactive wastes.

These subsidiary aims were to:

- develop a conceptual representation of the science underpinning deep geological disposal;
- test whether the public could and would engage in discussion about the science of deep geological disposal if presented with these conceptual ideas;
- consider the impact of this type of dialogue for the presentation of scientific information and the role of the scientist in environmental decision-making.

10.3 Dialogue Methodology

The dialogue was designed to enable plenty of time and open-ended discussion to generate thoughtful responses from the participants. Eight focus group discussions were held with members of the UK public. All groups comprised equal numbers of men and women but their composition varied in terms of age, lifestage and socio-economic circumstances, allowing us to achieve a broad cross-section of the UK population. The groups were conducted in a variety of locations around the country: Carlisle, North London (Cockfosters), Paisley and Cardiff. The Carlisle and North London groups were held in late November/early December 2001, while the Paisley and Cardiff groups were held in January 2002.

The groups were composed as follows:

Carlisle	20-30 yrs	No children at home	ABC1
Carlisle	40-50 yrs	Children at home	C2DE
North London	30-40 yrs	Children at home	ABC1
North London	50-65 yrs	No children at home	C2DE
Paisley	30-40 yrs	Children at home	ABC1
Paisley	50-65 yrs	No children at home	C2DE
Cardiff	20-30 yrs	No children at home	ABC1
Cardiff	40-50 yrs	Children at home	C2DE

People who are or have ever been employed by or connected with (i.e. no close family member employed by) the nuclear power industry, the Ministry of Defence or any other government department were excluded, as were employees of environmental campaign organisations such as Greenpeace, Friends of the Earth and CND. This was to reduce the chances of distortion in the findings of the survey.

Each group of people were invited to two sessions. The first session was a general discussion of the issues of nuclear energy and radioactive waste, while the second session focused on the specific issue of the phased disposal concept. Each session lasted approximately two hours. The two sessions were held on successive evenings in order to maximise the amount of learning and thinking that people retained from the first session and carried into the second session. In addition, by holding the sessions so close together, it was hoped to minimise the degree to which any individual participant was able to discuss the first session with a relative, friend or colleague who might have specialist knowledge or interest in the issues involved and might, therefore, influence the participant's approach to the second session.

The purpose of the **first session** was to bring the participants 'up to speed' in terms of their knowledge and awareness of nuclear energy and radioactive waste. This was considered essential for participants to then be able to address the specific topic of phased disposal. It was also important for establishing the various participants initial positions, so that we could better appreciate their subsequent responses to the idea of phased disposal.

At the start of the session, participants were asked about their spontaneous knowledge of radioactive waste. They were then given printed material outlining the basic issues and facts involved in the management of radioactive waste. Participants were encouraged to give their views on the information that they had been given: what was new to them, what they did or didn't believe, what they did or didn't understand, and whether or not the information had altered their understanding and attitudes.

The **second session** focused on the specific topic of the phased disposal concept. Participants were asked to read an introductory pack that explained the overall framework of the concept. They were then encouraged to share their thoughts on what they had read.

Next, they were lead through a step-by-step discussion of the concept's phases. For each phase, they were given a page of text and an illustration that explained the phase in greater detail. They were then encouraged to comment upon what they had read before moving on the next phase.

The **introductory material** used for the discussions (a combination of printed text and illustrations) was adapted from existing Nirex literature. Printed material was used. In previous focus group discussions (*Establishing the Value of Wider Public Consultation*, November 2000.) it was found that people tended to prefer a written text to, say, a video presentation because they felt that the text gave them a greater sense of control over the subject matter. They were able to read things at their own speed and to re-read bits that they weren't sure about. Also, it was useful for both facilitator and participants to be able to refer to the material during the course of the subsequent discussion.

A summary of the findings is given below. The full report from the Future Foundation can be viewed on Nirex's website www.nirex.co.uk. Throughout this summary, verbatim quotations from the focus group discussions are given in italics.

10.4 Summary of findings

10.4.1 Overall

Generally speaking, the participant's awareness and attitudes were in keeping with findings from previous studies (Future Foundation 2002).

- By their own admission, people knew very little about the issues of nuclear energy and radioactive waste. They had never given much, if any, thought to the matter. Nevertheless, they expressed a strong but vague mistrust of nuclear energy and were cynical and suspicious about the nuclear industry.
- Once they had been given information about radioactive waste, they recognised the importance of the issue and were surprised at how little they – and, by extension, the public in general – knew about such an important topic.
- There was widespread agreement that radioactive waste was a problem that needed to be tackled by the current generation – and participants were surprised and alarmed to read that no long-term solution had yet been agreed.
- For many people, the scale of the problem was a strong argument for stopping nuclear energy now. They were unwilling to separate the issue of waste management from the issue of waste generation. Given that no agreement had been reached on what to do with the existing waste, it was considered irresponsible and immoral to continue producing any more.
- There was strong support for the wider dissemination of information about radioactive waste into the public domain. This was regarded as a prerequisite to proper accountability.

- There was a common feeling that, whilst the public should be kept informed, the final decisions about the management of radioactive waste should be made on its behalf by representative organisations. It was crucial, however, that these organisations should be accountable to the public and open to public scrutiny.
- Participants suggested that, in addition to the wider dissemination of information, accountability and scrutiny could be achieved through two key measures:
  - Involving a cross-section of interested parties in the decision-making process
  - Establishing a credible, independent watchdog to oversee the management of radioactive waste

The views that people expressed were often contradictory. For instance, participants argued that the public should be better informed but they also said that Nirex should concentrate on finding a technical solution rather than wasting time on communicating with the public. They also admitted that they were unlikely in real life to read or watch any material that was produced on the subject. Partly such contradictions stemmed from the fact that people did not have established views on the subject. They knew little about the issue and had never given it much, if any, thought. Consequently, their views were fresh, spontaneous and easily changed in the light of other people's comments.

Participants continued to express contradictory attitudes in their discussion of phased disposal. For instance, they expressed a desire to 'get rid of the stuff' but, at the same time, they argued against the idea that monitoring of the waste would ever cease.

10.4.2 Concerns about deep geological disposal

Many people were reassured by what they read about phased deep geological disposal. The level of detail – especially in the information about the individual phases – reassured them that the experts were giving serious thought to the matter.

"It's the common sense option. I can't see them coming up with anything better."

I'm happier knowing that they're really working at it and trying to make it safe."

"I'm convinced now that it's a lot better organised and safer than I expected."

As in any focus group discussion, the critics of an idea or issue were far more vocal than those who were in favour or who did not have strong feelings. In these sessions, the participants who said that they were reassured tended to be those who did not offer spontaneous opinions. Rather, they needed to be prompted to contribute to the discussion. Their quietness does not mean that their opinions are any less valid (or any less representative of the wider population), but it is inevitable that such a discussion will be dominated by those who were more vocal. Also, the dialogue was designed to encourage participants to express their concerns.

Many participants expressed broad satisfaction with the phased disposal concept 'in theory'. They were concerned, however, about what would actually happen in practice, once the concept was put into action. In particular, they wanted to know:

a) What happens if something goes wrong?

b) How are you going to pay for it?

c) How do you get the timing right?

What happens if something goes wrong?

Participants were not concerned primarily about the routine, day-to-day operations of phased disposal. Rather, they wanted to know what would happen if something out of the ordinary occurred. They were worried about the scale of damage to the wider environment if there was, say, an explosion or a leakage – and they wanted to be reassured that there were mechanisms in place to limit the scale of the damage. Participants queried whether there were back-up plans that anticipated and took account of potential accidents and mishaps. In particular, they were keen to know whether it was possible to close the deep repository immediately in an emergency situation. They wanted to hear that there was some form of ultimate safety option that would contain the potential threat to the wider environment.

> *"They don't say what they'll do if there is a leakage."*
>
> *"Is there a safety feature in place - and I know it's not the ideal option - where you could just seal it?"*
>
> *"Flick a switch and it'll fill up with concrete."*

The concern about 'something going wrong' was crucial with regard to the post-closure phase, since people tended to regard the eventual corrosion of barriers and the leakage of radiation as 'something going wrong', rather than as anticipated aspects of the process.

How are you going to pay for it?

Participants were concerned about how phased disposal would be financed over such enormous timescales. They wanted to know how a budget could be ensured for the hundreds and thousands of years that would be involved. People were worried that money for the project would eventually run out and the waste would not receive the proper attention to ensure its safe management.

"How much money have they got?"

"Who's going to keep funding it? Because if the company went bust, well, we're not going to pay for all the people working [in the repository]. It's going to be quite expensive, isn't it?"

"Someone will have to be paid to look after this stuff. The more dangerous it gets, the higher the price."

How do you get the timing right?

Some participants could see that the success of the concept rested on 'getting the timing right' – that is, on containing the waste for long enough for its radioactivity to decline to acceptable, background levels. Given that timing was critical, participants were concerned that they were not being given more precise timescales. In this way, the flexibility of the concept was seen as a negative attribute. They considered phrases in the prompt material ('at a future date', 'at a measured pace', 'at an appropriate time', 'for a period of up to several hundred years') to be too vague.

Participants wanted to understand the basis for scientific and technical models and forecasts.

- How can scientists know how long a material will remain radioactive?
- Given that mankind has only been producing radioactive waste for a few decades, how are scientists able to extrapolate the waste's behaviour over the course of hundreds and thousands of years?
- And how do they know how the materials of the barriers (for instance, the stainless steel canisters, the backfill cement) will interact with the radioactive waste over the very long term?

"I don't think they can forecast what condition the container or the cement will be in a thousand years."

10.4.3 Prompted concerns about what happens after the repository is closed

During the second session, participants were asked for their comments on specific stages of deep geological disposal. In some cases, these concerns were prompted by the facilitator's questioning. The issues that arose when discussing the post-closure stage are outlined below.

Most participants were disturbed by the idea that there would ever be an end to human management. They argued that monitoring should continue for as long as the waste exists.

Furthermore, many participants resisted the idea that the containers – like any other material – could not be guaranteed to last forever. They were worried that, over the long timescales under consideration, the containers would eventually corrode and that the radioactivity would dissipate into the surrounding geology. Corrosion of the containers and leakage were regarded as 'something going wrong' rather than as being anticipated and acceptable developments in the phased disposal concept.

> *"They can't guarantee that the things they put them in will last forever, can they?"*

The potential for leakage was all the more alarming if the sealed repository was no longer being monitored.

> *"It's a bigger problem with it sealed than if it's open."*
>
> *"Surely you can't just lock it away and throw away the key and forget about it. Someone's got to monitor it."*

People expressed a fear that, without monitoring, the location of the repository would be forgotten and that future generations would build housing on contaminated land above the site.

> *"I don't like to think of loads of these places underground, under housing estates, under children's playgrounds, or whatever. I mean, we're going to move... and we're going to build in different places."*

The major concern about the post-closure phase was the question of 'getting the timing right' – that is, containing the waste and isolating it from the wider environment long enough for the radioactivity to decline to acceptable levels. Participants were worried that there would be leaks while the waste was still dangerous and that the leaked radioactivity would reach the human environment on the earth's surface.

> *"What if it corroded quicker than expected?"*

Participants were concerned about whether Nirex knew enough about future geological developments to be sure that the radioactivity would be contained.

- What would be the impact of earthquakes?
- Or the shifting of tectonic plates?
- Could the level of the land fall, so that the repository was no longer so deep underground after thousands of years?

- What were the implications of rising sea levels?
- Some of the Carlisle participants, who were familiar with the RCF refusal, were concerned about the impact of groundwater and the need for the repository to be sited in a suitable geology.

Underlying people's unease about post-closure was their desire for a 'full stop' to the whole process. Many people accepted that there was no 'magic wand' solution – and that the reality of the waste's existence could not be simply wished away – but they continued to hope for a 100% guarantee of safety, which phased disposal does not provide.

> *"They say 'decrease the risk', but they should say, 'There's no way it's going to happen.' It's not very reassuring, is it?"*

This desire for a definitive resolution explains the popularity of partitioning and transmutation – the idea that radioactivity can be reduced or removed (but, again, we stress that participants were not actually given any detailed information about P&T).

10.5 Reflections on the dialogue design

Useful material to guide the development of an analytic-deliberative approach to performance assessments can be obtained from looking at both the outcomes of the dialogue process and the process by which it was developed.

The design stage was a crucial aspect of this study. Initially, experts within Nirex[a] and the facilitator from the Future Foundation discussed ways in which the science of the Nirex Phased Disposal Concept could be presented. We set out to have a lateral discussion about how to structure discussion material for this trial in a manner not necessarily influenced by how scientific research is managed within Nirex, nor the manner in which scientists tend to think of the environmental impacts.

The scientific basis for deep geological disposal is often presented as a set of discrete topics. In 2000, Nirex published three separate "Foundation Reports" describing the science and engineering basis for deep geological disposal. The "Generic Assessments" published by Nirex in 2001 describe the phased disposal concept and its associated risks in detail and are similarly divided into three discrete assessments which capture the

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[a] My thanks and acknowledgement to Brendan Breen and Elizabeth Atherton.

outcome of extensive research programmes managed by three separate departments within Nirex (Table 23).

Table 23 Management of technical research within Nirex during 2002

Department	Research directions	Generic assessment
Engineering	System design, operational safety	Generic Operational Safety Assessment
Packaging and Transport	Package design, transport safety, packaging advice	Generic Transport Safety Assessment
Science	environmental and repository evolution	Generic post-closure performance assessment

With extensive cross-departmental working and integration this is a valid means of managing a research budget involving a wide range of different scientific and engineering expertise. However, it does not necessarily provide an appropriate structure for presentation to non-expert audiences for the following reasons:

- the distinction between science and engineering is not clear and is slightly different for different people;
- the distinction between different scientific disciplines is not obvious;
- the public will not necessarily distinguish between the operations of a facility and its subsequent evolution or impact;

Therefore, it was felt that using the generic assessment structure might not be helpful to the discussion of perceived hazards and concerns. It was felt that such an approach could both end up leading the consultation exercise and could promote semantic debate about definitions. Either of these outcomes would divert precious time away from the aim of the consultation work – to identify perceived hazards and concerns about the phased disposal concept, regardless of where they would impact the research programme.

Nevertheless, some structure was felt necessary. The Nirex Phased Disposal Concept identifies a series of different stages in the life of a repository for the long term management of radioactive wastes. These are:

- Transport to a repository site;
- Emplacement of waste in a repository deep underground;

- Underground monitored storage with the option of waste retrieval
- Sealing of the repository
- Post-closure period

These occur sequentially and provide a way of structuring thought about the repository based on time horizons. Since the long time for which radioactive wastes will be hazardous is identified as one of the main difficulties in making decisions about radioactive waste management, it was felt that structuring on the basis of time would be a useful way of developing discussion guides for the consultation exercise.

10.6 Reviewing the output of the dialogue

The aims of this trial were to test whether people could and would engage in discussion about the science of deep geological disposal and consider the impact of this type of dialogue for the scientist. Lessons can be learned from this exercise by analysing both the output of the consultation and the process of undertaking the consultation.

10.6.1 Is engagement possible?

In order to determine whether people can and will engage with the science of deep geological disposal it is useful to consider the output of the consultation process itself. The Future Foundation report contained in Appendix F provides a significant amount of analysis of the output of the consultation process. In summarising the exercise, the Future Foundation concluded that:

"The research exercise for this project was undoubtedly a demanding one: members of the public were being asked to read and discuss a considerable amount of printed material on a complex issue that they knew nothing about. Nevertheless, we found that people were able to engage with the subject matter and expressed considerable interest in the information that they had been given. Furthermore, they were able to comprehend the broad outline of the phased disposal concept and to articulate their responses to the concept and its different phases."

Therefore, it seems that people can and will engage with a highly technical issue.

10.6.2 Was the information useful?

The Future Foundation's report includes a lot of comments that relate to the value of the discussion material for the participants. The report states that:

"Many participants commented that there was a limit to the amount of information that they felt able to take on board in a single reading. While few claimed to have had trouble

actually understanding the material, several people said that they would have liked more time to absorb what they had read. On the evidence of the discussion that followed, it was apparent that participants had indeed followed much of the information – but also that there was plenty that they had not absorbed or had only half-understood. Crucially, it was clear that some participants had not picked up all of the key elements of the phased disposal concept – either at the end of having read the prompt material or even at the end of the whole discussion."

Nevertheless, in the limited time available to them, it seems that the participant absorbed a considerable amount of information and were able to contribute significantly to the technical debates and discussion about the Nirex Phased Disposal Concept.

10.6.3 What were the issues of concern?

Comparing published statements about key research areas [Nirex 2001] with the list of frequently asked questions provided at the end of the report also establishes that the public were able to articulate points of technical detail that are very relevant to the research areas of expert scientists. I have reproduced the list of frequently asked questions directly from the Future Foundation's report in Box 6. The list is not structured in any way although it broadly reflects questions about the different phases of the disposal concept and hence broadly relates to ever more distant times into the future.

The issues raised in Box 6 cover an immensely broad range of topics from technical question to cultural concerns, management issues and questions about design. Embedded within the issues raised in Box 6 are some "showstopping" questions and some trivial issues. Determining which are the showstoppers and which are trivial will be a matter of perception and cultural perspective. The issues are raised in a very superficial manner and many of them would split into a number of subsidiary issues if explored any further. This suggests that visual language, with its hierarchical approach to information, offers some potential to assist dialogue about the issues.

The public articulation of the issues identified in Box 6 is not necessarily given with the level of technical accuracy and precision that experts may have come to expect, and is generally not framed in the same way. For example, the focus groups identified a very real concern with "*getting the timing right*", which has been highlighted strongly in the Future Foundation report. The translation of this provided by the Future Foundation is that

"People wanted to understand the basis for Nirex's scientific and technical forecasts. The precision of these forecasts was regarded as crucial, given that the success of the concept rests on 'getting the timing right' – that is, on containing the waste and isolating it from the wider environment long enough for the radioactivity to decline to acceptable levels."

This shows that the focus groups identified and engaged with the crucial issue in the long-term management of radioactive wastes – mitigating any potential exposure to radioactivity for the very very long timescales for which the wastes can remain radioactive. This concern drives the majority of Nirex's research on environmental and repository evolution and post-closure risks assessments (technical forecasts).

The Future Foundation report identifies that: "*the transportation of radioactive waste was probably the largest concern expressed freely*" and "*Participants also expressed considerable unease about the post-closure phase*". These two stages of the Nirex Phased Disposal concept represent the one with the most direct and tangible impact (transportation) and the one over which society retains no control (post-closure). These concerns influenced a lot of the comments made during consultation and seemed to lead people back to one or two central issues such as the sheer quantity of waste in existence and the enormous timescales involved.

10.6.4 Was the dialogue appropriate?

There were some indications that the context for the dialogue was not clear to the participants. The UK national situation is one of policy review and formulation with no firm option being supported by the Government. However, participants were being asked to comment on a specific option. Additionally, in the Future Foundation's reports there are some indications of a reaction to being asked for concerns – as if it meant that the experts didn't know what they were doing.

Participants were unhappy because, as they had already said, they believed that the public should be kept informed but that it was inappropriate for the public to be responsible for decision-making about the technical management of radioactive waste.

Some participants said that they didn't want to be given any details, let alone be told about the different options. They simply wanted to be given a guarantee of safety, to be told that the problem had been dealt with. Until they attended the focus group, they hadn't given any thought to the issue – or even been aware that there *was* an issue – and now they wanted to be given reassurance that they wouldn't need to worry any further about it.

- *"I just want to know that it's safe."*
- *"If the top scientists in the world agree that the best thing is to put it 5 miles underground, then put it 10 miles underground…Be doubly safe."*
- *"Explaining it raises doubts in people's minds."*
- *"The more you make an issue out of it, the more people are going to be worried."*

10.6.5 What could help in the future?

The Future Foundation commented that the discussion moved back and forth over certain issues to an "unusual degree". They state that:

"This curious fluctuation in the discussion suggests that many participants had only a tentative grasp on the information that they had been given, due to the complexity of the issues involved and the short length of time they were given to absorb the material. By moving onto the more detailed, complex issue of phased disposal, we were taking people further and further away from solid ground. After all, they had only been introduced to the general topic of radioactive waste on the previous evening and had not had any opportunity to consolidate their basic understanding before moving on to a discussion of the phased disposal concept"

This suggests that there should be limitations to expectations about public engagement with technical detail. The Future Foundation conclude that:

"People need the 'building blocks' of knowledge about the general issues of radioactive waste before they can move on to discuss a more detailed, complex topic such as the phased disposal concept."

However, many participants took confidence from the material that was presented. The Future Foundation report that:

"Many people were reassured by what they read about phased disposal. The level of detail – especially in the information about the individual phases – reassured them that the experts were giving serious thought to the matter.

This is encouraging since it suggests the participant were recognising the complexity of the issue being addressed and allowing that a lot of expertise was being applied to the issue. In the Nirex 95 performance assessment which formed the basis for the discussion of science at the RCF Public Inquiry, the emphasis of the scientific material is on risks – elimination, mitigation and identification. So although there can have been little doubt about the level of scientific effort being put into the issue, it is not surprising that the message communicated at the Public Inquiry was one of uncertainty and lack of knowledge.

So the choices made about the style of the discussion material seemed to be effective in enabling debate.

10.6.6 Implications for the scientist

A number of lessons about developing scientific material for consultation purposes can be learned from process of conducting this trial and its output. These are outlined below.

The public will not necessarily engage with a scientific subject in the manner with which the scientists approaches the same subject. This has already been highlighted in Chapter 8. The scientists needs to understand this, and be prepared to work with a different articulation of issues than that which may arise from peer group. It does not necessarily mean that the insights from public consultation are less valid.

Culture and mindset will influence the manner in which any individual presents information for dialogue and may give an impression markedly different to the one desired. This happened twice during the development of the discussion material for this consultation exercise.

The first occurrence was when the facilitator was developing a consultation guide, as agreed, on the stages of the phased disposal concept. The first draft of the guide ended at repository closure. On reflection, this is a natural enough conclusion for the non-expert to make. However, one of the most difficult areas of scientific research into deep geological disposal is into what will happen post closure. The importance of this stage had obviously not been conveyed to the facilitator, despite the fact that it is fundamental to any consideration of environmental hazards from the Phased Disposal Concept.

The second occurrence where my mindset and culture was a barrier to communication was when the facilitator sought to rectify the omission of the post-closure stage in his consultation guide. Having been referred (by me) to a recent publication on post-closure behaviour (which I co-authored) he identified that what Nirex was concerned about post closure was finding the best route for radionuclides to return to the surface environment. This is almost diametrically opposed to what we are trying to do – which is to contain the radionuclides under the ground for as long as possible. However, because the focus of the Nirex scientific work is on researching what could go wrong, we can forget to discuss the conceptual reasons for disposal deep under the ground. This mindset clearly affected the manner in which I conveyed information about the post-closure stage of the Nirex Phased Disposal Concept to the facilitator.

The key point from this experience was that I had to iterate with the facilitator in order to develop a shared understanding of the information we wished to provide to the discussion groups. As a result of this iteration, we both learned and were able to shift our respective positions to develop information that was hopefully more relevant and appropriate to the intended audience. The opportunity for this iteration therefore influenced the success of the subsequent dialogue. I had to learn to see this iteration as necessary and valuable, rather than as a failure on my part to communicate "my" science.

Another lesson to be learned from the consultation exercise, was that the public want experts to be authoritative. The Future Foundation report a degree of reluctance to express an opinion. This is, in itself a barrier to dialogue which cannot be addressed by considering more conceptual presentations of an environmental issue. The Future Foundation record that :

"Participants argued that they lacked the scientific knowledge to form a valid opinion – and, realistically, they would never acquire the levels of expertise possessed by scientists who deal with the issue on a daily basis. They had no means to assess the scientific and technical bases to the phased disposal concept".

Furthermore, some participants argued that the little knowledge they did have (and which they based their opinions on) was derived solely from the introductory material that they had been given to read. They had no way of knowing how accurate or exhaustive this information was – and, therefore, they had no way of knowing whether or not their opinions were rooted in solid facts and sound arguments.

This finding reflects conclusions within the academic literature [Pette and Leach, 2000] that public consultation benefits from the provision of expert information from many different sources. In the case of this consultation exercise, the discussion material provided was developed linearly on the basis of the sequential stages of the phased disposal concept. It was produced by Nirex experts and contained no discussion of alternative viewpoints. No alternative opinion was provided to the consultation process and this clearly affected the contributions made by the participant.

This suggests that the provision of material from a single source is not sufficient to overcome the problem of institutional trust.

10.6.7 Can people, and do they want to engage with scientists in building knowledge about environmental hazards?

The work described above indicates that the public are capable of engaging with the concept of deep geological disposal at a "scientific" level. The format used – two sessions of two hours long was not as long as other forms of consultation such as citizens panels or public meetings. Nevertheless, the participants were able to assimilate a large amount of knowledge and respond with astute and relevant questions.

The results of the consultation and the questions asked during the consultation demonstrated an interest in the topic and an agreement of its significance and importance.

Whilst some concern about why scientists were consulting with the public was expressed, this seemed to be more motivated by the lack of context provided and a mistrust of Nirex, rather than science.

Similarly, review and discussion of the presentational material generated a lot of comments that indicated a raising of interest levels and a heightened awareness of scientific concepts influencing the role of the geosphere in deep geological disposal. Indeed, the review gave rise to a number of valid challenges to the scientific mindset. Sometimes the opposite impression to that intended was given. The fact that this was identified and discussed is evidence that engagement and dialogue was being achieved.

However, the results of the consultation give strong indications that the public will not necessarily respond in the manner expected by the scientists or by those preparing briefing material. At the very least, the level of understanding of science will vary dramatically. The expert could choose to view the frequently asked questions recorded by the facilitator could be regarded as naïve. Unless scientists manage their expectations, it is possible that the knowledge that could be gained from public consultation may not be fully appreciated.

10.7 Conclusions for this thesis

An impressive aspect of the consultation was the speed with which, once the engagement had begun, the participants got to the really key (and tricky) issues associated with radioactive waste management. Whilst they were not articulated in the manner used by the decision-makers and technical experts, the participants targeted similar points to those being raised by the experts. Many of these points, for example, the way the industry is organised, the behaviour of the industry, the agendas of the key players and the need for openness are reflected in current UK thinking about developing a future policy.

The findings of this study, on the very specific topic of deep geological disposal, supports the general literature discussed earlier. There is interest in the topic of radioactive waste management, stakeholders and public constituents can engage with it and make sense of even highly technical issues but the opportunities to do so need to be created. The question is, how can this interest be stimulated and engaged in the knowledge building processes adopted by scientists?

The facilitator recorded that the consultation exercise was undeniably demanding on the participant since they were expected to *"read and discuss a considerable amount of printed material on a complex issue that they knew nothing about"*. Nevertheless, a considerable amount of simplification went into preparing the discussion material for the consultation exercise – and this was by scientists and engineers committed to making their work transparent and open to wide discussion. So there are very different definitions of what constitutes scientific complexity between those trying to convey the science of deep disposal and those seeking to engage with it.

This difference is also evidenced by the review of what experts and non-experts think about performance assessment – work undertaken by the French as a contribution to the RISCOM project [EDF 2001]. It was noted earlier that, based on an analysis of value judgements, the focus of attention for experts was at a completely different level than those which were the focus for non-experts. In essence, different epistemic communities have very different frames for viewing the scientific underpinnings of deep geological disposal, depending on culture and training.

This conclusion suggests that the idea of engaging the public by seeking to improve the communication and presentation of performance assessment *as defined by the experts* has limited application in improving the engagement of, and dialogue with non-experts. Hence the focus of this research used two of the highlighted issues to come out of the dialogue work for further investigation. These were the issue of the long timescales involved (how do you get the timing right?) and the interest in what happened under the ground when the repository was no longer under any form of human control.

A key finding from the study was the dawning awareness of the issues raised by the long term nature of the problem of radioactive wastes was also significant, particularly when coupled with the alarm that this began to raise in people' minds. It suggests that it is possible to ask people to engage with the longer term post closure performance issues. However, in doing so it would be very easy to undermine confidence in the concept of deep geological disposal before any meaningful dialogue had taken place. This appears to be a matter of risk communication which is worth some attention. In response to this finding, Chapter 11 examines new ways of communicating the results from analyses designed to assess the environmental risks once a repository has been closed.

This dialogue process indicates that stakeholder engagement will not necessarily conform to the expectations of experts. The issues of concern, the linking up of issues and the manner of discussion were a surprise to the experts. The desire for material from a range of sources has also been highlighted. In Chapter 12, new ways of presenting the scientific basis for deep geological disposal, in order to build knowledge about risks is presented and tested. And finally, Chapter 13 draws together all these studies an offers a revised methodology for the assessment of risks associated with deep geological disposal based on scientific analysis and stakeholder consultation.

Box 7: Technical questions that people would like answered

Why does Nirex use stainless steel for its containers? Isn't lead a more effective means to contain radioactivity? Isn't titanium more resilient and longer lasting?

Aren't the walls of the 500 litre drum too thin? Wouldn't they be easily damaged or pierced? Hasn't Nirex thought about making the walls thicker?

Is cement effective as waste packaging and backfill? Is Nirex proposing to use normal cement from the local hardware store?

Why has Nirex chosen 4 cubic metres as the size for a box? And why a 500 litre drum? Why not use a bigger container – or smaller?

Why can't you just keep on repackaging the waste?

Why would you ever need to repackage the waste? Why not get the packaging right in the first place?

How do you put waste into a container without contaminating the outside of the container?

Does conditioning produce more waste?

Can I stand safely next to a container?

Is anyone else testing and monitoring Nirex's specifications?

Do Nirex staff visit the waste producer sites? Does they take the waste packages away and test them at Nirex's laboratories?

Why do the waste packages need to be placed inside transport containers? Does this mean that the packages aren't adequate?

Would a lorry carrying radioactive waste be given a police escort? Would the vehicle be marked or unmarked?

Has a test crash been conducted on a transport container with actual waste inside? Is it possible that the impact of a crash would trigger some kind of reaction or explosion in the waste?

Would transport containers be able to withstand a fire generated by aviation fuel?

Why do the waste packages need to be taken out of the transport containers on arrival at the repository? If the containers afford an extra level of containment and protection, then why remove them?

If the waste packages are safe, then why do workers need to be protected by shielded bays?

If the packaging is effective in containing the radioactivity, then why would there be any need to monitor contamination of the rail tunnel and vertical shaft?

Is it more dangerous to have the waste distributed at different sites or to stockpile the waste in a single location? Does putting all the waste together increase the risk of an accident or explosion?

Has an underground repository already been built? If yes, then why isn't it already being used? Is there a technical reason for needing to keep the waste packages on the surface for a few more decades?

Where will the repository/repositories be built?

How will you dig a hole big enough for a repository? Won't the earth on top of the repository be looser than before (because you've dug it up)? And won't that affect the ability of the geology to contain the waste?

Has anyone ever built anything this far down? On this scale?

What is the capacity of the repository?

How many vaults are there going to be?

How quickly will the vaults be filled up?

What will be done with the additional waste that is generated in the future? (Based on an assumption that the proposed repository would only accommodate the waste that is currently in existence.)

Is the repository a fixed size? Or can it be expanded to accommodate additional waste?

How many repositories need to be built?

Won't the weight of all the overlying rock crush the vaults and the containers?

Will it be possible to close the repository immediately in an emergency situation?

What would happen if there was a spillage in the contaminated areas? How would it be dealt with?

What would happen if the overhead crane malfunctioned? How would it be retrieved and repaired?

How would the waste packages be monitored? Would monitors be fitted on the inside or the outside of each container? If there was a leakage, would the monitors remain intact or would they be damaged by the radioactive materials?

What are the 'acceptable levels' of radiation that workers would be exposed to? What does acceptable' mean?

How do you decontaminate things?

What happens to the water that is used to decontaminate things? Does it wash away into the wider environment?

Are you going to have a drift tunnel or a vertical shaft – or both? Why can't you decide which is best?

Will you backfill everything (ladders, rooms, etc) – or just the vaults containing the waste packages?

Would it be possible to retrieve the waste packages from the backfill?

Can the repository be accessed after closure? Is anything ever really sealed and closed?

Have you got enough cement to carry out all the necessary backfilling and the sealing of the repository?

What would be the impact of earthquakes on the repository and the waste?

Or the impact of shifting tectonic plates?

Could the level of the land fall, so that the repository was no longer so deep underground after thousands of years?

What are the implications of rising sea levels?

How do scientists know how long a material will remain radioactive?

Given that waste has only been generated for a few decades, how are scientists able to predict the waste's behaviour over the course of hundreds and thousands of years?

How do scientists know how the materials of the barriers (for instance, the stainless steel canisters, the backfill cement) will interact with the radioactive waste over the very long term?
How can scientists be sure that the materials won't behave differently once they're placed at deep levels?
Once the repository has been closed, how will people know if there has been a leakage?
Are you expecting that waste will eventually leak out of the containers?
Is rock effective at stopping the spread of a leakage? How long does it take for radioactivity to travel through rock?
If there's a leak underground, does the radiation go up or does it go sideways?
How do you limit the spread of a leakage into the surrounding geology once it has started?
What would be the impact if the radiation did leak to the surface?
What impact will groundwater have on the vaults and containers?
If you dropped a bomb on a storage facility, would there be a nuclear explosion?
Can you make a bomb from the waste? Can containers be turned into weapons?
If there was an explosion or leakage, how far away would people need to be to be safe?
What is going to be done with high level waste?
What are the precise timescales for each phase?
Would the repository take in other country's waste? Or are we just dealing with UK waste?
What are other countries doing with their waste?

11 CONVEYING PERFORMANCE IN TERMS OF TIME AND EVOLUTION

11.1 Introduction

The dialogue presented in the preceding chapter identified the long timescales and the lack of human control as issues for non-expert stakeholders. Previous work has highlighted the importance of style in the presentation of information into dialogue. In this chapter the possibilities for making the timescales and output of the performance assessment more comprehensible are considered. A critical issue under investigation here is whether the performance of a potential repository can be made more accessible to wider audiences without compromising its ability to meet the requirements of the regulator. In part, this is looking at the notion that demonstrating compliance with quantitative regulatory criteria have been allowed to overshadow more qualitative indicators of performance and that this has moved the performance assessment outside the realm of interest to the wider stakeholder community. The work was undertaken primarily in discussion with performance assessment specialists.

Regulatory criteria tend to focus on doses or risks. However, over the past decade, the regulators have made significant efforts to increase emphasis in regulatory guidance on qualitative measures of performance [EA, 1997]. This has had the effect of shifting the debate about performance a little and encouraging scientific debate on the effectiveness of each of the engineered and natural barriers.

This means that it is appropriate for a performance assessment to consider both the manner in which each barrier contributes to safety and the extent to which they are likely to perform. The results need presentation in close association with a discussion of the underlying scientific reasoning. In particular, discussions of barrier efficiency should refer directly to key experiments and natural evidence and openly debate the uncertainties. This is increasingly being recognised and reflected in more recent assessments of performance [NEA, 1997, Nirex, 2001f] and also in regulatory guidance documentation [EA, 1997].

11.1.1 Aims

The aim of this work was to explore ways of making the scientific knowledge about the long term evolution of the repository more transparent by considering how to represent performance in a meaningful way.

Nirex assesses the risks from radioactive waste management facilities in a number of ways. As discussed in Chapter 8, "post-closure" performance assessments evaluate the possibility of environmental contamination once a repository is no longer being managed by humans. These assessments primarily aim to represent the behaviour of a radioactive waste management system for millions of years into the future. They therefore seek to capture and quantify complex science and uncertainty. Methods for assessing performance have been developing over the past twenty years [NEA, 1997] as a result of increasingly sophisticated analytical methods and developing experience in setting environmental standards. Earlier chapters raise the question whether greater focus on conceptual understanding could help dialogue about risks with both regulatory and non-regulatory audiences. The work on visual language presented earlier is one way of raising the profile of conceptual knowledge. Another is to consider how to represent conceptually the information coming out of the risk models.

11.1.2 Approach

The work included reviews of current trends in the communication of complex information, not solely in the nuclear industry. Additionally, feedback on different presentations of results was sought, from both scientific and non-scientific audiences. The application of these studies to the presentation of performance assessment was considered, in order to identify potential developments for future assessments.

11.2 Envisioning information

The output of a post-closure performance assessment is typically shown graphically as the variation in "expectation value of risk" over a million years. Furthermore, the variation in risks associated with individual radionuclides is commonly given as well, often on the same plot. Wrapped up in this single representation of risk is a plethora of complexity in terms of possible futures, important features events and processes, knowledge and lack of knowledge about data – all the information identified in Chapter 8 that has been translated via the risk analysis into a calculation of risk.

In his book "The visual display of quantitative information"[Tufte, 1983], Edward Tufte explores the way in which graphical representations can either encourage or discourage reasoning. He concludes that

"*What is to be sought in designs for the display of information is the clear portrayal of complexity. Not the complication of the simple: rather the task if the designer is to give visual access to the subtle and the difficult —that is,*

the revelation of the complex,."

Tufte has worked extensively in the area of how to design graphics to convey understanding and he identifies six principles to be followed [Tufte, 1997]:

- The representation of numbers, as physically measured on the surface of the graphic itself, should be directly proportional to the numerical quantities represented

- Clear, detailed and thorough labelling should be used to defeat graphical distortion and ambiguity
- Show data variation, not design variation
- In time-series displays, deflated and standardized units of monetary measurements are nearly always better than nominal units
- The number of information carrying dimensions depicted should not exceed the number of dimensions in the data
- Graphics must not quote data out of context.

A typical representation of risk from a post-closure performance assessment does not conform to a number of these principles. In particular, to accommodate the long timescales involved, logarithmic scales are used with exponential labelling. Key events, such as the changing role of the engineered and natural barriers in containing radionuclides are not shown at all on a typical risk/time curve.

So in terms of conveying performance, existing post-closure performance assessments focus very significantly on a single, lumped representation in which a number of complexities are bundled together to represent repository performance over very long timescales into the future. This brings its own difficulties in terms of envisioning results. Conceptually, this form of presentation does not begin to give an idea of how the repository may evolve over time.

However, presenting the safety concept and the conceptual understanding underlying the post-closure performance assessment in a manner which is accessible to a wide range of audiences therefore requires careful thought. "Information overload" is a common complaint for many issues where complex ideas need to be conveyed to a wide range of audiences. However, it has been suggested that problems with information overload are less a function of the volume of information han the gap between the compiled information and the audience's ability to make sense of it Horne, 1998]. Recent advances in techniques for mapping ideas and combining visual and verbal skills could be applied for the presentation of performance assessments. Such skills are in common usage in journalism, advertising and the design of hands-on dynamic computer displays and are increasingly being applied to the presentation of scientific data [Tufte, 1983]. The power and accessibility of the conceptual basis of a performance assessment could be enhanced if it was graphically presented using some of the novel ways of combining ideas and visual images.

One of the problems with communicating concepts about the long term evolution of the disposal oncept is the complex interaction of events and processes which could possibly affect it. A omprehensive scientific description of all these possible events, the permutations resulting from heir interactions, and associated uncertainty could give rise to a rather indigestible treatise which would do very little to contribute to debate and dialogue. Those reading it would probably be considered to be experts, and the ensuing dialogue would be over the areas of the conceptual presentation with which they disagreed. It is uncommon for experts to identify areas of agreement when engaged in scientific debate. Other interested parties hearing the debate receive a reinforced sense that the "experts" cannot agree over the disposal concept. Therefore it becomes easy to mistrust claims of safety or expressions of confidence by scientific experts.

However, techniques for mapping debates are being developed [Horne, 1998]. In the preceding chapter, the concept of "visual language" is used to capture the essence of the safety concept and the areas of ongoing scientific debate (representing areas of scientific uncertainty). The hierarchical presentation of this information seeks to enable audiences with different levels of expertise to consider the conceptual understanding and associated levels of uncertainty in a manner appropriate to their level of interest.

In this chapter, the emphasis is on conveying the results of a risk analysis in a descriptive manner aimed at responding to the more qualitative aspects of environmental standards and regulations for the disposal of radioactive wastes [EA, 1997]. The work focusses on two aspects:

- Presenting the time dependency of the results with much more clarity; and
- Conveying repository performance without resorting to risk results

Earth science can assist in both these areas. The historical timescales of interest to the earth scientist are on a par with the future timescales of interest in a post-closure performance assessment. Additionally, the descriptions of environmental processes and multiple evolution hypotheses provide the foundations of earth science analysis as well as the basis on which to describe future repository performance.

11.3 Presenting results for long timescales into the future

Traditionally, the results from Nirex post-closure performance assessments have been presented in terms of graphs showing how calculated radiological risk varies with time. It is often difficult to gain an appreciation of the timescales under consideration since they extend for millions of years into the future. The presentation of risk/time graphs makes very little concession to non-scientists or to the fact that factors affecting the perception of risks from a repository will be different in different timeframes. In particular:

- the function of the different components of the repository system will change
- the validity of different indicators of performance will change over time
- the relative value of quantitative risk modelling and qualitative arguments will change
- the level of concern (about different timeframes into the future) felt by stakeholders will vary.

The presentation of results therefore needs to give some meaning to the timescales under discussion and also recognise the need for assistance in understanding the terms used in a graphical representation of risk. Such presentations may have a significant impact in terms of promoting dialogue.

11.3.1 Representing time

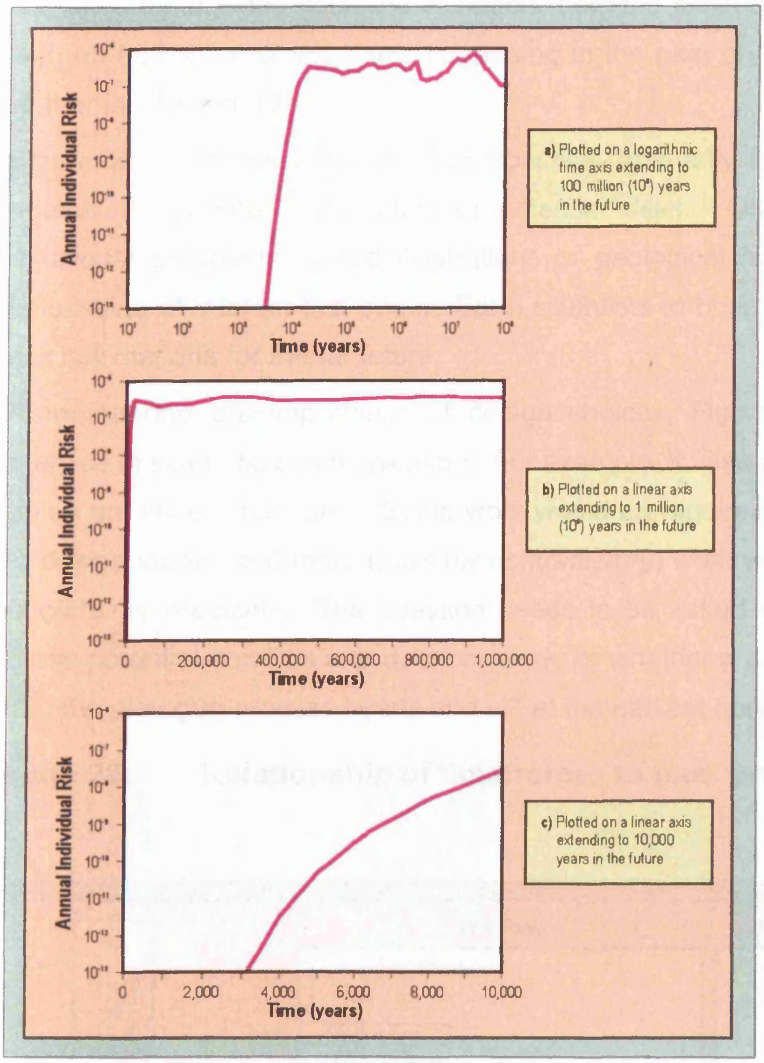
The very long timescales considered in a post-closure performance assessment are difficult to assimilate. In past assessments, most attention has been focussed on times in excess of thousands or tens of thousands of years into the future. There are large uncertainties inherent in making assessments over this timescale. In addition, it is very difficult to convey the magnitude of the timescales involved to the general public. Continuous risk against time plots do not present results in a manner which addresses either of these points because:

- the line indicating expectation value of risk tends to be taken as indicating a best estimate prediction of risk;
- especially on a log scale, it is not possible to meaningfully convey temporal yardsticks such as time since civilisation started;
- it is not scientifically justifiable to seek to match predictions to observations for specific times in the future, given the small amount of information upon which such predictions are based and the uncertainty in this information;
- the cursory impression created by a continuous risk plot can vary significantly depending on the choice of scale.

To illustrate this point, Figure 25 shows the same data from the generic post closure performance assessment [Nirex, 2001f] (how the risk from the proposed repository changes into the future) plotted against three different time axes. Each representation reflects a different stylisation of the same data and the impression given by each graph is very different. Since the stylisation and the manner in which the data are represented are design *choices* they are subjective. The question is therefore whether the design choices are equally legitimate. If not, then the legitimacy of any stylistic representation of a more complex dataset can ever be legitimate.

Good communication practice might suggest that time be plotted on a linear, rather than logorithmic scale (see plots b and c in Figure 25). However, in comparison with plot a, does it help to give the impression that high risks arise early in the time period under consideration (plot b) or that the risks are still rising at the end of the time period under considerations (plot c)? Partly this problem arises because the plots all relate to a single time-period (100 million years for plots a and b and 10,000 years for plot c).

Figure 25: Risk variations with time plotted on different time axes



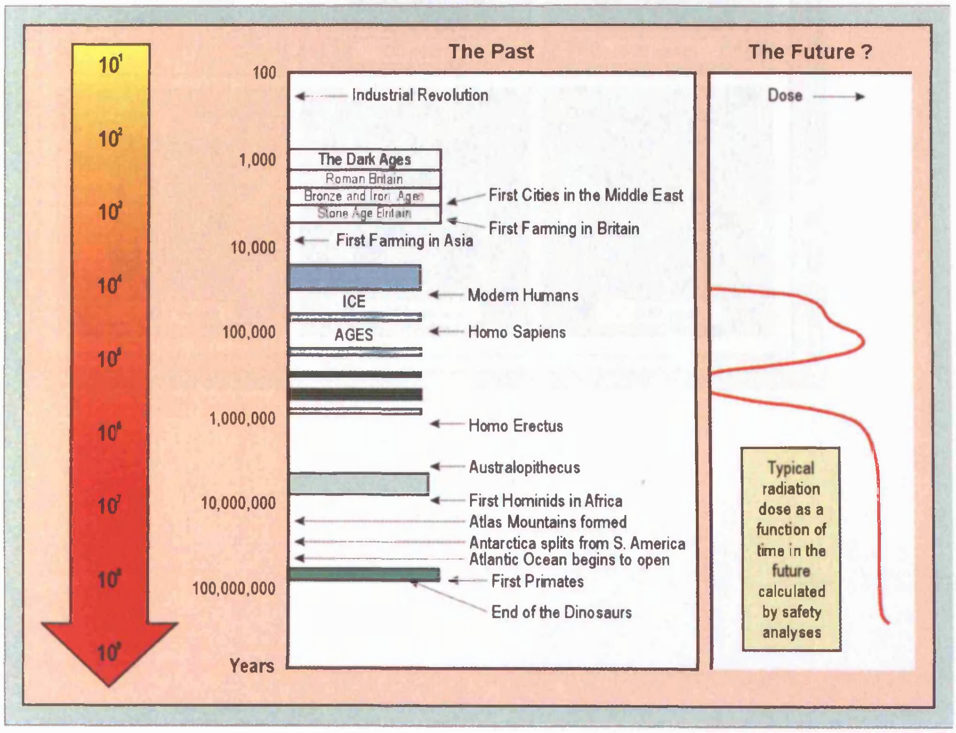
Another problem with the plots illustrated in Figure 25 is that the risks are plotted on a logarithmic scale and use numbers that are relatively meaningless. Partly this is because a single parameter (risk) is being defined to cover a tremendous period of time, and the root causes of the risks in different timeframes will vary. The plots therefore end up capturing a multitude of issues in a single parameter which. Of necessity, this parameter becomes fairly coarse, particularly when the myriad sources of uncertainty are taken into account, as discussed in Chapter 8.

Breaking time down into several periods may help overcome some of the design issues raised by seeking to represent the variation of one parameter over a single timeframe. Therefore, other presentations that explicitly seek to provide a meaningful representation of time have been suggested. For example, risk estimates for particular time frames (e.g. 1 to 100 years, 100 to 1000 years etc) would enable differentiation between different timeframes for which different processes may be significant or for which there are different levels of concern. The main events in these identified timeframes could be indicated (perhaps pictorially) to give further perspective, possibly with an indication of what was happening in the past on the same timeframe. This idea is taken further in Chapter 13.

Figure 26 illustrates a historical perspective, (primarily from anthropological history) juxtaposed against a schematic illustration of potential risks. Obviously Earth scientists could provide additional perspectives and illustrations of geological history and it is this familiarity with the timescales of interest that enable Earth scientists to bring a special understanding to the result of risk calculations for the far future.

Remembering the importance of design choices, Figure 26 contravenes many ideas of best practice in scientific communication. For example, it uses a logarithmic scale and talks about dose as an undefined measure. Some work would be required to modify Figure 26 so that it conforms to design ideals, and more (possibly contradictory) work would be required to represent dates and uncertainty precisely. The question needs to be asked whether it is more important to resolve these potential conflicts and do more work, or whether a diagram such as Figure 26 should be got into the dialogue process "warts and all" at the earliest opportunity.

Figure 26: Relationship of timeframes to past events – a pathway through time



If the motivation for Figure 26 is

- to convey expertise, then it needs to be precise and accurate;
- to communicate, then it should be pleasing and representational;
- to promote dialogue then it needs to find a balance between the two and needs to be made available to the dialogue participants.

An alternative technique would be the use of time series visualisations to describe the evolution of the repository. Different visualisations could be used to indicate different aspects of the repository system at different scales. It is suggested that such visual storyboards should be constructed at the waste package, repository vault and geological scales showing both the evolution of the system and of radionuclide migration. Examples of different storyboards on different scales are given in Figures 27, 28 and 29. Although such techniques have been used in scientific reports, in the past they have not often been adopted within a performance assessment report itself.

Figure 27: Visual storyboard of canister evolution

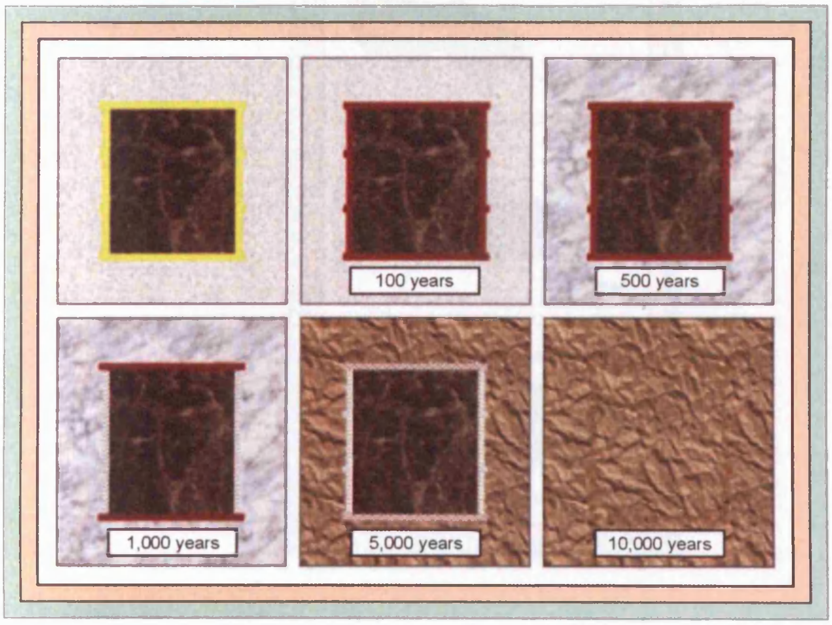


Figure 28: Visual storyboard of a canister plume

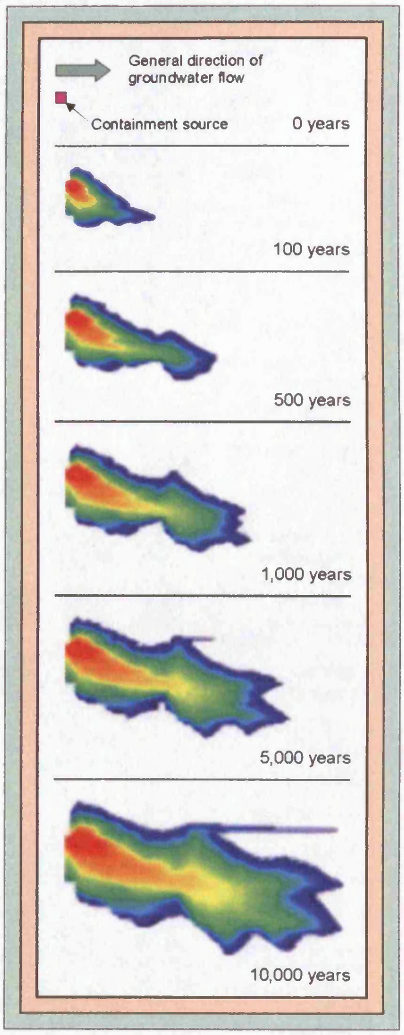
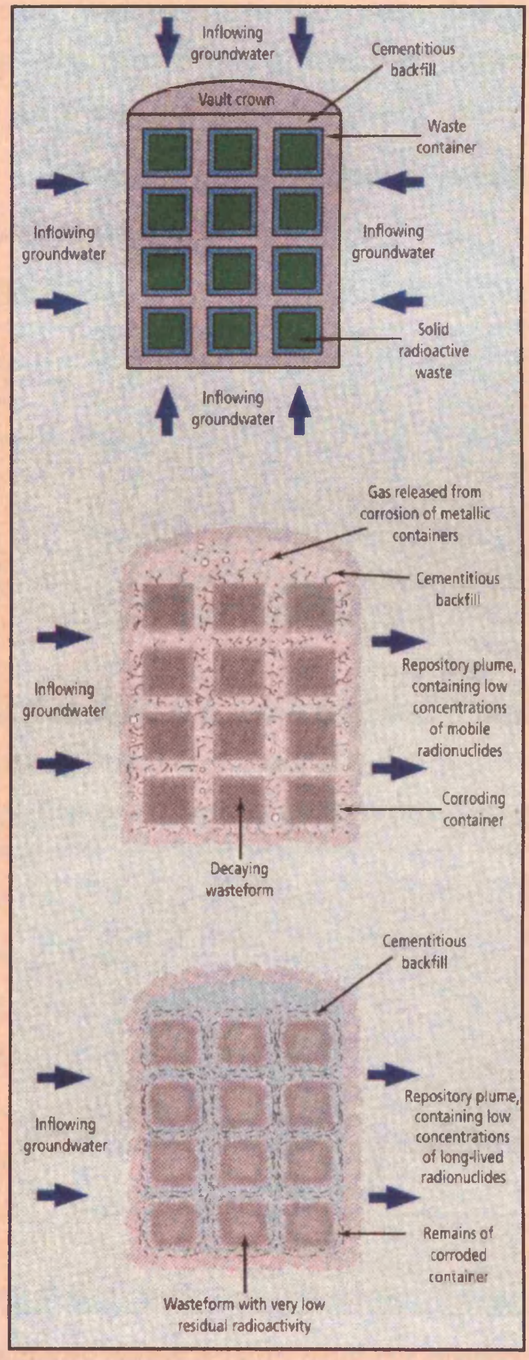


Figure 29: **Repository vault evolution illustration**



(a) Over hundreds of years

During this period, repository evolution would be characterised by:

- resaturation with inflowing groundwater;
- consumption of trapped oxygen by aerobic corrosion;
- conditioning of cement pore water to a high pH;
- a high degree of physical containment of radionuclides;
- gas generation from corrosion of wastes, containers and the microbial degradation of organic materials.

(b) Over thousands of years

During this period, repository evolution would be characterised by:

- the equilibration of repository pore water to high pH and reducing conditions (low Eh);
- the continued slow anaerobic corrosion of the steel containers (releasing gas and leading to penetration);
- physical and mineralogical changes to the cementitious backfill;
- the continuing radioactive decay (including ingrowth) of the initial inventory.

(c) Up to one million years

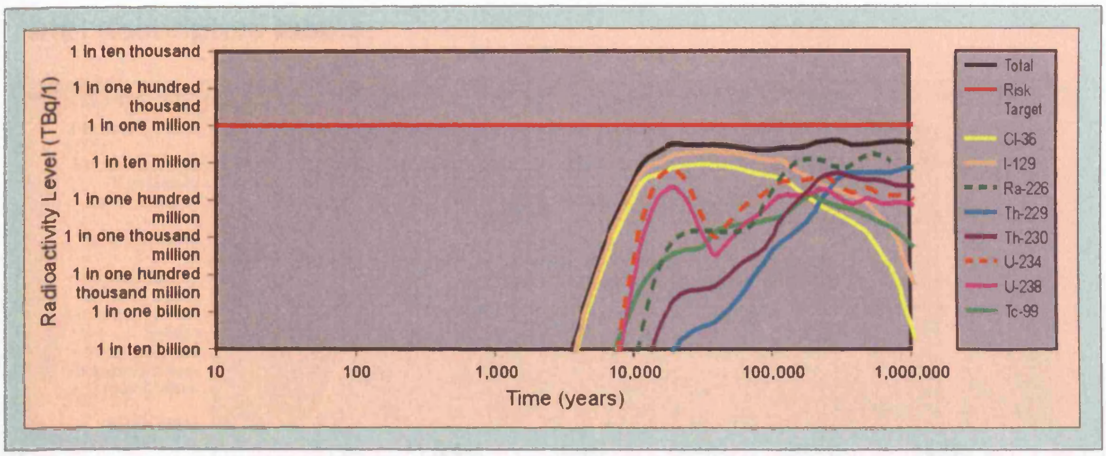
During this period, repository evolution would be characterised by:

- the maintenance of long-term chemical conditioning of repository pore water;
- slow mineralisation processes preventing the migration of residual activity;
- the continued decay of radionuclides.

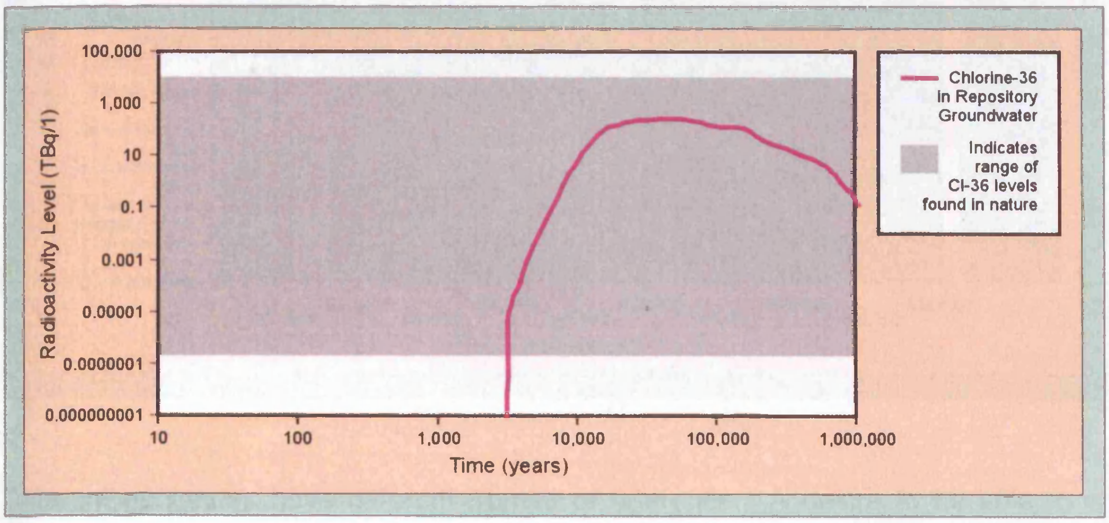
11.3.2 Presenting risk results

To investigate how easy it is to understand the graphs that are typically used to present the risks calculated by a post closure performance assessment, 10 non-technical staff at Nirex were asked for comments. Various graphs were presented to the participants, who included non-scientists. In most cases, the axes of the graphs have logarithmic scales and span a very large timescale. Examples are shown in Figure 30(a and b).

Figure 30: Typical presentation of results calculated in the Generic Performance Assessment [Nirex, 2001f].



a. Annual individual radiological risk



b. Radioactivity levels arising from the presence of chlorine-36 in repository groundwater

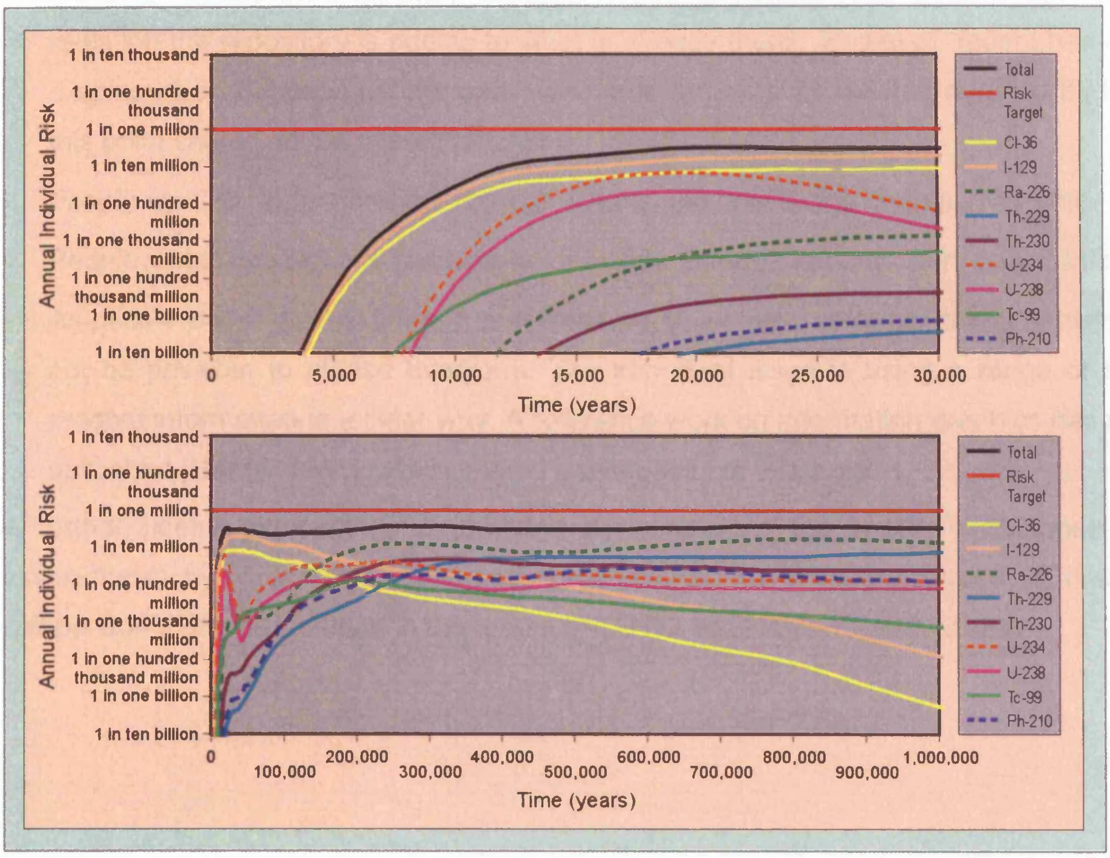
As a result of feedback from the review participants, it is suggested that the presentation could be improved for non-scientists in several ways:

- by not using scientific notation
- when talking about risk, by saying 1 in a million, (rather than 1E-6 or 0.000001)
- by trying not to use 'technical' definitions

- by writing the names of radionuclides, not their symbols
- by keeping information on one graph succinct
- by using linear plots and highlighting early times.

Implementing these suggestions would develop the graphs into those shown in Figure 31. (a and b are plotted on different scales). During the meetings people said that these graphs were easier to understand and clearer.

Figure 31: Average annual individual risk from the repository as calculated in the Generic Performance Assessment [Nirex, 2001f], presented on a linear timescale with descriptive labels.



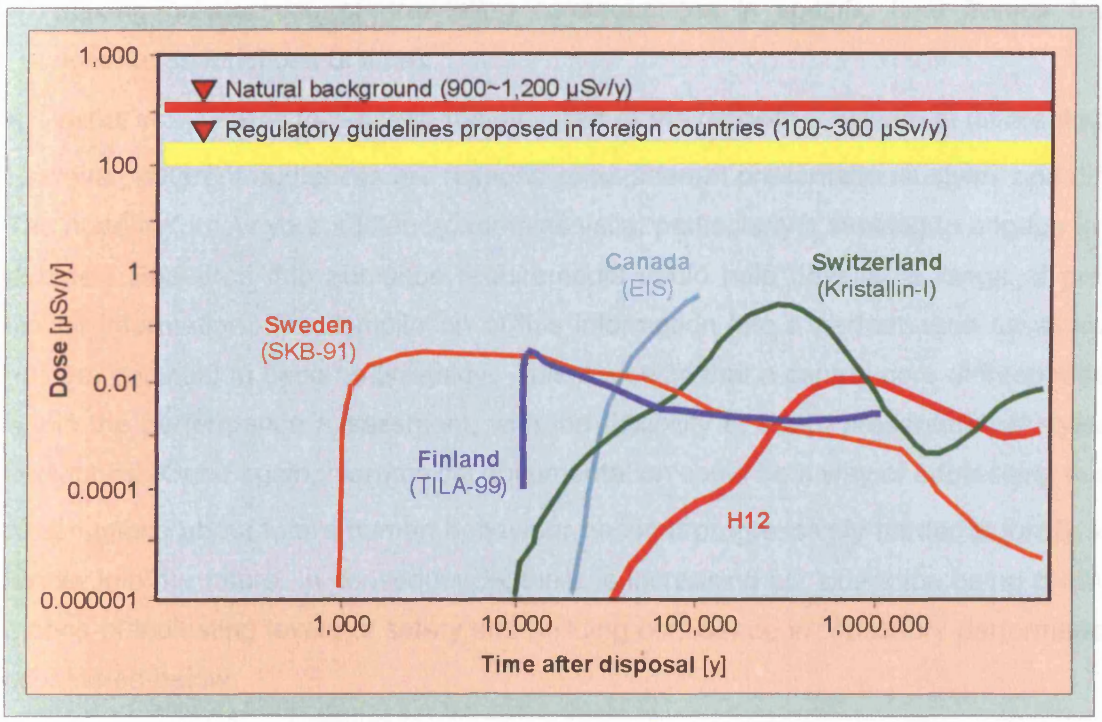
Different audiences have different frames of reference. A desire to be able to understand the results in context whilst appreciating a bigger picture was expressed. Suggestions for achieving this included:

Make sure that key issues are covered in the text surrounding the graph and that technical terms are explained carefully. Assumptions need to be stated clearly and uncertainty in the models and the data should be explained or reflected in the graphs. This is especially true over long time scales.

- Try to use measurements and scales that people understand or can relate to. This will be audience specific and may require some preparation in terms of understanding the stakeholder's perspectives and values.
- Try to relate the timescales to dates in the past and the future, to give people some context.
- Too much information can be confusing.
- If levels of radiation from the repository are to be compared to levels in nature, the context of the natural levels needs to be explained. Average UK values would be useful. This also needs to be related to how dangerous the levels are to people.
- It is important to emphasise that people are already living in a radioactive environment and that the area around the repository contains natural radiation. Then people can see how much radiation the repository is adding to what is already there. However, recent has indicated that a comparison between natural and man-made radioactivity is often rejected by the public, so this point should not be overemphasised.
- People want to understand the chain of events and how things change over time.
- People would like pictorial representations of the information and 'story board' information.
- As people like or dislike different presentations (they may prefer pie charts to histograms) it will not be possible to please everyone. The important issue is using a range of techniques to present information in a clear way. A reference work on information graphics has recently been published [Horne, 1998], which should prove useful in this context.

A further useful perspective is provided by comparing the results with those from earlier assessments by Nirex and by overseas organisation. For example, Figure 32 presents such a comparison that was included in the recent JNC H12 assessment [JNC, 2000b].

Figure 32: Comparison of radiological dose calculated in various performance assessments.



A direct comparison between the different performance assessments is not meaningful since they are for different inventories of radioactive waste and adopt different repository systems in different environments. However, such a comparison helps to establish the timescales of concern in different countries and also invites consideration of the differences in terms of different assumptions about the repository system. It thus focusses attention on the underlying basis of the performance assessment.

11.3.3 Implications

There are a number of competing themes here. A balance has to be achieved between simplifying technical descriptions, so that they are understandable to non-technical audiences, while retaining technical accuracy. Also, there is a desire for results to be presented in context with more background information, and yet to reduce the amount of information contained in graphical presentations of results. The results have to be comprehensive and accurate, but they also need to convey large amounts of information in a comprehensible manner. Some representations are good for some people, others are good for others. All this implies the need for a toolkit of presentational methods that can be applied in an audience-specific way. Specifically, there is benefit in adopting much wider use of:

- relevant and understandable yardsticks;

- high quality schematic diagrams for explaining key processes and the flow of information and models from measurements to assessment;
- making greater use of presenting consequences in specific time frames (rather than as continuous functions of time);
- visual storyboards to illustrate the evolution of the repository system at different scales.

However, different audiences are responsive to different presentational styles and different issues. The need to " know your audience" remains valid, particularly if seeking to engage in dialogue and debate. Research into audience requirements could help develop a range of presentations of similar information. The compilation of this information into a performance assessment therefore has the potential to become unwieldy. This suggests that a central core of information is valuable within the performance assessment, with the flexibility to adapt presentational styles for different audiences. Once again, hierarchical documentation could be a way of addressing this issue.

Assumptions about future human behaviour become progressively harder to justify as one moves further into the future. In consequence, there is increasing consideration being given to additional means of indicating levels of safety and building confidence in repository performance. These are considered below.

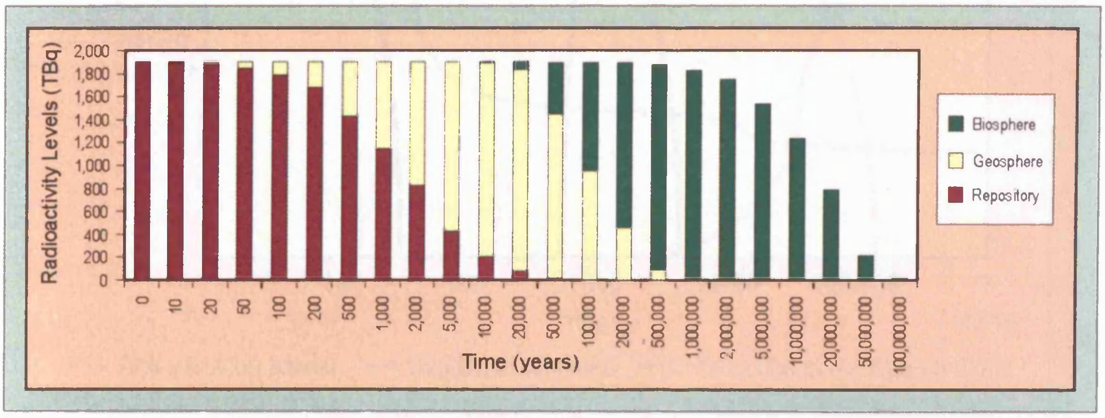
11.4 Conveying repository performance

Much of the above discussion emphasises the importance of a meaningful context for the presentation of results. Increasingly attention is being focussed on the use of multiple lines of reasoning to reflect repository performance over long timescales. In terms of complying with regulations, both qualitative and illustrative demonstrations of safety have their place, as well as consideration of a wide range of quantitative safety indicators to provide alternative perspectives and supporting arguments [IAEA, 1994]. Examples of safety demonstrations include comparisons with natural analogues [Knight, 1998] and the creation of demonstration facilities [SKB, 1996]. Recent international guidelines indicate that greater consideration should be given to the protection of the natural environment itself [IAEA, 1999]. This chapter discusses ways of providing additional context by considering both alternative presentations that emphasise barrier performance and alternative lines of evidence.

11.4.1 Emphasising barrier performance

Since the multibarrier concept relies on various barriers to radionuclide migration, stakeholder confidence in performance assessment is likely to centre on indicators of how well the barriers are likely to perform. In consequence, the presentation of results in terms of the performance of these barriers is increasing [USDoE, 2000]. Figure 33 indicates an alternative representation of the results of the Generic post closure Performance Assessment. Although this does not directly equate to risk to an individual at long timescales it does convey the idea of the near field providing containment for some long time into the future. Once again, there may be a need to trade off comprehensiveness in the visual presentation of results in order to make key points and achieve comprehension. Amongst the non-scientific review groups, this presentation was well received.

Figure 33: Accumulated radioactivity levels from iodine-129 in the repository, the geosphere and the biosphere at different times (after [Nirex, 2001f])

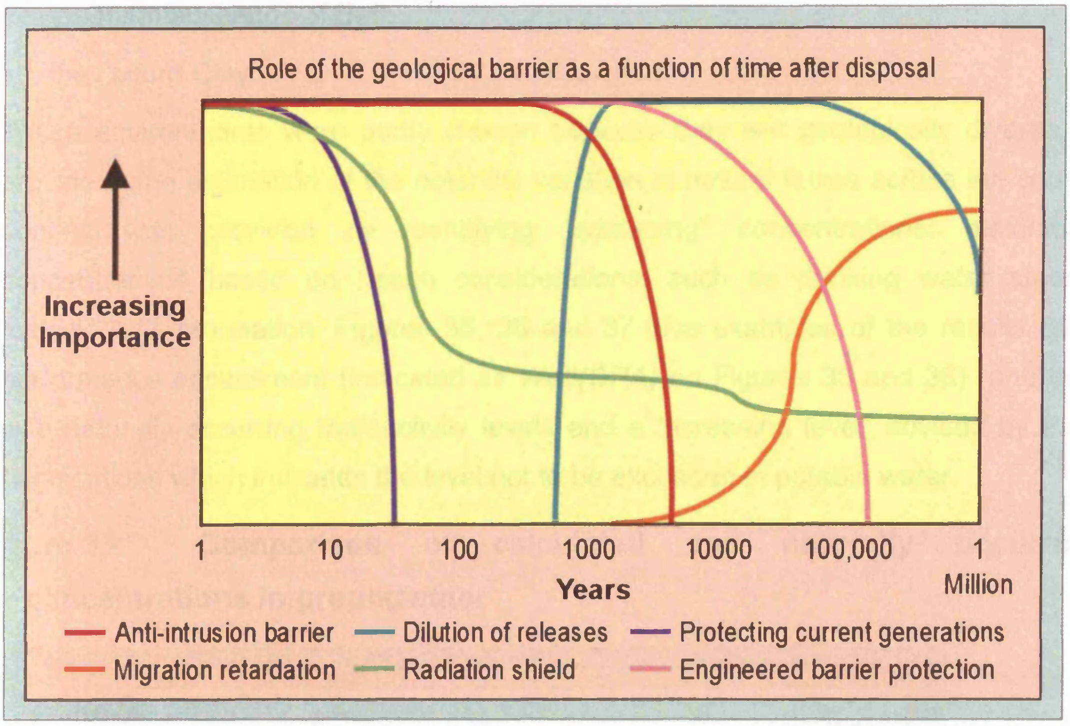


Representations of the amount of radioactivity (flux) passing through the barriers of the multibarrier containment system is also a useful indicator of barrier performance. Such fluxes are calculated as part of the process of calculating radiological risk. However, in the past they have not been emphasised in the presentation of the performance assessment.

An indicator of barrier performance that relates directly to timescale is the consideration of radiotoxicity indices. These indices use the inherent hazard presented by radioactive waste as a safety measure, typically considering the time needed before the hazard presented by the waste declines to that of natural uranium ore. Radiotoxicity indices show how the hazard declines with time (due to radioactive decay), and are qualitative indicators of the time scales of interest for safety analysis.

As discussed earlier, the roles of the barriers change over time. Figure 34 indicates the different roles played by the geological barrier over the timescales of relevance. This point is not always clearly drawn out in performance assessments focusing on radiological risk as an end point.

Figure 34: The role of the geological barrier with time



11.4.2 Considering radiological impact on the surface environment

The performance assessment calculates the amount of radioactivity emerging into the accessible environment (the biosphere) as part of the process of calculating radiological risk. This information can be presented in the form of:

- fluxes in the biosphere;
- environmental concentrations.

Given such a presentation, additional context can be provided by comparing assessed results with naturally occurring radioactivity in the environment. Such comparisons allow an estimation of the radiological impact on the environment resulting from the presence of a repository. Although there is some evidence that the public do not feel that comparisons between natural and man-made radioactivity are valid, they do provide context for discussion and are valid for discussions of environmental impact.

Recent work [Miller, 2000] has used the distributions of naturally-occurring chemical species as a datum against which repository releases can be compared and assessed. The fluxes derived as part of the calculation of radiological risk in the performance assessment were used. Context was provided by comparing these results with naturally occurring elemental and nuclide concentrations and fluxes for four geological environments in the UK:

- the Carnmenellis Granite in Cornwall;

- the chalk aquifer of the London Basin;
- the thermal springs of Bath;
- the Oxford Clay.

These environments were partly chosen because they are geologically diverse and, therefore, provide some estimation of the potential variation in natural fluxes across the country. Additional context was provided by identifying "screening" concentrations: maximum permissible concentrations based on health considerations, such as drinking water standards or other toxicological information. Figures 35, 36 and 37 give examples of the results calculated by the performance assessment (indicated as ***Well(GPA)*** on Figures 35 and 36) and their comparison with naturally occurring radioactivity levels and a "screening level" advised by the World Health Orgnisations which indicates the level not to be exceeded in potable water.

Figure 35: Comparison of calculated and naturally occurring uranium concentrations in groundwater

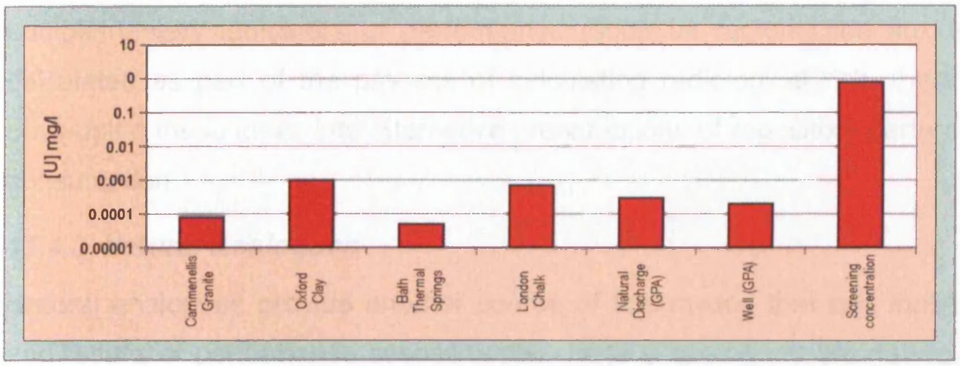


Figure 36: Comparison of natural and calculated copper concentrations in groundwater

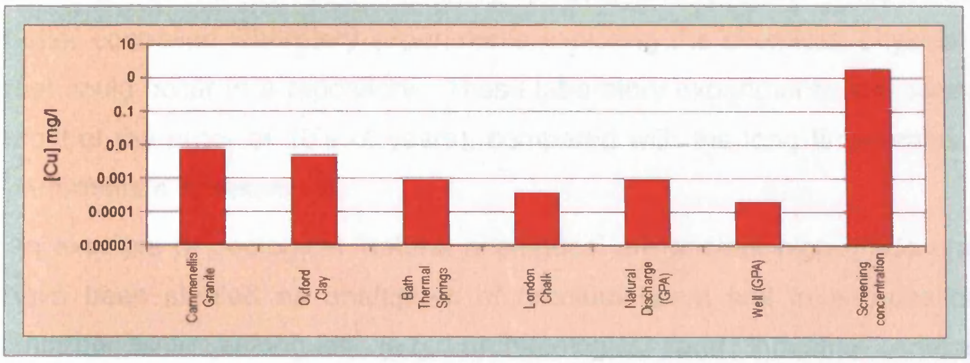
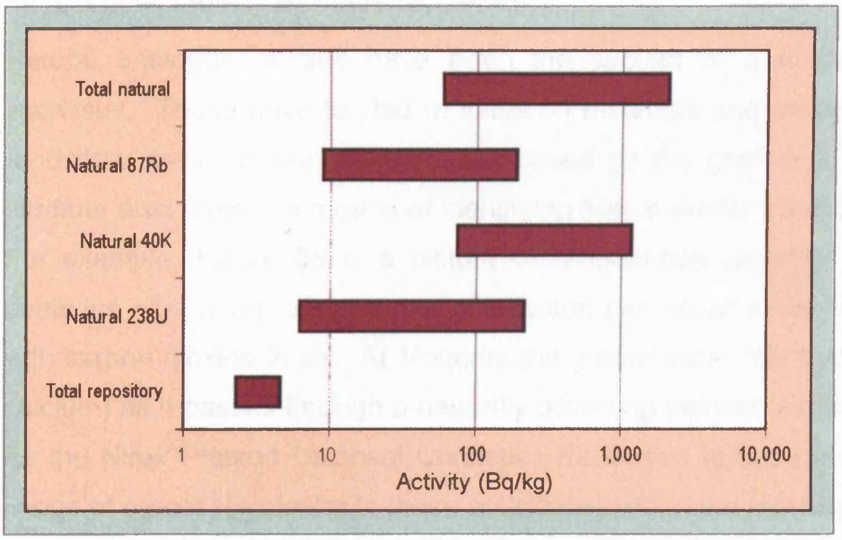


Figure 37: **Comparison of calculated and naturally occurring radioactivity levels.**



There is still a lot of scientific debate about the validity of such comparisons and the level to which conclusions regarding repository safety can be drawn from them. However, since these complementary indicators of performance (such as radionuclide flux to the land surface) are calculated as part of the process of calculating radiological risk, there is a lot of potential for developing these ideas into alternative presentations of repository performance for wider audience consumption.

11.4.3 Natural Analogues

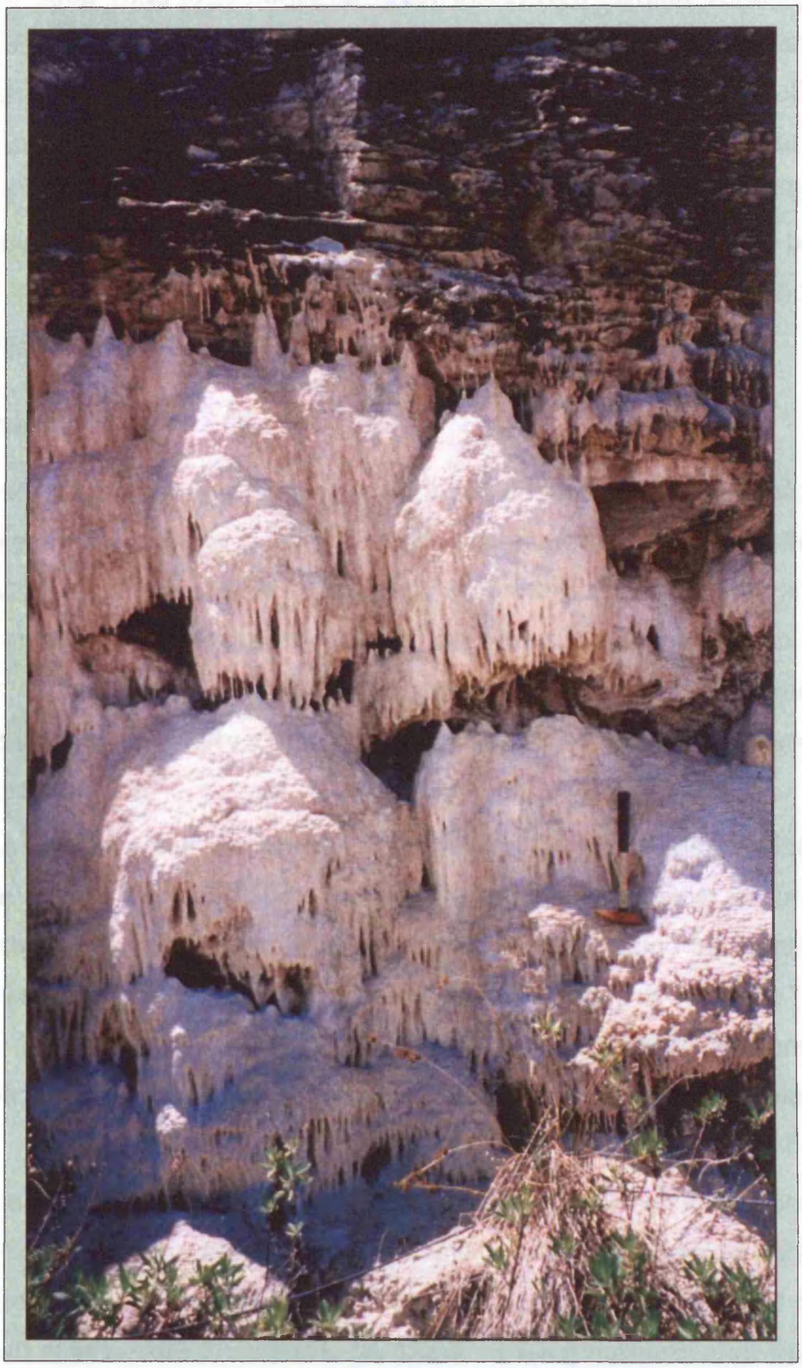
Natural analogues provide another source of information that can make more tangible the aims and results of performance assessments. Natural analogues are naturally-occurring examples of how materials and processes present in a deep geological repository will operate over both archaeological and geological (measured in many millions of years) timescales [Knight, 1998]. These are both in excess of repository operational timescales. They can complement results from better controlled laboratory experiments exploring the chemical, physical and biological changes that could occur in a repository. These laboratory experiments are normally of short duration (at most of the order of 10's of years), compared with the long time-scales typically of interest in a performance assessment.

An example of geological 'natural analogues' are ancient high grade uranium ore bodies, which have been studied as analogues of uranium spent fuel in a repository for high-level waste. Anthropogenic analogues (e.g. archaeological and industrial artefacts) can also provide information relevant to processes occurring over timescales measured in hundreds to thousands of years, for example the extension of steel corrosion rates to corrosion measured in buried industrial pipelines or archaeological artefacts. In fact such man-made analogues could be more in tune with public perception precisely because their origins are not natural, and thus they are more relevant to a man-made repository

Natural analogue studies have been the subject of a number of international collaborative exercises. These have tended to focus on materials and processes likely to be found within the repository itself. However, analogies based on the geological environments with some unique attribute also provide a means of identifying how a similar geological site may evolve in the future. For example, Figure 38 is a picture of calcium-rich deposits at the Maqarin (Jordan) natural analogue site. It indicates the deposition that can occur when highly alkaline groundwater reacts with carbon dioxide in air. At Maqarin, the groundwater has become alkaline (and saturated with calcium) as it passes through a naturally occurring cement, similar to the backfill being considered for the Nirex Phased Disposal Concept. Reference to this natural analogue creates a powerful image of processes similar to those anticipated within the repository system.

However, natural analogues have a complex, often imperfectly understood, developmental history, which ultimately limits how the data can be used. Whilst initially it was considered that the use of natural analogues could provide 'hard' data, similar to those obtained from carefully controlled laboratory experiments, this has only proved possible in some circumstances, rather than as a generality. In some circumstances, natural analogues have also provided a valuable, albeit limited, test of software and databases used in performance assessment.

Figure 38: **Calcium carbonate formation at Maqarin (Jordan) caused by the reaction of highly alkaline groundwater with carbon dioxide in the air.**



Experience of the use of natural analogues within the radioactive waste community has demonstrated that a more qualitative, 'softer' use of analogues increases the range of materials and processes for which natural analogue data can be considered. Natural analogues can therefore provide an important line of evidence to enhance understanding of the long-term behaviour of emplaced radioactive waste, although the limitations on their use must be recognised.

Natural analogues offer evidence for the effects of natural processes in the past. As such, they can be used as supporting arguments for ideas about how natural processes will develop in the future. However, because natural analogues are essentially present day manifestations of a range of intertwined and complex past processes there is rarely a unique explanation for their existence. Alternative conceptual models for their development can frequently be put forward and this has been one of the limitations in using them for performance assessments in the past. If a conceptual understanding of environmental processes achieves a higher profile in debate about environmental risk then natural analogues may similarly adopt a higher profile role in the performance assessment process.

11.5 Analysis

One of the reasons for focussing on the performance assessment in this chapter is because one of its key values lies in the manner in which it synthesises information, understanding and uncertainty to develop a view on performance. Capturing this, without it being overshadowed by technical detail could encourage the debate about the knowledge underpinning the performance assessment in more general stakeholder dialogue. Therefore, there should be considerable mileage in conveying repository performance by considering how to present the output of the performance assessment.

A balance has to be achieved between simplifying technical descriptions, so that they are understandable to non-technical audiences, while retaining technical accuracy. Also, there is a desire for results to be presented in context with more background information, and yet to reduce the amount of information contained in graphical presentations of results. The results have to be comprehensive and accurate, but they also need to convey large amounts of information in a comprehensible manner. Some representations are good for some people, others are good for others

In summary, there is a lot of potential for increasing the application of performance assessment as a tool for communication. Realising this potential is more difficult and requires modifications to the focus and presentation of the assessment. Remembering the importance of the regulator as an expert champion in the analytic deliberative model of environmental decision-making, we need to ensure that any modifications to performance assessment do not detract from its primary purpose - to rigorously and transparently analyse and quantify long term risks from a radioactive waste disposal facility.

The work described above puts forward some specific recommendations which are mainly aimed at those involved in undertaking performance assessments. These recommendations are not rocket science and do not fundamentally affect either what the performance assessor will do, nor what his peer reviewers will expect to see. It may make the presentation of the performance assessment more attractive to non-experts, but it suffers from being a one way form of risk communication. Those with broader interests in the proposed repository but without specific risk assessment expertise are not enabled to input their issues and concerns – they do not have an opportunity to influence the performance assessment itself. In consequence, this approach does not really open up dialogue and discussion about environmental risks in their broadest sense. The definition of environmental risks remains that determined by the expert community.

However, three crucial observations were noted when developing the work described above:

- tremendous variation and entrenched opinion in the experts definition of performance assessment;
- a real worry that any attempt to improve the accessibility of the performance assessment to those other than performance assessment experts would result in a loss of rigour.
- The work described here is essentially a one way form of risk communication. It does not necessarily enable input to the performance assessment process in its early stages.

These observations are worth analysing in more detail.

11.5.1 The definition of performance assessment as a barrier to dialogue

The differences of opinion amongst performance assessment experts about what a performance assessment is derived, in part, from the many similar but different terms used in the radioactive waste industry to represent an analysis of a proposed facility. Terms such as risk assessment, performance assessment, safety assessment, safety case, risk analysis, safety analysis have been used interchangeably in the past, depending on organisational and cultural affiliations. The difficulties raised by this have now been recognised, and recently the NEA have sought to provide very clear guidelines on the definitions of safety case, safety assessment and performance assessment. I have seen for myself a lot more rigour amongst the expert community to define what is meant when a term such as performance assessment is used. Nevertheless, until, the experts have settled into a consistent use of the terminology, the phrase "performance assessment" itself is likely to act as a barrier to dialogue with other stakeholders.

In undertaking this work, I was adopting the idea of a very broad definition of performance assessment. In this broad definition, any scientific knowledge, or lack of knowledge was *an integral part of* the performance assessment. So information that built confidence in the proposed repository was just as much a part of the performance assessment as information that helped to parameterise the assessment models. However, for many experienced workers in this area, confidence building measures are *not* part of the performance assessment but part of the development of a broader "safety case", one aspect of which is to build confidence in the results of the performance assessment.

These are two very different ways of looking at the relationship between the performance assessment and the conceptual understanding of the environmental risks from a proposed repository.

As a result of this work, and the Visual Language work described in Chapter 13, I now believe that it is not helpful to try and impose a certain definition of performance assessment to the exclusion of all others. We will end up in semantic debate between performance assessment experts, rather than an opening up of discussion about environmental risks with other stakeholders. Therefore, although the work described above indicates possibilities for improving dialogue, it doesn't seem to realise the full potential of conceptual earth sciences for enabling dialogue about environmental risk. The definition of "performance assessment" remains a barrier to dialogue.

11.5.2 Is the opening up of performance assessment to dialogue desirable

Careful consideration needs to be given to the extent to which it is valuable to open up performance assessment to dialogue, and which stakeholder groups might get involved. Consideration of the work presented above suggests that pursuing ways of making the performance assessment accessible actually deflected me from the real objective: to shift the emphasis of debate and discussion from quantitative measures of risk and the methods used to derive them, to the key uncertainties about the chances of harm being caused to the environment.

When coupled with the concerns expressed by experienced performance assessment specialists - that too much emphasis on other stakeholder groups could undermine the rigour with which the performance assessment addresses the concerns of the regulatory stakeholders - there seems to be a danger in trying to make the performance assessment itself a vehicle for dialogue. It could end up being neither an expert evaluation for expert peer review, nor something enabling broader debate and discussion.

11.5.3 Does this form of risk communication open up the performance assessment process

In essence, the ideas described above are about communicating the output of the assessment process. A danger of this type of approach is that it ends up being a sophisticated form of the deficit model of the public understanding of science. The deficit model adopts the idea that the need is for the education of the non-scientific audiences and hence it does not make cultural demands on the scientists. This may be partial explanation for the many examples of work by scientists emphasising risk communication as a way of meeting the challenges of consultative decision-making. However, risk communication on its own will not open up dialogue between expert and lay audiences in the early stages of the assessment process. Hence it does not conform to the idea of iterative and recursive knowledge building put forward at the beginning of this thesis.

Nevertheless, risk communication could operate in a different way and provide opportunities for discovery and co-operative learning that enables dialogue and knowledge building. The differentiation between risk communication operating as a deficit model or as an opportunity for co-discovery will depend on the attitude of the presenter and his/her objectives in seeking new ways of presenting risk results. As with the visual language trial, the attitude of the information presenter is critical in determining whether or not an iterative knowledge building process is able to occur. For the iterative knowledge building advocated in Section 1, dialogue has to happen and scientific methods have to be open to incorporating the output of such dialogue. The next two chapters look at whether such early dialogue and iteration is possible.

11.5.4 Conclusions

The traditional methods used for presenting the output of performance assessment can be enhanced in many ways. However, such enhancement will not, of themselves, promote dialogue, particularly if they are undertaken after the analysis has been performed. Ideally, the scope of the analytical process should be established via dialogue, in particular about the environmental issues and concerns held by a broad representation of stakeholders. So the need is for a medium by which stakeholder issues and concerns about the environment can be collected and described in a manner that can be incorporated by the specialists into the performance assessment.

The next chapter explores the use of visual information in a different manner – to promote dialogue rather then to communicate information. A particular approach called visual language is adopted for the study since it is advocated as a new medium for communication in the 21st century (Horne 2000).

12 PRESENTING DEEP GEOLOGICAL DISPOSAL IN VISUAL LANGUAGE

12.1 Background

The previous chapters establish a hypothesis that the conceptual scientific underpinnings of technological applications have the potential to act as a vehicle for dialogue and debate. This was not tested in the previous study, which was about communicating numerical information in a more accessible form so that stakeholders can understand the timescales and evolution involved in deep geological disposal. The use of conceptual descriptions in a far more dialogic manner requires the development of new skills on behalf of the scientists. A balance between simplification and comprehensiveness needs to be achieved so that dialogue is promoted. To do this, a number of factors need to be taken into account:

- The conceptual description should capture the scientific knowledge on which a proposed technological application is based at an appropriate level of detail. The appropriate level of detail may well be different for different types of dialogue and different players in the dialogue process.
- Additionally, it will be important to provide information that responds to questions raised by those engaged in the dialogue. These questions will evolve as the dialogue proceeds, and this may well affect the level of detail that is valuable in support of the dialogue.
- Finally, in the interests of openness, this common frame of reference must openly acknowledge scientific uncertainty so that those with differing values can form their own judgements about risk.

Recent developments in the integration of images and words to help convey complex information appear to have the potential to address these points. The theory behind these developments can loosely be called " Visual Language".

12.1.1 Aims

In this chapter, "Visual Language" – the tight integration of images and words to improve the communication of complex subjects - has been used to represent part of the conceptual basis on which deep geological disposal is founded. The research was undertaken to assess the value of visual language in facilitating dialogue about the physical and chemical processes which affect the environmental impact of burying radioactive wastes.

There were two aims for the work presented here:

- To encouraging dialogue about the environmental impact of radioactive waste disposal outside the field of specialists;

- To develop transparency in terms of what scientists do and don't know about the physical and chemical processes affecting radioactivity in the environment.

12.1.2 The potential for change

The power of presentation is universally acknowledged from the business world to the fashion industry, from marketing to the delivery of academic papers. The impact of information on its audience is very much determined by its presentation and by its presenter. Since the need identified in Chapter 8 is to develop new ways of sharing and building information, it seems reasonable to look at the presentation of information as an agent for bringing about this change.

In this chapter, changes in how to present complex scientific ideas are considered with a view to altering the audiences perceptions of their own ability to engage with the material. If the audience can feel empowered to enter into discussion and dialogue about the material, then there should be scope for a qualitative change in the content of the material as a result of dialogue and social learning.

However, there is a fine line between dialogue and communication, and an even finer one between communication and marketing. How can complex information be presented in a manner that enables, rather than inhibits dialogue? To explore this, recent trends in the presentation of complex phenomena and debates were considered.

12.1.3 Visual Language

Pictures and words are frequently used in communicating information. However, it has been observed [Tufte, 1983, p180] that:

> *"Words and pictures are sometimes jurisdictional enemies, as artists feud with writers for scarce space. An unfortunate legacy of these craft-union differences is the artificial separation of words and pictures; a few style sheets even forbid printing on graphics.....Words and pictures belong together."*

With the advance of information technology, the use of images has expanded exponentially. In the United States, it is now being claimed that the full integration of words, shapes and images into a single communication unit is emerging as a distinct language [Horne 2000].

- Words provide shape to the communication. They enable the naming and classification of distinct elements and also supply the capacity to discuss relevant abstract concepts.
- Images draw on other parts of the brain and are very powerful in their own right. However, in the absence of words, they remain visual art.
- Shapes are more abstract than images. They have been used in the presentation of scientific information for centuries and, when combined with words they have formed the basis of diagramming systems.

Table 24 presents a description of the key elements of visual language [Horne 1996]. This work has been exploring the use of concept diagrams, information graphics and information murals to the science underpinning deep geological disposal.

Table 24: Visual Language Communication Units

Name	Description	Size
Icon/Vlicon elements	Smallest unit of meaning in visual language. Usually a simple graphic containing one or two works or a phrase to clarify the visual elements	Generally small (< 1 inch square)
Concept diagram	A simple to moderately complicated accompanied by one or two sentences. Usually cannot stand alone as an autonomous communication chunk, but appears in the context of sequencing or grouping.	Roughly a quarter to half a page
Information graphic or "infographic"	Larger spreads usually containing a large and often complex central visual element or group of visual elements. Frequently contains several blocks of text. Can stand alone as an autonomous communication chunk	Half, 1 or 2 page spread
Information mural or "infomural"	Includes one or more infographics. Types: usually recognisable by format: landscapes, mandalas, matrices, process diagrams, time lines and so forth	Usually the size of a wall or part of a wall

12.1.4 The issue for debate - deep geological disposal

As discussed earlier, the long-term management of radioactive wastes is a contemporary environmental issue with a history of failures in finding an acceptable solution. The scientific underpinnings of deep geological disposal have traditionally been communicated using performance assessments in which mathematical calculations of risk are used to assess compliance with a quantitative risk target. Experience in the nineties shows that this medium has not necessarily ensured effective debate and dialogue about the underlying scientific issues. Therefore, deep geological disposal is a valid and valuable issue for the application of visual language in order to enhance debate and dialogue.

As discussed in Chapter 5, deep geological disposal is generally accepted as a potential means of ensuring the necessary level of isolation for long lived radioactive wastes. This disposal concept makes use of engineered and natural barriers, working in conjunction to prevent or limit the movement of radionuclides from the repository to the human environment (multibarrier containment). There are many aspects of the science underpinning radioactive waste disposal that make it difficult to enter into widespread dialogue about the technical basis of deep geological disposal. This is because:

- There are a complex set of interacting physical and chemical processes that may affect the system;
- Long timescales require consideration (up to millions of years). This means that there are very many possible future evolutions that need to be taken into account.
- There is a wide choice of different levels of detail and topics of interest around which communication could be based;

These aspects mean that the science underpinning deep geological disposal has essentially remained in the specialist domain. There has been little opportunity for other stakeholders to enter the scientific debate. Additionally, debate has tended to focus on scientific uncertainty, most often manifested as disagreements between scientists working on behalf of organisations with different objectives. I have hypothesised that there is value in moving scientific discussion towards a more balanced debate, and to enable others to enter the debate and understand the key issues. Visual language may offer a means of doing this.

12.1.5 Approach

The approach used in this research was to develop visual language representations of important geosphere processes, with particular emphasis on capturing uncertainty about the behaviour of the geosphere by identifying the main points of departure in the scientific debate about the same geosphere processes;

Visual language was used to develop a scientific representation of the geosphere in deep geological disposal.The work was undertaken in a number of stages.

1. Initially, a diagrammatic representation of the key factors influencing the long-term safety of a deep geological disposal system was developed. In a simple manner, this representation links high level questions about the behaviour of the disposal system, to scientific processes addressed as part of the underlying research programme.
2. One of the components of this diagram – the Geosphere - was selected for the trial application of visual language. Previous work has indicated that the behaviour of the geosphere is very important to the levels of safety offered by the Nirex concept for deep geological disposal. A " visual framework" was developed to explain the role of the

geosphere in the disposal system. The visual framework comprises a series of hypertext-linked pages that link fairly high level scientific concepts to increasingly detailed representations of the important scientific processes typically addressed as part of the research programme.

3. At some level of detail, scientific uncertainty becomes significant. Where this happens, "argumentation maps" have been developed. These argumentation maps seek to capture the different lines of argument that can ensue as a result of scientific uncertainty. The intention is not to promote one line of argument, rather to capture areas of agreement and areas of disagreement, together with the point of departure. In this way, it is hoped that argumentation maps can help increase transparency in the scientific debate surrounding the behaviour of the geosphere.

4. Subsequently, the visual language representation of the geosphere were subject to both technical and non-technical review. The review was undertaken in two stages. Firstly, technical and non-technical focus groups using staff at Nirex - the agency charged with developing options for the long term management of radioactive wastes - were involved in an initial round of review (see Appendix E). The Visual Language materials were modified as a result of comments received. **Version 2 of the visual language products are provided on the accompanying CD.** Subsequently, an external review was undertaken using staff and researchers at the University of Lancaster (see Appendix F).

5. Finally, the outcome of the different stages of review were analysed to determine how effective Visual Language was at communicating the role of the geosphere in deep geological disposal and the state of scientific knowledge about geosphere processes. The success of the trial was be considered both in terms of how well technical and non-technical audiences are able to comprehend the science, and in terms of whether they are able to engage in debate and form opinions about the science.

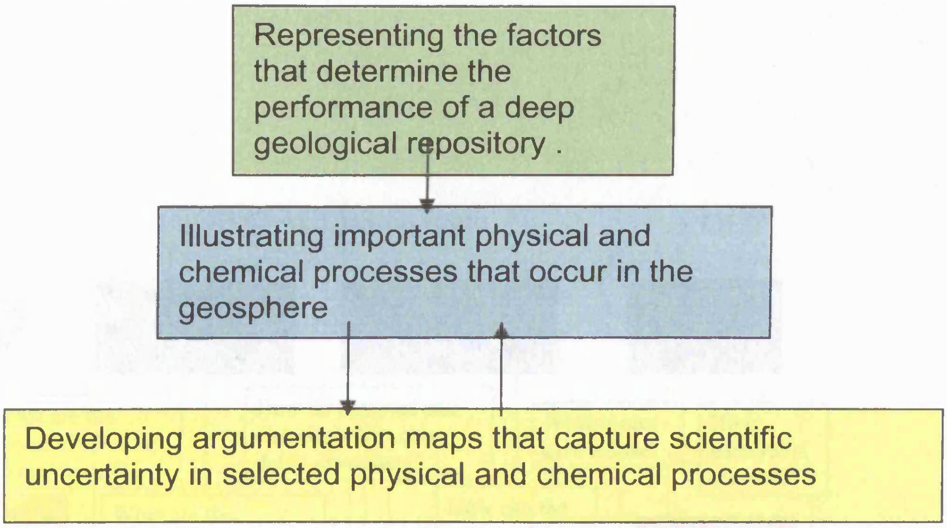
The visual language material was developed in discussion and dialogue with a researcher who has a long history working for Friends of the Earth[1] in opposition to the nuclear industry's proposals for radioactive waste management. Many ideas about the potential advantages and disadvantages of visual language arose out of this collaborative working which are captured in the discussion below.

12.2 Deep geological disposal – in visual language.

Visual Language representations of key elements of deep geological disposal were developed in three stages. These are illustrated in Figure 39

[1] My thanks to Rachel Western

Figure 39: Stages in the visual language project



The application of these three stages to the issue of deep geological disposal is discussed further below.

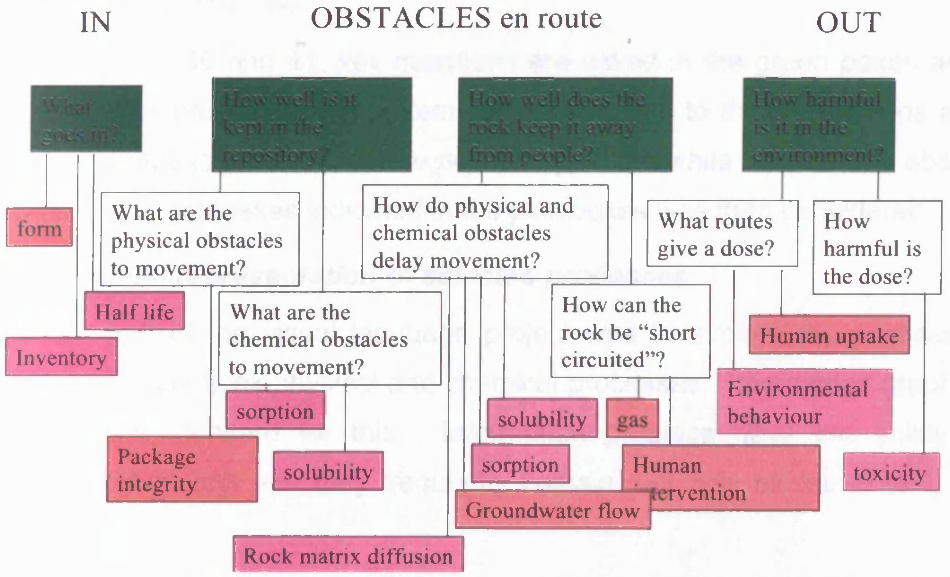
12.2.1 Stage 1: Factors influencing performance

The scientific research programme underpinning deep geological disposal focuses on many important physical and chemical processes, often at quite a high level of technical detail. A starting point for the trial was the development of a diagrammatic way of relating these physical and chemical processes to simple questions about the repository on a single sheet of paper. There were a number of important aims for this diagram:

- That it should act as a bridge between the technical terms used by the scientists and more common questions raised by other stakeholders;
- That it should reflect the different barriers of the repository system, since the multibarrier concept is the broad principle on which deep geological disposal is founded;
- That it should provide a reference point for the full scope of the scientific research work undertaken by Nirex;

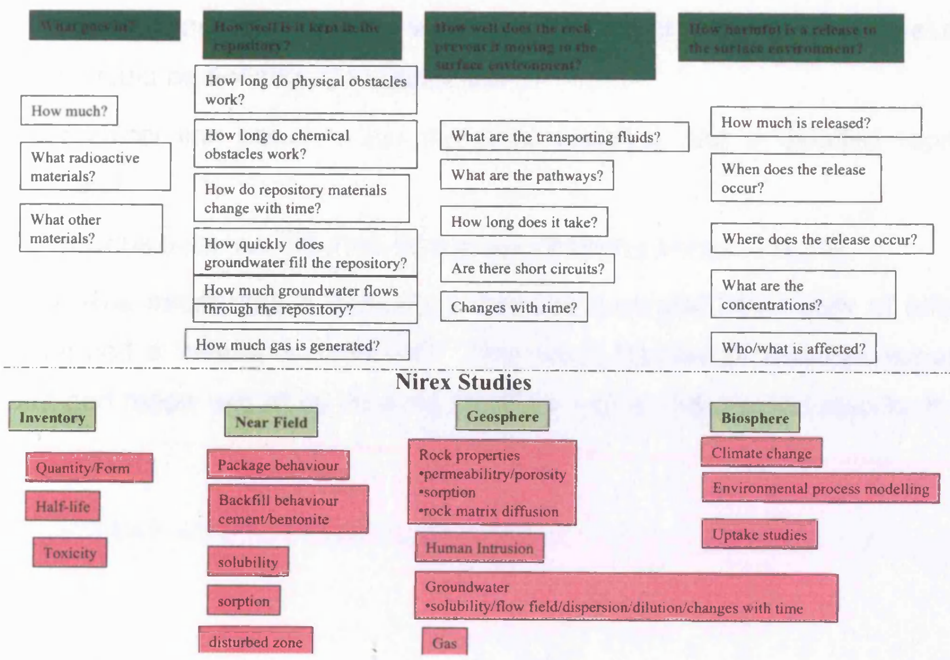
A brainstorming session was convened with members of the science department within Nirex. After many debates, the diagrammatic representation shown in Figure 40 was developed.

Figure 40: Factors affecting the performance of a deep geological repository



Subsequent discussions identified that there was an element of confusion in this diagram between factors influencing safety, and studies undertaken by Nirex as part of its scientific research programme. An alternative representation of similar information was developed (Figure 41).

Figure 41: Questions about long term safety



These diagrams (Figures 40 and 41) are concept diagrams (using the terminology of visual language). They cannot easily standalone as an autonomous communication unit, but in the context of some supporting text, they can convey a lot of information at a single glance. The diagrams also have relevance in providing context for much of the scientific research undertaken by Nirex. In view of the fact that Figure 40 was developed in a more consultative manner, it was the one selected for use.

In both Figure 40 and 41, key questions are asked in the green boxes and the detailed physical and chemical processes that determine the answers to those questions are identified in the pink boxes. Linkage is provided, where necessary, in the white boxes. The ability of visual language to represent the processes indicated in the pink boxes was then considered.

12.2.2 Visual representation of selected processes

A major part of the visual language project was to explore the success of visual language in representing complex physical and chemical processes. Information graphics were identified as a potential way forward for this. Information graphics have the ability to stand alone as a communication unit and they frequently contain, not only blocks of text, but also several visual elements.

Representing all relevant physical and chemical processes (pink boxes in Figure 33) in detail was unrealistic at this stage of the research. However, because of the complex and interacting nature of these processes, it was important to select a group that were related and that would stretch the ability of visual language to illustrate interrelationships. Since the emphasis of this research is on the role of earth science in environmental decision making, processes that influence the behaviour of the geosphere were chosen – i.e. those that affect the question " how well does the rock prevent keep radioactivity away from people" (Figure 40) or "how well does rock prevent the movement of radioactivity to the surface environment" (Figure 41)

It quickly became apparent that there were many levels of detail at which these processes could be tackled. It would be necessary to reflect both:

- the hierarchical link between the top level question and a detailed representation of the process; and
- the interactions between different processes at similar levels of detail.

Therefore, it was necessary to develop a three-dimensional framework of information graphics, which we termed a "Visual Framework". The visual framework was developed within Microsoft PowerPoint and made use of its drawing facilities, clip art library and also its facility for hypertext linkages

12.2.3 Capturing scientific uncertainty

The visual framework seeks to capture scientific principles that are generally fairly well accepted. However, ultimately the performance of a deep geological repository is dependent on the extent to which those processes may or may not operate in the future. This is uncertain. There are a number of general reasons for that uncertainty, for example:

- the process may be dependent on certain physical and chemical conditions. The conditions that will prevail may be unclear;
- the relationship between the process and the physical and/or chemical conditions may be unclear;
- the evidence for the process may be ambiguous;
- confidence in our ability to represent the process in a predictive model may be low.

The source of uncertainty will be different for different processes. The reasons for scientific debate will therefore be process-specific. In the trial, information murals were developed for selected processes. These murals sought to capture explicitly the source of uncertainty for that process and the specific point of departure for scientists with differing opinions. These process-specific murals were called "argumentation maps" [Horne 1998]. The intention is not to promote one line of argument, rather to capture areas of agreement and areas of disagreement, together with the point of departure. In this way, it is hoped that argumentation maps can help increase transparency in scientific debate and openness about uncertainty.

Two topics were selected for argumentation maps:

- Uncertainty in solubility – a process that is reasonably constrained in terms of is relationship to physical and chemical conditions;
- Uncertainty in rock matrix diffusion – a process that is relatively unconstrained in terms of evidence for its existence and the extent to which it may operate under different conditions;

12.3 Review and development

The aim of this trial was to assess the ability of visual language to communicate and enable debate and discussion. Its success is therefore dependent on what other people think of the Visual Language products. Additionally, it would be arrogant to presume that the design and presentation of information within visual language can be undertaken by the project team alone. Feedback from prospective audiences has to considered a major input to developing a useful product. Therefore the review process for visual language was undertaken in three discrete stages as an integral part of the project, rather than as a concluding activity:

- An initial review using focus groups made up of technical and non-technical staff at Nirex;

- Modification of he visual language materials in the lights of the focus group comments
- External review of Version 2 of the visual language materials at an independent workshop involving the staff of the Institute of Public Policy and Philosophy at Lancaster University.

12.3.1 Focus group comments on version 1.

Version 1 of the visual framework and argumentation maps (described above) were initially subject to focus group discussions. Four focus groups were run, each for one hours duration. The facilitator of these groups was not involved with the project and recorded the comments from the groups independently (see Appendix E). The groups were organised so that those with similar levels of technical knowledge about the long-term safety of deep geological disposal were together. There were two non-technical groups, and two technical groups, of which one was a group of scientists working on the subject of post closure safety.

During the discussion, the participants were:

- initially presented with the first few electronic, hypertext linked pages of the visual framework and asked to comment on whether the idea was sound;
- encouraged to look at a hard copy presentation of the visual framework and asked for their views as to whether they preferred electronic or hard copy presentations;
- shown the solubility argumentation map and asked whether they could follow the discussion/debate and whether there were any detailed comments on the material;
- asked if they would like to be involved in a second round of review, and how they think this review should be run.

In general terms, there was fairly universal support for the concept, both from the technical and the non-technical groups. A big success was the fact that everyone was keen to be involved in the second round of review, and even "looking forward" to it.

A general preference for the electronic version of the visual language products was given. Browsing the material electronically gives a sense of control over the material, as long as it can be considered at ones own speed. Some people felt that having both together would help people to have an idea of the "big" picture whilst moving through the information in their own way.

A number of comments were made about the need to improve the introductory material and manage expectations – the index to version 1 of the Visual Framework was clearly unfriendly and some of the earlier slides suggest material that is not there. For example, knowledge of the other barriers (non-geosphere) is assumed and hence the importance of hydroxide ions on solubility is discussed. However, there is no explanation anywhere as to why hydroxide ions may be present in the first place (because the near field is cementitious, partly to provide a source of hydroxide ions);

Comments on the hard copy presentations were mixed. There was a general feeling that there was too much to take in, and that this was off-putting. However, for some people, it was useful to be able to see the full extent of the material available electronically. The posters were likely to be more useful for some audiences – in particular for schools audiences and to act as browsing material at meetings and in support of more general discussion.

People read the posters in very different ways. The layout was very influential in leading the eye, and what one person liked, another disliked. It was suggested that "chunking" the information up into more manageable bites would be helpful – the eye could ignore the detail and focus on the headlines.

The non-technical groups identified a number of issues where things had been taken for granted, and also where an inappropriate impression had been given. For example, in the solubility argumentation map, the impression is given that we are trying to do everything we can to get as much radioactivity to dissolve as possible. Similarly, it could be construed that post closure safety is about getting as much radioactivity back to the surface as possible.

The technical groups identified a great number of detailed comments about words, phrasing and diagrams used in the slides. Whilst there was general support for the idea of simplifying the scientific concepts, everyone had a different way of doing it. Crucially, when at the greatest levels of detail in the argumentation maps, phrasing and layout determine the overall impression about the quality of the science. The technical groups were not happy with the way that the solubility issues were presented as it cast doubt over the whole modelling process.

A lot of useful comments were made about the general layout and feel of the slides – for example going for consistency with the Corporate image, utilising existing sketches for different management options presented in the Options paper.

There was a lot of enthusiasm for involvement in a second round of review. It will be important to provide adequate time for this, and people would like to be able to explore the electronic material themselves. Different people like to work in different ways. There was general support for the idea of issuing the material electronically (perhaps an individual version that could be commented on using a change tracking system). Additionally, the idea was mooted of setting up a number of terminals in the same room, providing 10 – 15 minutes for exploration followed by a 10 – 5 minutes sharing of ideas – repeated a few times.

Some other, generally held, comments were made:

- Who is the audience?

- What are you aiming to achieve with the material?
- How do you expect to present the information (as this will involve slightly different approaches)
- The headings need to be appealing
- Words and style need to be consistent
- There is a balance between making information accessible and being patronising or too simplistic
- It is important that the posters have a clear end or "close off" rather than leaving people hanging
- Important to introduce timeframes
- Be careful not to introduce unfamiliar terms at the detailed levels that have not been explained
- More pictures – fewer words

In summary, it was concluded that the visual language products contained great potential for changing the perception of scientific information and encouraging engagement. Comments from the technical focus group differed from those of the non-technical focus groups, reflecting the different cultural backgrounds. The design of the information required very careful consideration. However, such design decisions are, in essence, an exercise of power and condition how the information is received.

12.3.2 Modification and Development

In the light of the first ground of review, the Visual Language products were modified and revised. Not all comments were taken into account. Points of detail were not always addressed due to time considerations.

In summary, the revisions addressed the following points:

1. Revision of the visual framework to:
    - Improve the introductory slides – in particular the index
    - Use the options sketches to provide more information about "other options"
    - Establish some slides identifying the role of physical containment, the near field and the biosphere.
    - Incorporate the reference diagram as a fast track route to the key issues and the argumentation maps
    - The development of "signpost questions" to help provide a storyline running through the material and enable fast-tracking to points of interest.

2. Consideration of a common format for the argumentation maps adopting an approach that lays the material out against three questions: does the process exist (theory), to what extent does it exist (experimentation) and is it significant (modelling) (see Figure 42)
3. Revision of the argumentation maps using the common format
4. Modification of the "key questions" diagram to present the issues in a common way – i.e. to describe how the various scientific processes contributed to safety (as opposed to undermining it, or mixing the two). The revised diagram is given in Figure 43.
5. Development of a range of hard copy layouts of the visual framework and one argumentation map.
6. Consideration and incorporation (where appropriate) of more detailed comments from the focus groups.

Greater weight was given to the comments of the non-technical focus groups since they were considered to be more representative of the stakeholders and public constituents who we are seeking to engage. Additionally, a mixture of styles was used in all the products, despite the first round comments about consistency. This was partly to flush out any comments about what styles worked and what didn't with the external reviewers.

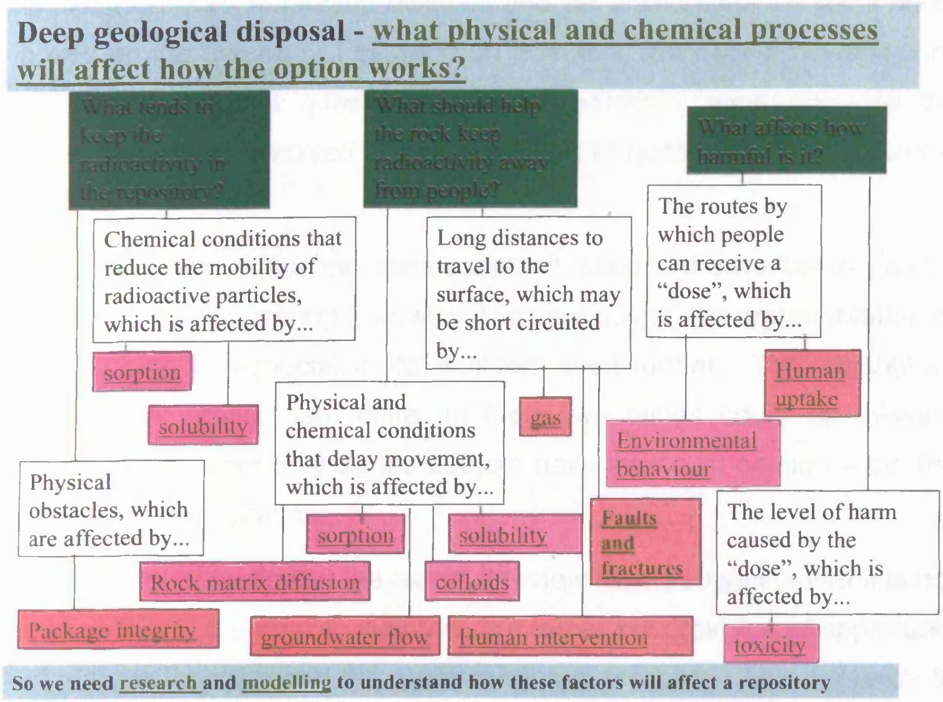
Following these revisions, new products were developed and have been recorded on the attached CD. In addition, hard copy posters of the revised material were also made.

Figure 42: Common format for the Version 2 argumentation maps

Matrix structure used for the argumentation maps

	Theory	Observation/ investigation	Modelling
General science	What is the general theory for the process?	What support is there from general observation?	
Applied science	Hypothesis - how does this contribute to safety?	Is there evidence to support this hypothesis?	How can we make calculations based on this hypothesis?
Uncertainty		What is known? What isn't known?	How significant is this for safety?

Figure 43: Version 2 safety factors diagram



12.3.3 External Review of Version 2

An external review of the visual language products was undertaken by members of the Institute of Public Policy and Philosophy at the University of Lancaster. A key component of this review was the conduct of a workshop on 15th February 2002. Appendix F is the review report compiled by the University of Lancaster.

A key output of the review was, once again, the need for consistency of style, and also the obvious value of applying IT design and graphics to the project. A designer was asked to undertake a pilot study to indicate the potential of the material in the hands of a professional designer with modern IT techniques. A CD of the output is available.

The second round review identified many issues that had not been considered at the outset of the Visual Language trial. These are comprehensively documented in the review report and specific points are summarised in Box 8.

The external review report suggests that there are three fundamental issues which need to be addressed if Visual Language is to be used to open up dialogue.

Firstly, control over the information is still being exercised by the technicians – the scientists are still in the position of presenting "their" science and hence it is still a (rather sophisticated) form of the defect model of the public understanding of science. This was evidenced by an emphasis on technical (to the exclusion of all other) issues, as highlighted by the key questions diagram. The diagram itself was found to be quite helpful, but also very narrow in scope. It raised none of the social issues related to phased disposal and yet such questions were begged by the text used in the boxes on the diagram. Following on from this, the external review commented on the closed nature of the signpost questions. These questions were intended to open up discussion. However, they were criticised as being the sort of questions that the scientists would ask, not the audience.

Secondly, an informal, but important comment made at the workshop was that, by trying to capture all lines of discussion arising from scientific uncertainty, the argumentation maps may be in danger of marginalising non-specialist stakeholders even further. The laudible intention of opening up debate so that others can make up their own minds could be misinterpreted to be one of demonstrating that not only do the authors have their own opinion – but they also know about all the other potential opinions.

Thirdly (and very practically) the external review report suggests that it is not the complexity of the information that is a barrier to dialogue, but rather the provision of opportunities to engage with the sort of material contained in the visual language products. This suggests that the presentation of information on its own is not enough. Physically, audiences have to be brought into contact with the information for there to be any chance of consequential shared knowledge building.

Box 8: Summary of Key Points from the External review of Visual Language

The following key points have been abstracted from Appendix E.

General comment: "the potential for use of the material to encourage and enable dialogue and two-way communication is welcome, [] with the caveat that [] the reader is positioned as a passive recipient of authorised knowledge".

Scope of material: "the VL project has scoped the scientific map of radioactive waste management, and selected particular topics for detailed working up. The context of these topics is presented as being the overall scientific requirements of deep geological disposal (or phased underground disposal). The social, ethical, political and economic context is entirely invisible"

"The slide entitled 'key questions' makes this very clear. In response to the question 'radioactive waste – what is the problem?' we are given a number of responses – all in terms of rock, water movement through rock, etc. Not only does this presume deep geological disposal on the Nirex model, but it makes no reference whatsoever to any non-scientific issues. The question should be 'radioactive waste – what are the scientific issues in relation to deep geological disposal, not claim the entire territory of radioactive waste problems and then define them so narrowly. This narrow framing is off-putting, offensive, and inappropriate. A much wider 'funnel' at the beginning of the material is required, which at least acknowledges the breadth of the issues, and then goes on to focus on specific sub-areas."

The relevance of earth science: "The material is inherently interesting for many. Particularly, many reviewers mentioned the diagrams of rock structure and water movement through rock: it seems that some contents of science are more interesting than others".

Dialogue "The material clearly has uses in relation to dialogue and consultation, both as information provision and as a prompt to discussion. If the material is basically envisaged as information provision [] there are different implications for design. The material currently reads as if this is the intention. If, however, the intention is to generate discussion, then questions about the purpose of that discussion need to be answered, or at least considered.] However, the design in relation to dialogue uses is not the most important consideration: developing the material as information provision will not preclude its use within dialogue. That the material provides access points to discussion is itself valuable."

Audience: "It is not at all clear who the intended audience or readership is. If a 'general' readership is assumed then the comments on providing a 'simple story line' as well as more detailed and complex storylines is extremely pertinent, as are comments on the need for a clear map of the structure of the information. A much simpler and more straightforward 'top layer' needs to be produced – similar in tone and detail to the options descriptions poster – where users can gain an overview of the material and decide which areas to pursue".

Accessible Science "In general, the material was considered successful in providing an introductory understanding of solubility, rock matrix diffusion and sorption. However, quite what this understanding was is another question. The issue of whether people understood what was being presented in terms of the content presented – whether they could then answer a test 'correctly', for example - was not a focus of this review; some informal discussion indicates that understanding in this sense was not comprehensive"

"The accessibility of the science in the sense of providing introductory and/or framework understandings was considered to be patchy. The solubility argumentation map is clearer and more understandable than the rock matrix diffusion, and it is worth considering why this is the case. Firstly, solubility is a more familiar concept than the immediately incomprehensible terminology of 'rock matrix diffusion'. Secondly, the solubility AM lays out a clearer sequence of concepts and steps, whilst the rock matrix diffusion AM is more difficult to follow in terms of its internal logic, and is more sloppily produced in terms of explaining unfamiliar terms, providing an accessible sequence of ideas, and making its points clear. This provides some clues as to what makes science more accessible: familiarity is one dimension, but clarity of presentation is highly important"

"Too much too soon" – there are several places where a clutch of concepts are introduced simultaneously [] – i.e. a series of maps of key concepts. It is good practice when 'teaching' to introduce one concept at a time, and use or apply or give example to that concept before moving on to the next.

The importance of design "The <u>way</u> in which something is represented carries <u>its own</u> message. Design and stylistic choices themselves communicate particular messages, including messages about how the authors of the material wish to present themselves. No design choice is neutral.

"The particular points regarding design can be summarised in one comment "this is crying out for a professional designer – and it's a plum job for someone". This captures the enthusiasm and potential of the project – and the recognition that the development of VL in Nirex is in its early stages."

12.4 Analysis

Throughout the trial, there has been consistent enthusiasm for the Visual Language project from those who have been exposed to its aims and outputs. A common reaction has been "how can I use this in *my* work?" which suggests that it does indeed have potential for engaging people who are trying to communicate. Additionally, those who have been involved in its review (both technical, and non-technical) have expressed readiness and keenness to be involved in later stage, which suggests that it has potential for engaging those who might be considered the communication targets.

Nevertheless, three factors suggest that the "real" (as opposed to trial) application of visual language should not be undertaken lightly. These factors are:

- the extensiveness of the external review comments, which draw on research from a range of fields to identify issues about the presentation of, and response to, such information that need careful consideration. However, a better definition of target audience, and the purpose of developing a visual language presentation might enable strategies for responding to these comments to be developed.
- the response of technical experts to the visual language material was generally very supportive. However, once that generality was articulated, there was considerable (and generally critical) comment about the (lack of) details, accuracy and precision of the wording and graphics used. These comments were primarily triggered by the simplification techniques adopted in an attempt to get over the sense of the scientific process, without being bogged down by the jargon and detail. In the trial, these sorts of comments were purposely not addressed as they were not perceived to be helpful to the aim of rapid visual engagement of a less expert audience. Nevertheless, in a real application of visual language, this may prove a difficult issue to address in developing an approved representation of complex scientific issues for use in a Corporate context.
- The costs of developing new visual language products would be high. The level of effort required to develop the material used in this trial was about 0.5 man-years of professional staff time. Because the development of diagrams is part of the thought process, this could not be significantly reduced in the developmental stages.

To set against these three difficulties, a tighter definition of the target audience for Visual Language, and the communication aim would help resources to be much more efficiently focussed. The trial concentrated on the tremendous potential of visual language to take "vertical" slices through hierarchical information and to cut down into greater and greater detail. In the review process, it was noticeable that different people tended to take "horizontal" slices through the material depending on their background, enthusiasm, available time and willingness to engage. Often, people were frustrated in taking these horizontal slices because they very quickly came to the boundaries of the information. A further application of visual language, with a more tightly defined target audience could concentrate on developing context of relevance to the audience, and need not provide so much opportunity for "mining down" through the information. There was clearly a lot of ambiguity over the audience for the trial - which was exacerbated by the vertical linking of information from contextual information to very detailed scientific concepts and debates. There was strong feeling that we should be much clearer about the audience for visual language.

Context is very important. During each round of review, more context was requested. The focus of visual language on phased disposal, and indeed on very detailed technical aspects of phased disposal was confusing. Those who knew a little about radioactive waste management wanted to be encouraged to explore the live questions – for example about policy development and the relationship to nuclear power.

Design styles had a strong impact, both on the way people reacted to the material and on the general "feel" of the information. There was no unified style in the visual language products developed. Once again, care is needed in adopting a design style – too sophisticated and the material may appear too much like propaganda, too little and it will appear amateurish. There is also a fine line between people feeling patronised by simple diagrams, and comfortable because they help relate the concepts to everyday things.

The importance of design choices cannot be underestimated. The same material can be developed into very different hard copy presentations, just by adopting different approaches to the structuring of the slides in two dimensions. Tremendous power is wielded by the designer and the resulting design, whilst tremendously powerful, may be highly schematic (for example the London Underground map).

A key conclusion of the external review is therefore the importance of applying graphical design expertise. Experience with developing the multimedia pilot CD indicates that this design process will need to occur *after* the development of the raw products, since the designer needs the content in order to start the design process.

A distinction needs to be drawn between the success of visual language as a communication media, and its success in terms of drawing out scientific uncertainty via argumentation maps. It is more difficult to draw conclusions about the success of the argumentation mapping. In the first place, significant argumentation was elusive. As the arguments were debated and considered, ways of representing the issue in a manner agreeable to both parties were identified. Therefore, argumentation was taken over by dialogue, which generated new meanings. Obviously this should be considered a success in its own right, but it casts doubt on the ability to develop a structured presentation of a polarised debate within an argumentation map developed in a single organisation – things are never as black and white as they seem, especially where scientific uncertainty is involved!

Once again, this may be an audience issue. The argumentation maps, which fundamentally need to mine down into scientific detail and theoretical debate are probably more relevant to a different audience than those who seek context at the higher levels. Again, this challenges the value of vertical slicing through the information that formed part of the initial aspirations of the visual language trial.

Another challenge to the development of argumentation maps was that eventually, there was very little argumentation in then! This reflects the difficulty of capturing exactly where the point of departure lies for two lines of reasoning. As the argumentation maps have been developing, and dialogue about areas of scientific uncertainty has occurred, the maps have focussed on presenting the common understanding, and the point of debate has been elusive. Further work will be required to ensure that the scientific issues are not lost in ever more sophisticated ways of presenting common knowledge.

12.5 Going forward – points for discussion

A key question for this thesis is determining whether visual language is simply a sophisticated communication tool, or whether it is somehow greater than the sum of its parts and can take a formative role in encouraging dialogue about science. Whilst this question cannot be answered conclusively without further application of visual language in dialogue and research into its value, it is important to identify that visual language played two very distinct roles during this trial:

- *assisting broad stakeholder dialogue about science:* where the visual language products worked as a tool to enable experts to share understanding and promote dialogue by encouraging people with more than a passing interest to engage with the live debate as policy for radioactive waste management develops;
- *encouraging expert-expert learning:* where the process of developing the visual language products acted as a vehicle for experts to develop shared ideas about scientific concepts, methods and key points of departure between those with differing opinions about evaluating options for the long-term management of radioactive waste,.

In conclusion, considerable potential for visual language to help encourage dialogue and debate has been identified. In particular, visual language helped elucidate ideas about areas of scientific uncertainty, and to develop new meanings between researchers (both experts in the field and from other fields) about the nature of that uncertainty. The nature of visual language encourages experts to move from their zone of comfort (terminology, concepts and reference literature) and face up to different ways of thinking and presentation. In a way visual language can *facilitate* two-way discussion between different groups, rather than the giving of information from the expert, and the receipt of information on the part of the non-expert. This can be very valuable in developing research needs in areas of uncertainty. A number of examples of this happening were experienced during the visual language trial.

The audiences for visual language used in this context are likely to be different to the "stakeholders and public constituents" which this work originally sought to engage in dialogue. Since the aim would be to highlight areas of uncertainty, visual language used in this mode could contribute to a review, preview and expert regulation. In this mode, the need for design and review is not so important. The development of visual language information graphics using packages such as PowerPoint could be undertaken by the people involved in the discussion, or by a third party involved as a facilitator. The value of this exercise is that it may help us understand some of the difficulties people have in engaging with long term risk calculations in the face of high scientific uncertainty. However, it will not necessarily enable social inclusion..

Whether visual language is a useful tool for sharing understanding depends on having a clear purpose for doing so. Given the observations about the importance of context, visual language is likely to be most effective in a more central role, rather than focussing purely on scientific issues. The boundaries imposed by focussing solely on scientific issues undermine the value of visual language and frustrate the audience. If it is to be taken forward in this way then significant resources are required for developing the content and then for its design and review. Additionally, opportunities for stakeholder and public engagement with the development of the visual language products need to be created, early in the process and continuously during its development. Those responsible for its development need to be receptive to input from others with different frames of reference.

Nevertheless, it does appear to have benefits in enabling the scientific and technical issues to be presented as part of a broader communication tool. The tremendous flexibility of visual language means that it is capable of absorbing and representing a very broad scope of information and hence seems a valuable tool for developing a shared knowledge platform.

In both cases, a key benefit of visual language arose from the development *process* rather than solely from the product. In terms of promoting dialogue, whether it is between experts or between a broader range of audiences, this suggests that there is value in sharing information early in any development process. This is again an aspect of moving forwards which may be very uncomfortable for some scientists and experts who are used to providing the "right" information and for whom it is very important to “have the space” to develop ideas and information prior to sharing it.

In the next chapter, opportunities for applying visual language and dialogue as part of the performance assessment process are considered. By so doing, it is hoped to develop a truly analytic-deliberative process for assessing risks from deep geological disposal.

13 A NEW APPROACH TO BUILDING SCIENTIFIC KNOWLEDGE IN SUPPORT OF ENVIRONMENTAL DECISIONS .

The previous chapters have considered new ways of presenting and discussing information and knowledge about deep geological disposal. The aim of these studies has been to look at how to engage with a greater range of stakeholders. However, for a truly analytic-deliberative approach, both analysis and deliberation should be integrated. In this chapter, the potential for building deliberation into the risk assessment process described in Appendix C is considered.

13.1 Integrating science and dialogue for radioactive waste disposal – what have we learned?

Chapter 9 postulated that clear and understandable presentations of conceptual models of environmental processes may be helpful as a common platform for iterative knowledge building, and Earth scientists should claim a central role in the development and evolution of these conceptual models.

Chapter 10 confirmed previous findings that there is interest in engaging in discussion about the scientific underpinnings of deep geological disposal waste. However, these discussions will not necessarily be on terms that the scientists are used to dealing with. In particular, time was a big stumbling block for those seeking to engage with scientific projection into the far future. Two points highlighted in the public consultation exercise were the question" *how do you get the timing right?"* and concerns about the lack of control once the repository was finally closed. Both of these issues are central to the scientific rationale for the deep geological disposal of radioactive wastes. Decisions about the safety of a deep repository consider calculations of risks for millions of years into the future, based on the idea that the natural system will provide "passive safety" – safety without reliance on any human intervention or control. However, although they are central to the concept of deep geological disposal, the concept of passive safety, and the amount of active management that goes into designing, operating and monitoring the repository prior to closure get very little mention in the post-closure performance assessment.

Although many frequently asked questions relate to the post-closure period, the public are most concerned with the behaviour of the repository system during its operational period and in the time period immediately following repository closure. Since the results of the performance assessment are integrated over millions of years it is very difficult to draw out scientific knowledge about what may happen on shorter timeframes and how the system may evolve over time. It has also become apparent that the previous assessment methodology (which, loosely speaking, considers how radioactivity could "leak out" so as to calculate risk) actually undermines the presentation and communication of the concepts underpinning deep geological disposal in which the physical and natural barriers both act to contain radionuclides.

Chapter 11 examined evolving ways of re-presenting the output of the performance assessment and the complex system that will develop around a radioactive waste repository. The limitations of using a single parameter to represent performance over a single (and very long) time period into the far future were examined and representational methods to address this were considered. Broadly speaking, alternative representational methods broke down future time into discrete periods and increased the use of qualitative supporting evidence (such as analogues) for environmental processes in the different time periods. However, there was a concern that changing the representation of risk for a wider audience would reduce its robustness to peer review and expert regulation – which continue to be requirements for the development of a legitimate scientific knowledge platform on which to base environmental decisions.

Following on from this, Chapter 12 examined the use of visual language as a means of presenting complex scientific knowledge conceptually. Analysis of the work suggested three important issues needed to be addressed if visual language was to be more than just a sophisticated communication tool. Firstly, the importance of context and framing was identified and the need to be open to other forms of expression. Secondly, the *process* of developing visual language presentations was as valuable as the output in terms of engendering shared understanding. Thirdly, design choices exerted a strong influence over the output and the manner in which the output is received. Legitimate design choices need to be made which meet the needs of the audiences. All of these issues mean that there needs to be opportunities for involvement throughout the development of a visual language representation of a scientific topic – i.e. continuous dialogue between specialists bringing expert knowledge to the debate, and other participants seeking to engage with, and contribute to the debate.

Based on these findings, a new framework for scientific knowledge building in support of environmental decision-making needs to provide certain things. The *process* of scientific knowledge building needs to provide opportunities for involvement and dialogue throughout the knowledge building process. This includes involvement very early on when the knowledge platform is being specified, framed and designed. As part of this discussion, consideration should be given to how to breakdown the time period of concern into manageable chunks (timeframes). The number of timeframes required will depend on the decision-problem and the timescales of concern.

Additionally, the resulting scientific knowledge base needs to be sufficiently flexible to respond to the needs and interests of potential audiences from outside the expert community. This flexibility needs to recognise the importance of context (for example why are you proposing certain design aspects) and assumptions (about what will happen in the future) which tend to be implicitly accepted amongst a specialist audience. Cultural attitudes and design issues will strongly affect this flexibility. Enhanced use of supporting evidence based on environmental observations may encourage involvement but such supporting evidence needs to be described and represented in a manner that meets the needs of the audience – which requires careful consideration of who the potential audiences are;

And finally, the scientific knowledge base needs to be developed with sufficient rigour and analytical precision that consequential risk calculations remain robust to detailed peer review. The expert community remains an important, if not the most important audience for risk analysis and risk analysis remains an explicit user of scientific knowledge. The need to provide methods that evaluate compliance with environmental standards in a scientifically robust manner cannot be overstated.

All these issues combine to provide a new framework for the presentation and discussion of the scientific knowledge underpinning deep geological disposal. Whilst this new framework may not significantly change the cognitive content of the knowledge base, the hope is that it will to better meet the needs of a more consultative approach to decisions about the management of radioactive wastes.

13.2 A new framework for scientific analysis

Analysis has always been central to the scientific method. Given the continued need for expert regulation in environmental decision-making, analysis should continue with a central role in scientific knowledge building. The question is how can the analytical process be opened up so that other stakeholders and public constituents can engage with the underlying scientific principles and influence the analytical content?

Based on the preceding research, the following issues need to be considered:

- The analysis needs to be robust to scientific and technical peer review
- Context (whether scientific or non-scientific) should be explicitly discussed from the beginning of the analytical process
- Opportunities for non-expert input should be created as early as possible
- The analytical process should be open to non-expert input (if any) from the beginning.
- The analysis needs to enable an evaluation of compliance with environmental standards
- The analysis needs a balanced presentation of calculations of risk, expected performance and levels of safety
- The analysis should recognise the importance of early timeframes in the minds of many stakeholders

- Opportunities for stakeholder involvement in making the value judgements that define the analytical process (e.g scenarios) should be provided at the earliest opportunity
- Stakeholder concerns can and should be explicitly addressed
- A range of ways of indicating performance should be considered
- Whilst the adoption of conservatism in modelling assumptions remains valid and necessary for robust calculations, it may not command confidence for the non-expert audience.

If analytical methods can be adapted to address these issues, then the analysis can developed from debate and discussions between lay and expert audiences. As discussed in Chapter 9, at the very least this requires a shift of analytical focus away from the cleverness and complexity of the model calculation and also requires that stakeholder concerns are addressed as part of the analysis – particularly when values are to be considered.

Visual Language offers a tool that can help with this shift in focus. The hierarchical presentation of information provides a flexible tool which can be developed and built upon as dialogue proceeds. However, opportunities for dialogue need to be created, and individuals need to be identified with responsibility to develop visual language representations based on the output of this dialogue. Iterations are required before a truly shared scientific understanding will be captured visually.

Once captured, this understanding can be used as the basis for analysis. In order to communicate to both audiences using the same underlying scientific knowledge, the challenge therefore is to develop a methodology that can meet expert and regulatory requirements whilst demonstrably responding to stakeholder concerns. The balance between these two drivers will depend on the manner in which the analysis is to be used within a decision-making process and the nature of the decision-making process itself.

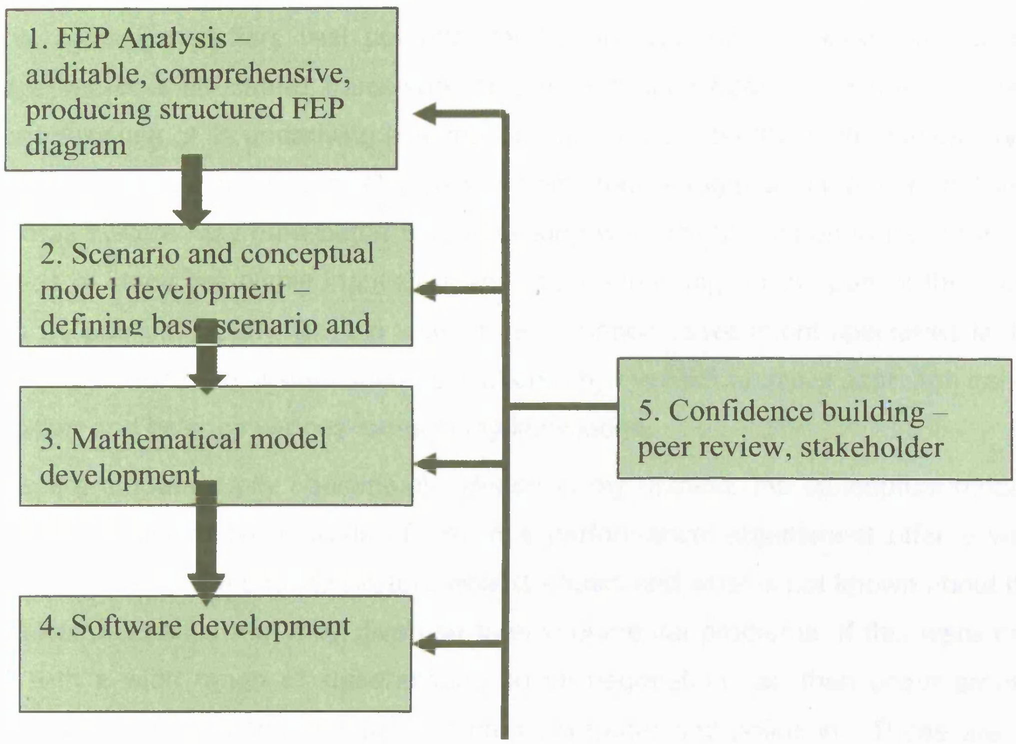
And finally, there is little point in re-inventing the wheel. The focus here is on evolution of analytical methodologies, rather than developing a revolutionary approach which would not be easily accepted by those experts with years of experience in the business of risk analysis. Therefore, the approach adopted in this thesis is to work with an established and peer reviewed process to enable its adaptation into a more inclusive analytical approach.

13.3 Illustration: How might this framework apply to performance assessment methods for radioactive waste disposal?

The framework described above is very general. Below, its specific application for the development of a new analytical approach for the assessment of deep geological disposal is outlined, in order to consider its practical implications.

Many countries adopt an approach to performance assessment that are centred upon an analysis of environmental processes and scenarios about how they might combine in the future (scenario analysis). For example, in the UK, Nirex has developed a five stage approach to performance assessment [Bailey and Billington 1997], as indicated in Figure 44. In this approach, a systematic analysis of all the features, events and processes (FEPs) relevant to the performance of the disposal concept leads to the identification of a base scenario and a number of variant scenarios that define potential evolutions of the repository. Each scenario is represented by a range of conceptual models, developed from a knowledge of the FEPs operating in the scenario.

Figure 44: The Nirex 5-stage assessment methodology



The feasibility and practicality of integrating stakeholder views into different processes of scenario definition requires consideration. In common with many other countries, Nirex has developed an approach to scenario development that uses very structured analysis of the features, events and processes that could affect the repository evolution (the FEP analysis approach) [Nirex, 1998b].

The approach has been reviewed and endorsed by the scientific peer community. However, partly because of its robustness and structure, it has some limitations in terms of taking on board the concerns (value judgements) of others. The methodology allows for the screening of features if they are deemed to be of low probability or consequence. Alternatively, they may be "subsumed" into other scenarios. If this process of screening and subsuming to establish key scenarios is undertaken in isolation from the values of non-expert stakeholder groups it can appear as if FEPs of genuine concern to some stakeholders may be lost from the calculations.

This is matter of method application. The FEP analysis approach provides a logical, systematic and comprehensive framework for developing scenarios for investigation in a performance assessment process. It could be applied in a manner that involves stakeholders in the process of identifying scenarios, screening and subsuming. In this way, the base scenario could be, at a minimum, supplemented by the additional exploration of variant "what-if" scenarios derived during dialogue or expected to be of concern to stakeholders.

The FEP analysis approach to scenario development is inherently reductionist – it seeks to break a complex system down into component parts and their interactions. This is one of its strengths since this breakdown offers real potential for the incorporation of extended facts and local knowledge within a structured framework of scientific knowledge. However, it also leads to challenges because of its underlying assumption that we can identify all the necessary processes and couplings between processes. Complex system studies suggest that a more holistic approach to the overall system may be a better way of tacking what might happen in the future. However, these areas of study are highly innovative and require learning on the part of the specialists, let alone the lay publics. Meanwhile, the view of performance assessment specialists is that the use of a known and structured system such as is offered by the FEP analysis approach can be used to draw together and balance various forms of lay knowledge.

Scenarios are fundamentally conceptual. Hence in my opinion, the conceptual models used to underpin the mathematical analysis of risk in a performance assessment offer a way forward. These conceptual models seek to capture what is known and what is not known about the physical and chemical processes that may give rise to environmental problems. If this were the focus for dialogue with a wide range of stakeholders, social negotiation can then occur around tangible concepts - rivers and streams, rainfall and crops, weather and pollution. These are issues with which people have direct knowledge, whether specialist or experiential.

In the Nirex five stage process (Figure 44), Stages 1 and 2 (FEP analysis and conceptual model and scenario development) are essentially qualitative and descriptive exercises. Given the research described above, they are stages that lend themselves to debate and discussion which need not be contained within the expert community. Visual Language, with its hierarchical approach to information and its ability to identify links and consequences multidimensionally offers a tool to assist in such debate. For this to occur, there must be a willingness to open up the FEP analysis work and scenario development stages to wider discussion. This has significant time and resource implications.

Since FEP lists already exists, and pre-existing assessments already contain predefined scenarios, it is very tempting, when time is of essence, to undertake Stages 1 and 2 by returning to pre-existing information without any further questioning. This approach prioritises the technically demanding task of developing mathematical models over the socially and ethically demanding task of debating issues and environmental futures. New approaches to analysis for environmental decision making need to rethink these priorities and consider what is most significant in developing a legitimate knowledge base on which to make decisions.

Given the lessons learned from the previous research, the need for an inclusive approach to stages 1 and 2 in Figure 44 (and equivalent stages in other analytical approaches and performance assessment methods) is significant. The interest in time and scenarios shown by the participants in the dialogue described in Chapter 10 suggests that there is great merit in using the scenarios as a vehicle for dialogue, perhaps with a greater delineation of time within the assessment. This idea has been used to propose a new approach to performance assessment based on the identification of discrete timeframes and the subsequent description of important features, events and processes for each timeframe. However, this raises important questions about how should timeframes be defined, who should define them and how should common FEPs in different timeframes be linked.

13.3.1 Timeframe definition

One approach to defining the timeframes could be based on the evolution of the repository system, with timeframes being distinguished by the importance of certain significant FEPs. For example, timeframes could be defined by: the period of institutional control; the expected time of container integrity; or the period for which the geosphere can be assumed to remain in more or less its current form. This approach provides a clear link to the changes in the repository system with time, but needs to acknowledge the uncertainty associated with the timing of particular FEPs becoming important and hence with the definition of the timeframes.

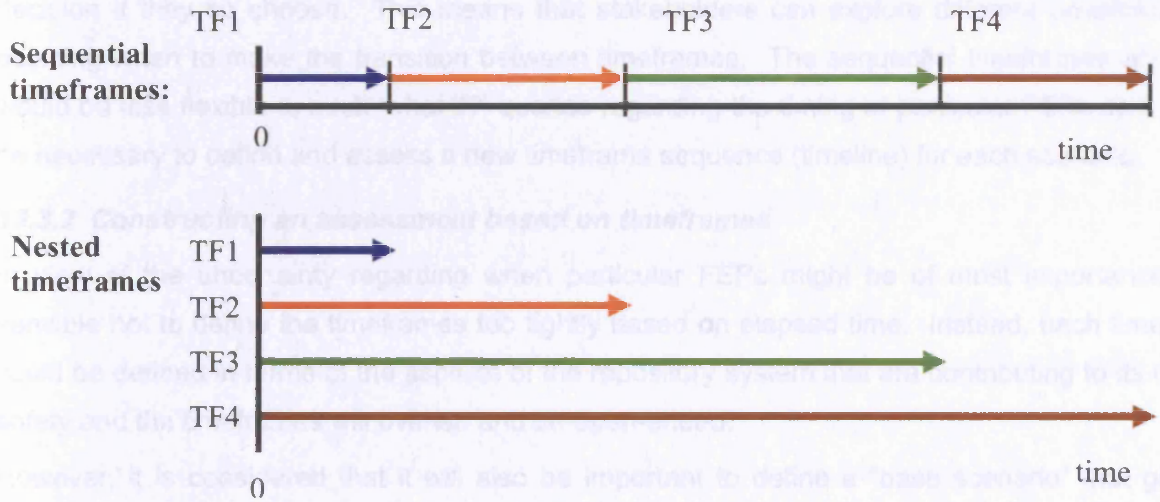
An alternative approach would be to define timeframes to reflect the periods of interest to stakeholders. This latter approach provides a clear mechanism for stakeholders to make early inputs to the assessment process, but may not always be easy to integrate into the production of a safety assessment that has to respond to scientific and technically-defined regulatory requirements.

The challenge then is for an approach which simultaneously:

- accommodates the uncertainty in the timing of the impact of particular FEPs;
- presents a clear view of the most likely repository system evolution; and
- enables stakeholders to make inputs to the assessment process and explore a range of different assumptions regarding the timeframes of interest to them.

It is believed the above requirements can be achieved if, rather than defining timeframes sequentially, they are 'nested'. Nesting means that for modelling purposes each timeframe is started at time zero, but the timeframes extend for progressively longer periods, as indicated schematically in Figure 45.

Figure 45: Alternative approaches to timeframe definition



Dividing the assessment timescales into different timeframes will provide flexibility to model each timeframe in a different way. This will be true for both nested or sequential timeframes. Each timeframe can be analysed differently (for example, encompassing different FEPs and hence different conceptual models, using different ranges of parameter values and even different assessment software). The aim is that by allowing this flexibility it may be possible to use tighter definitions of repository conditions, particularly for the earlier timeframes, and hence produce a more meaningful and robust assessment. It also increases the ability of the assessment to incorporate directly issues and concerns raised by stakeholder dialogue programme such as that presented in Chapter 10.

Chapter 12 identifies the potential of supporting arguments and analogues for informing dialogue. Whilst this is not a new idea, there has been little progress in explicitly linking supporting arguments and risk calculations for ten years. Either approach to timeframes would enable supporting evidence to be woven into the fabric of the assessment (for example, alternative performance indicators, the use of natural analogues, confidence arguments, heterogeneity representation and new methods of risk communication), rather than just present them as add-ons. For example, natural analogues could be presented up front as arguments in support of the conceptual assumptions made for a particular timeframe, and there would be the flexibility to look at different performance indicators in different timeframes, rather than focusing solely on meeting a radiological risk target. This would shift the focus of the performance assessment more towards describing the factors that contribute to safety, rather than just calculating risk.

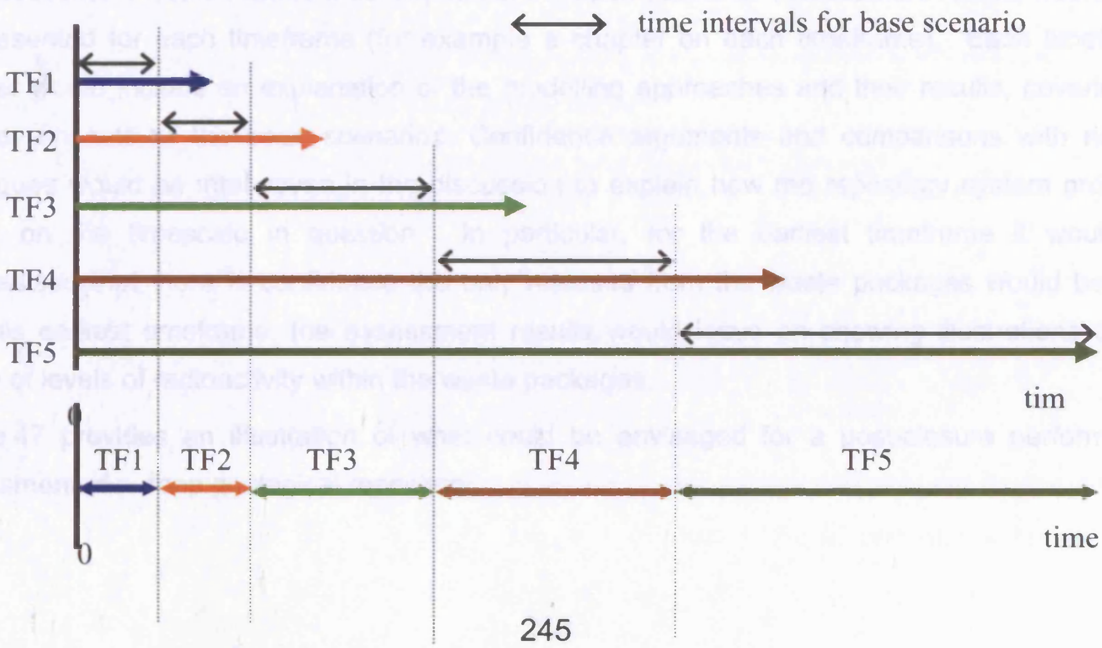
A key difference between a sequential and nested timeframes approach is that with the former the decision on when to move from one representation of the system (timeframe) to the next is made at the stage of defining the basis for the performance assessment, whereas with nested timeframes sufficient information is presented to enable the assessment audience to make this decision if they so choose. This means that stakeholders can explore different possibilities by deciding when to make the transition between timeframes. The sequential timeframes approach would be less flexible to such 'what if?' queries regarding the timing of particular FEPs as it would be necessary to define and assess a new timeframe sequence (timeline) for each scenario.

13.3.2 Constructing an assessment based on timeframes

In view of the uncertainty regarding when particular FEPs might be of most importance, it is sensible not to define the timeframes too tightly based on elapsed time. Instead, each timeframe could be defined in terms of the aspects of the repository system that are contributing to its overall safety and the timeframes will overlap and be open-ended.

However, it is considered that it will also be important to define a "base scenario" that gives a broadbrush description of a reasonable expectation of how the repository system may evolve. This base scenario would include a recommendation of how each timeframe relates to the others (as illustrated in Figure 46). It is suggested that the base scenario be defined on a cautious, but not overly pessimistic, basis. In addition to the base scenario, a number of variant scenarios would also be considered to deal with uncertainty about the way the timeframes of the FEPs relate to each other and to enable the assessment to consider the implications of FEPs not included in the base scenario. Determination of which variant scenarios to be considered could be the subject of further debate and discussion based on the articulation of specific stakeholder concerns such as those indicated in Box 7.

Figure 46: Construction of a base scenario from nested timeframes



As an illustration, the following five timeframes could be used to form the base scenario:

Timeframe 1 – waste containers as emplaced, repository backfilled and closed

Timeframe 2 – physical and chemical barriers evolving, institutional control of repository site

Timeframe 3 – chemical barrier operating as designed, near-field reducing conditions established

Timeframe 4 – homogeneous near field, stable geological barrier

Timeframe 5 – system responding to external change

In constructing the assessment, for each timeframe consideration would be given to the following:

- The definition of the timeframe, in terms of the importance of key FEPs relevant to changes in the repository system (the base scenario description).
- An indicative timescale (i.e. the period within the base scenario for which the timeframe assumptions might reasonably be considered appropriate).
- Confidence arguments – natural analogues and other arguments which support the scientific basis adopted in the base scenario, i.e. those used to define the timeframe.
- Relevant performance indicators.
- General modelling approaches, including:
- appropriate model scales;
- importance and relevance of different components of the repository system;
- importance and relevance of different pathways.
- Potential variant scenarios for consideration. For example, human intrusion into the repository would need to be considered as a possibility from Timeframe 3 onwards, once there is no longer institutional control over the site.

The assessment would include a description of the base scenario. Assessment results would then be presented for each timeframe (for example a chapter on each timeframe). Each timeframe chapter would include an explanation of the modelling approaches and their results, covering all the key impacts of the base scenario. Confidence arguments and comparisons with natural analogues would be interwoven in the discussion to explain how the repository system provides safety on the timescale in question. In particular, for the earliest timeframe it would be emphasised that there is confidence the only releases from the waste packages would be gas. For this earliest timeframe, the assessment results would focus on showing illustrations of the decay of levels of radioactivity within the waste packages.

Figure 47 provides an illustration of what could be envisaged for a post-closure performance assessment of a deep geological repository.

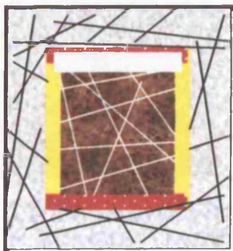
Figure 47. Possible base scenarios for a timeframes-based approach to performance assessment

Timeframe 1: Waste containers as emplaced
- Institutional control and monitoring (may include long-term storage period)
- Physical barrier intact, containment of radionuclides
- Repository starting to resaturate
- Releases limited to minor diffusive releases through vents and gaseous emissions

Key Performance Indicators
- Decrease in radionuclide inventory
- Zero flux from near field
- Gaseous releases

Confidence arguments:
- Steel corrosion measurements
- Decay of short-lived radionuclides

Modelling approaches:
- Decay within packages
- Gas generation and transport



Timeframe 2: Physical and chemical barriers evolving
- Repository fully saturated
- Physical barrier may start to break down but wasteform limits mobility
- Many radionuclides relatively insoluble, greatest release by diffusion
- Degradation of organics producing complexants
- Gas generation and migration

Key Performance Indicators
- Decrease in inventory
- Flux from near field
- Gaseous releases

Confidence arguments:
- Comparisons with corrosion of Roman nails
- Cement analogues

Modelling approaches:
- Package-scale model
- Near-field chemistry
- Gas modelling

Timeframe 3: Chemical barrier
- Reducing conditions in near field fully established
- Corrosion causes failure of significant number of packages
- Advective-diffusive release of radionuclides, particularly those which are poorly sorbed
- Gas generation and migration

Key Performance Indicators
- Flux from near field
- Gaseous releases

Confidence arguments:
- Cement analogues
- Maqarin site – limited movement of radionuclides away from repository

Modelling approaches:
- Repository-scale near-field model
- Steady-state, regional-scale groundwater flow

Fig 47 continued overleaf

Figure 47 cont. Possible base scenarios for a timeframes-based approach to performance assessment.

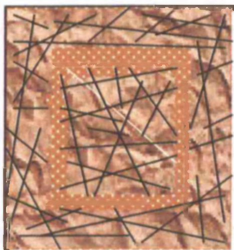
Timeframe 4: Stable geological barrier

- Most waste packages have failed, offering little resistance to radionuclide migration, therefore the near field is treated as homogeneous
- Migration of radionuclides from near field through far field

Key Performance Indicators
- Fluxes out of near and far field
- Radiological risk
- Environmental effects
- Comparisons with natural fluxes

Confidence arguments:
- Maqarin site – limited migration
- Oklo – retardation
- Palaeohydrogeology – geosphere stability

Modelling approaches:
- Homogeneous near-field 'soup' model
- Groundwater transport models



Timeframe 5: System responding to external change

- Homogeneous near field
- Migration of radionuclides from near field through far field
- Need to consider climate change and hydrogeological changes
- Releases to different climate states

Key Performance Indicators
- Radiological dose or risk
- Comparison with background radiation levels

Confidence arguments:
- Comparisons with natural radiation levels

Modelling approaches:
- Homogeneous near-field 'soup' model
- Reference geosphere
- Reference biospheres representing different climate states

The modelling approach proposed for Timeframe 5 is directly comparable with that used throughout earlier post-closure performance assessments. (e.g Nirex 2001a). The results for Timeframe 5 would therefore provide a direct comparison with Nirex's previous assessment work, whilst the results from the earlier timeframes will allow a more realistic evaluation of the roles of the barriers in containing the radionuclides at early times.

Whilst the nested timeframes approach avoids the need to define specific start and stop times and consistent boundary conditions for each timeframe, it will still be necessary to demonstrate consistency between the results from the various models at early times and to avoid the potential confusion of presenting multiple assessment results. These issues will need to be taken into account in the process of constructing the assessment. If conservatism (i.e the use of worst case ideas on an uncertainty issue or parameter) is being applied effectively in performance assessments as a means of dealing with future uncertainty, then this should result in a gradually worsening risk result as the timeframe of interest increases. If this is not the case, then the effectiveness of conservatism a means of handling uncertainty needs to be questioned.

It is suggested that variant scenarios are similarly represented on a timeframe by timeframe basis. A worst case scenario could be developed collaboratively for each timeframe. This would be presented in terms of all the things that would have to go wrong for the scenario to materialise, whilst explaining the mitigating features that would help to prevent each happening. This would ensure that these low probability scenarios are given appropriate conceptual consideration and are 'visible' to stakeholders.

Overall, the evolved methodology suggests a move away from presenting continuous risk-time curves, with the implication that the assessment is predicting what will happen at specific times. Instead, the focus would be on explaining why it is believed that the repository will be safe over each of the timeframes and what the expected impact (whether that is risk, flux out of the repository etc.) will be within each timeframe. Additionally, information would be presented on the worst, reasonably conceivable, scenarios for each timeframe.

The proposed approach will present some new challenges for research programmes, in that by increasing the focus on the earlier timeframes it will be necessary to develop a more detailed understanding of how the repository system is likely to evolve, including, for example, the resaturation phase and the effects of gas release and two-phase flow. Overall, it is hoped there will be less reliance on conservative assumptions for modelling processes and a greater conceptual understanding of the repository system behaviour.

13.4 Next Steps

The next obvious step in this research would be to trial the methodology using stakeholders perhaps drawn from the focus groups described in Chapter 10. However, this has not been possible within the scope of this research. Obviously any engagement with stakeholders has an affect on the relationships and levels of trust at play. There is continued uncertainty over UK policy for radioactive waste disposal. At the time of this research, Nirex considered it injudicious to pursue further dialogue on such a specific issue as the post closure performance of a deep geological repository. Understandably, a concentration on one option, and a specific aspect of that option could imply that the much broader policy dialogue being undertaken by DEFRA was not truly an open discussion.

13.5 Generic application – How would this framework be applied for building scientific knowledge in support of environmental decisions

13.5.1 Generic conclusions

The illustration given above suggests that without significant change to individual elements of traditional method and practice it should be possible to create increased opportunities for non expert audiences to be involved in the process of performance assessment. The illustration focuses on how to improve early involvement in developing conceptual knowledge about possible futures and in establishing an appropriate scope and design for a mathematical assessment of risks. Visual language work looking at new ways of bringing information into dialogue can be combined iteratively with analyses to build a knowledge platform about important timeframes and important features, events and processes that is equally relevant to lay audiences and specialists. However, for this to occur, the process of dialogue and interaction has to be seen to be as important as the output of visual language or risk assessments.

In more general terms, the proposed new framework for the development of scientific knowledge and the analysis of risks to the environment requires some significant changes to scientific practice in support of environmental decision making:

- A willingness on the part of scientists to open up their work, and be responsive to discussion and debate early in the analytical process
- An increased focus on the context surrounding the analysis
- A willingness to use descriptive methods to discuss underlying concepts and understanding
- An ability to think flexibly about the scope of the analysis and the value of different sources of information

However, these changes are more about attitude and about clearly understanding the role of the analysis than about methodological changes or changes to the analytical tools. Most competent scientists will already be fully aware of the context for their analysis and of any ambiguity in the way it relates to the decision-in–hand. Openess about these issues become a pre-requisite for an analytical-deliberative approach to environmental decision-making.

The biggest challenges will be about attitude changes. Even in this area, many competent scientists are aware of the need for greater openess and dialogue about their work. However, their attitude towards this dialogue may currently conform to a defecit model or may be strongly influenced by past dialogues with experts from "opposing" schools of thought or from non-Governmental Organisations. Time will be the main factor in changing this – time and experience in applying a deliberative framework for scientific knowledge building.

Another aspect of attitude change, will be the need for increased flexibility in thinking about and articulating the potential for environmental harm. In the performance assessment illustration given above, the definition of timeframes, the FEPs important within the timeframe and the way the timeframes link together into a base scenario and variant scenarios provide the platform for description and discussion of conceptual knowledge. These ideas:

- What timeframes are important
- What are the important features, events and processes that distinguish them from each other
- How do they link together into a prediction of the future

Are common to all considerations of environmental risk and all analytical procedures involving the future (e.g. a HAZOP study, a safety case for a new installation, a risk analysis for a landfill facility). However, quite often, these considerations are undertaken implicitly and then described once the analysis has been done when the report is being written up. The new framework suggests a much more explicit treatment of these issues and a declaration of them much earlier in the process. The aim of this early declaration is to initiate an iterative and recursive dialogue process between the analysts, and other stakeholders and interested public constituents.

Different individuals learn and think in different ways. If an aim of the early articulation of scenarios is to promote dialogue is will be valuable for individuals to be involved who think and work best in a descriptive, qualitative manner. This is one of the reasons why Earth scientists (as a group) may be significantly affected by the proposed framework.

13.5.2 The significance of conceptual geoscience

Hopefully the value of the Earth sciences will have already been apparent in the preceding discussion. Essentially, the evolved analytical approach relies more heavily on supporting evidence and on being more explicit about the environmental processes that could be operating in different timeframes into the far future. Earth science, with its emphasis on interpreting environmental observations in terms of processes operating in the past is a key source of evidence for both these issues.

The proposed framework is encouraging a greater emphasis on the description of important timeframes and important features, events and processes within those timeframes. Earth scientists and conceptual geoscience has always informed these considerations. However, the new framework is encouraging these considerations to be undertaken much more openly, and to be used to stimulate iterative and recursive dialogue with non-experts. Earth scientists will be important individuals to involve in this dialogue. Indeed, conceptual geoscience is well placed to act in this capacity since it is interpretive, qualitative and heuristic. As long as it is backed up by solid scientific theory, precedence and evidence then there is considerable potential for it to whet the appetite of non-specialist audiences and encourage input and debate.

It was noticeable at the RCF Public Inquiry presented in Chapter 9 that a large proportion of the cross-examination about the science of Nirex's proposals at Sellafield involved geoscientific considerations and differences of opinion fuelled by geological uncertainty. This emphasis cannot be very different to that expected when considering proposals for toxic waste disposal and climate change implications since over long timescales, thinking inevitably turns towards the environmental processes which are the subject of the Earth sciences. This is not to say that considerations of societal and biological futures are less important. They are not. However, on long timescales and large spatial scales, societal and biological futures generally receive a more statistical treatment and there is a shorter period of historical evidence to draw in to long term future predictions.

13.5.3 Would this respond to the needs of expert regulation?

It is important that the proposed approach is consistent with regulatory requirements and capable of eventually being applied as part of a regulatory submission. Guidance on regulatory requirements in the UK is publicly available. However, as with any regulatory guidance, it can be open to interpretation. Past performance assessments have been presented as focussed on determining consistency with the quantitative risk target laid down in the regulatory guidance. If this was all that was done, this could be seen as a very narrow interpretation of the guidance, which also sets out a number of qualitative principles such as the use of best science and the application of multiple lines of reasoning.

The assessment methodology proposed here would remain consistent with past, quantitative approaches since it will deliver a risk calculation in Timeframes 4 and 5. However, it will also respond more explicitly to the broader considerations set out in the regulatory guidance by integrating evidence from analogue studies, underlying research and performance indicators other than risk into the overall approach.

13.5.4 Would this assist social inclusion?

The methodology outlined above has the potential to remove some of the barriers to dialogue described in the preceding chapters of this thesis:

- It avoids the need to judge the exact timing of FEPs – timeframes are defined on the basis of key characteristics of the repository evolution, rather than with reference to elapsed time.
- The approach is consistent with previous published approaches, but provides more flexibility.
- The use of nested timeframes, with different modelling approaches in each, should enable a more accurate representation of the repository system for early times, whilst the approach proposed for the longest timeframe provides a direct comparison with previous modelling approaches.
- Confidence arguments and the use of natural analogues are interwoven into the assessment, hopefully providing an overall assessment that will be more meaningful to stakeholders.
- The approach addresses stakeholder concerns by placing more emphasis on the early timeframes and allows stakeholders to explore a range of 'what if?' scenarios by presenting nested, open-ended timeframes with different modelling approaches.
- Effectively, calculations would be performed for a series of different conceptual models of the repository system. Each conceptual model would be most relevant over a particular timeframe and the base scenario would describe a view on the most appropriate times to move between the conceptual models. However by nesting the timeframes, stakeholders are afforded the opportunity to form their own views on the time periods over which they believe each conceptual model to be valid. It is therefore hoped that this timeframes-based approach would not only provide the flexibility to take on board new trends in performance assessment, but will also be more meaningful to stakeholders.

13.5.5 Implications for practical application

Although the proposed framework seeks to be evolutionary rather than revolutionary, there are a number of practical implications associated with its adoption. The complexity of the modelling requirements for such an approach have not been considered here. Whilst I do not believe that the proposed framework necessarily affects the mathematical model adopted for risk analysis, there must be some question over the level of data available to support a greater emphasis on conceptual models for a range of different timeframes and for a range of variant scenarios. Nevertheless, even developing the conceptual models for a performance assessment using the above approach will yield some benefit since it will move the mathematical modellers out of their comfort zone, and provide opportunities for stakeholder engagement that have not existed in the past. Even if the tried and tested mathematical models are used for the calculations (because the data to support an evolved approach to not exist), the presentation and documentation of the performance assessment will be subtly different by having a different approach to conceptual development applied at the beginning of the process.

13.6 To what extent has the research identified new platforms for dialogue?

This section has explored the hypothesis that there may be sufficient common interest in the conceptual issues that underpin the risk analysis process for conceptual models to act as a vehicle for shared knowledge building. The work presented above shows that there is considerable interest in talking about environmental issues at a conceptual level and that careful use of visual techniques can help to promote such discussion. The attitude of the scientists will be a deciding factor on whether such dialogue is successful in enabling shared knowledge building and social inclusion in the analytical process.

A framework for scientific knowledge building in the future has been put forward. The implications of this on scientific practice do not appear to be significant but should increase the profile of geoscientific information in both the analytical process and in deliberation. Conceptual geoscience could thus become a pivotal factor in adopting an analytical approach to environmental decision-making.

However, the extent to which adopting these new approaches will engender a common platform of knowledge has to be questioned. In the absence of any testing of the proposed method, this question cannot be adequately addressed. Nevertheless, there are indicators that some stakeholders will continue to be excluded, or will self-exclude themselves. However, there does seem to be sufficient evidence that the new approaches advocated, and in particular the visual language have real potential to act as vehicles for debate, even if the resulting platform of knowledge is not truly shared.

In the following chapter, these conclusions are summarised against a general overview of the work contained in all three of the Sections of this thesis.

14 CONCLUSIONS – CAN WE IDENTIFY PLATFORMS FOR ITERATIVE SCIENTIFIC KNOWLEDGE BUILDING AND SOCIAL LEARNING?

The thesis started with the question:

"How can we get the right science in an appropriate social context to build an effective knowledge base for decision-making?

This question is about building capacity – developing a shared understanding with which to inform decision-making. However, as research into this question has progressed, an alternative and highly practical subsidiary question has emerged:

"What would help different stakeholders and public constituents engage in dialogue about scientific knowledge?

In this chapter, my conclusions are presented in an attempt to respond to both these questions and consider their implications on scientific practice. During the course of this research, the rather simplistic notion that I started with – that we should use risk analysis more effectively in public dialogue – has been overturned. The dependencies between knowledge, values and individual characteristics are so complex that no single action on behalf of an individual or a group will make the difference between a legitimate process and a dictatorial one. Hence I pursued a notion of developing a shared knowledge platform, or providing a vehicle for dialogue.

14.1 An outline of the preceding research

Section 1 of the thesis examined the social science and risk literature in order to identify the issues that are faced by decision-makers in the contemporary environmental arena. Issues such as:

- the move towards deliberative and inclusive decision-making processes;
- the nature of participation and the difficulties of collective choice; and
- the cultural nature of risk and the treatment of future uncertainty in risk analyses

are explored in general theoretical terms.

Section 1 concludes that a platform to enable knowledge building involving both scientific/expert and lay audiences could help the process of dialogue about environmental decisions. This presents significant challenges for the scientist. Earth sciences may have some particular attributes that can assist.

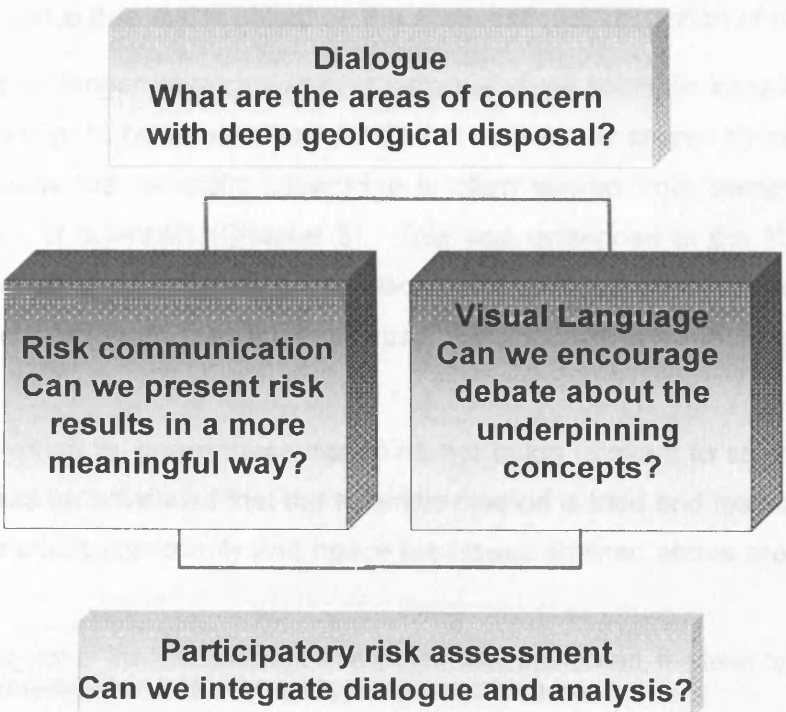
Section 2 examines the suitability of risk analyses as a platform for shared knowledge building. These have been the traditional vehicles for scientific knowledge in environmental decision-making. The specific case of radioactive waste management is considered in some detail. Past practices and (post-closure) performance assessment methods for the deep geological disposal of radioactive wastes are examined to consider:

- challenges to the way they treat uncertainty;
- the extent to which value judgements influence the analysis;
- whether the relationship between the analysis and the decision-making process are clear and hence whether the analysis is fit for purpose.

Section 2 concludes that there are some very real limitations to the use of post-closure performance assessments for wider dialogue, primarily resulting from its highly quantitative nature.

Therefore, in Section 3, more qualitative ways of communicating both the risk from, and the concepts underlying post-closure performance assessments are examined. Issues expressed by the public are described, based on an independently facilitated consultation process. An (as yet untested) evolved methodology has been proposed that seeks to integrate all these studies into a viable risk analysis process for radioactive waste disposal. It is hoped that this method will measure up to peer review, will respond to regulatory requirements and will provide opportunities for lay audiences to engage and contribute at an early stage.

- Figure 48 Linking between different elements of this research



14.2 The challenges scientists face from an analytic-deliberative approach to decision-making

The process for environmental decision-making is changing (Chapter 2). As the move toward combining analysis and deliberation in environmental decision-making gains momentum, the implications for scientists and scientific practice are becoming increasingly apparent (Chapter 8). New decision-making processes provide new context for scientific knowledge.

Three inter-related issues emerge that are individually very threatening for scientists. Collectively, they suggest that new thinking is required if scientific knowledge is to continue to influence socially inclusive processes.

- Scientists have lost the executive power they once enjoyed as a result of holding expert knowledge. Too many situations have now been experienced where scientific knowledge has been shown to be limited or hotly disputed. Trust in experts is at an all time low, and hence the power of scientific knowledge has been significantly reduced (Chapter 3).
- Where uncertainty[a] is high, the influence of subjective judgements, based on personal value systems and ethics, has been exposed by the work of people like Brian Wynne (Chapter 4). This does not sit comfortably with the notion of a scientific method that is impartial, value free and is based on the systematic interpretation of observations.
- Scientists no longer have control over dialogue about scientific knowledge. The frames of reference used by some scientists are not necessarily shared by other stakeholders, which means that scientific knowledge is often viewed from perspectives that differ from those of scientists (Chapter 3). This was evidenced at the RCF Public Inquiry where the scope of the discussions placed a lot of focus on the Nirex 95 performance assessment although the Nirex scientists were focussed on more recent information (Chapter 7).

It is quite tempting to ignore these issues as not being relevant to scientific practice. An argument could be advanced that the scientific method is tried and tested and is not aimed at the non-scientific community and hence the issues outlined above are not the scientists

[a] Here, as in the rest of the thesis except where otherwise mentioned, the term "uncertainty" is used in a general sense to mean lack of certainty, whatever the cause.

problem. Unfortunately, there are signs that this rather parochial attitude results in a downplaying of the value of scientific knowledge in the decision-making process. In consequence the decisions will not be well founded in an observational understanding of environmental processes and one of the conditions for deeply sustainable solutions (a broad and deep exploration of environmental issues [Chapter 2]) will not be met.

In consequence, it is my firm conviction that the scientific community needs to take action if it is to maintain an influential role in environmental decision-making. However, the action required must be constructive and outward looking, rather than parochial and paternalistic. Hence the focus in this thesis on identifying platforms for knowledge building that can be *shared* between scientific and lay audiences (Chapter 9).

14.3 What is required to build a shared knowledge platform?

Inclusive, stepwise decision-processes (see Chapter 6 for an example) need to be supported by knowledge building that is:

- *Iterative*; so it comes under constant and repeated scrutiny from both expert and lay perspectives and
- *Reflexive;* so that the knowledge supporting any step in the decision-process is never considered to be unassailable;
- *Adaptive;* so that it can respond to new issues arising as the decision-making process progresses or as new information comes into the frame.

Such iterative knowledge building is a pre-requisite for a parallel process of social learning (for both scientific and lay stakeholder groups). A process of social learning means that successive steps in the decision–process can be increasingly informed (Chapter 3). Therefore, a shared knowledge platform needs to be one which can adequately inform and respond to both experts – who may be involved in peer review or expert regulation; and other stakeholders – to enable social inclusion and permit the inclusion of lay knowledge (Chapter 5).

Nevertheless, experience shows that expert regulation is important in providing a "public champion" with the knowledge and expertise to provide effective checks and balances on scientific work (Chapters 5 and 7). A legitimate decision therefore requires a knowledge platform has scientific substance – i.e. it is supported by rigorous, peer reviewed analysis and detail. At this point, I considered that risk analysis would be the obvious candidate for such a platform, with suitable modifications and evolutions.

14.4 The use of risk analysis as a platform for shared knowledge building

Risk analysis is the traditional vehicle for inputting scientific knowledge into environmental decisions. Risk analysis generally arose for engineering decisions, but methods have been adapted into sophisticated analytical processes for more complex environmental decisions requiring consideration of potential consequences far into the future (Chapter 4). For radioactive waste management, this thesis uses the term (post closure) performance assessment for the risk analysis conducted to analyses what might happen once a deep geological repository is closed.

Broadly speaking, the risk analysis is a process of intellectual translation conducted in three stages:

- Development of conceptual foundations, based on an understanding of what is, and what isn,t known to develop hypotheses about current and future environmental processes and their cause and effect;
- Numerical representation in mathematical models, which includes thinking about how to represent uncertainty in a quantitative manner;
- Calculation of risks, which can then be compared with environmental standards.

For radioactive waste management, the ultimate need to compare the risk results with environmental standards has led to the development of highly quantitative numerical methods (Chapter 8). The claim is that these methods enable a systematic treatment of uncertainty within a mathematical framework. However, experience shows that the sophistication of these methods acts as a barrier to dialogue outside the specialist community (Chapter 8). Nevertheless, amongst the specialist audience there is a measure of agreement that these methods exemplify best practice in risk analysis.

Adaptation of the risk analysis to be a shared knowledge platform would have a number of difficulties:

- The "education" of non-specialist audiences to understand the numerical methods used would be an example of the deficit model of the public understanding of science. It may be appropriate for some audiences in some circumstances but is unlikely to be a good general approach since it is a one-way communicative action and rather paternalistic. The specialist will begin the process in a position of authority over the other stakeholders and this unequal power relationship would not be conducive for *shared* knowledge building.

- Encouraging interest and involvement in the quantitative risk analysis is likely to be difficult, not least because of the amount of education required to understand the analytical process.
- The claim that the numerical methods enable a systematic treatment of uncertainty is challenged by contemporary thinking about science and society. If very broad classifications of uncertainty are considered, the risk analysis does not address issues of "ignorance" or "indeterminacy" since they are, by definition, uncertainties that are not known (Chapter 4).

My first thought was to de-emphasise the quantitative nature of the analytical process, and to reformulate ideas about risk analysis that were based on qualitative illustrations of risk. However, following research into this idea, it appeared that this would result in an overriding concern in the minds of the analysts - that such a qualitative approach would be at the expense of developing a risk analysis that meets the requirements for analytical rigour and precedence anticipated by expert peer review and regulation (Chapter 8 and 11).

An alternative approach could be to focus on the first stage of the risk analysis and use the development of conceptual understanding as a platform for shared knowledge building. This would de-emphasise the quantitative nature of the analytical process for the purposes of dialogue with non-specialist stakeholders, but maintain it for the purposes of expert regulation and peer review.

14.5 Developing the conceptual foundations of risk analyses as a platform for shared knowledge building.

There are many examples in the literature where non-specialist stakeholders have expressed concerns about the environment using conceptual descriptions of environmental processes. These may not be articulated in the terms used by scientists, but that is a difference of expression, not substance. The first stage of the risk analysis is essentially descriptive – descriptions that can be informed by both scientific and lay knowledge about environmental processes. At this stage of the risk analysis process, stakeholders are exploring what their concerns and issues are, and the ideas that come forward are non-unique and hence able to adapt towards other frames of reference.

Initially, the idea that the conceptual foundations of risk analysis could act as a platform for shared knowledge building was explored by considering various was of communicating complex information (Chapters 11 and 12). There is a plethora of methods in the literature for making information available and attractive to different audiences and different personality types. However, a key finding from the work presented in Chapters 12 was the importance of the *purpose* of making such information available. Consultation into the Nirex Phased Disposal Concept demonstrated that stakeholders are sufficiently perceptive that the way they receive information is conditioned by the motives they ascribe to the holder of the information (Chapter 10).

The purpose of any information provision in support of shared knowledge building should be to *enable* dialogue, not to *communicate*. In consequence, it is probably more important to get broadly appropriate and accurate information out, than to get every last detail right. The notion of a "right" answer where environmental risks are concerned is under challenge anyway. This attitude of mind will be difficult for many scientists who are trained to provide rigorously analysed information that is robust to highly technical and critical peer review. So I now consider that in certain circumstances it is necessary for scientists to sacrifice precision and accuracy in the interest of providing understandable information – sacrificing comprehensiveness for comprehensibility.

However, the review of the Visual Language trial (Chapter 12 and Appendix F) suggested that even with this changed attitude, the aim of dialogue can be undermined because the scientist is still trying define (control?) the scope of the dialogue. A lot of power is given to the individual who provides the information about the conceptual underpinnings of risk analysis – and in the case of the Visual Language trial this was essentially done from a scientific perspective. Hence there is a danger that qualitative descriptions created by scientists can alienate both scientific stakeholders and lay stakeholder. For the scientists and analysts, removal of the quantitative rigour of their work, the sacrifice of accuracy for understanding diluted its ability to measure up to scientific peer review. For a lay audience, they are being asked to accept context that is predefined by an expert audience. Since the frames of these two stakeholder groups are very different there is a high chance that the *content* of material prepared by scientists will not cover the *context* that the lay audience wishes to consider (Chapter 12). This is not conducive to encouraging stakeholder involvement in the conceptual foundations of a risk analysis.

Nevertheless, past experience in public consultations, together with the discussion groups described in Chapter 10 indicate that there is broad stakeholder interest in discussing the processes, cause and effects that affect the environment and hence give rise to risks. Generally speaking, such engagement needs to be proactively encouraged, but once engaged, sensible dialogue quickly ensues (Chapter 10).

The discussion groups described in Chapter 10 identify an important focus on (Box 6):

- The timescales involved in thinking about the environmental impacts of radioactive waste disposal (e.g. *"how can you get the timing right?");*and
- The scenarios that are being considered *(e.g. "what would be the impact of earthquakes..?")*

It is possible to respond to these issues using new methods of conceiving the substance of the performance assessment. Evolved assessment methods that focus on environmental processes in different timeframes have been proposed (Chapter 13) and, theoretically at least, have been well received by performance assessment specialists [Bailey and Littleboy, 2002].

However, the practical application of these new methods has not yet been tested. The explicit modelling of separate timeframes will require new mathematical models and the evolved approach will be very data intensive. Nevertheless, even if it is not possible to adapt the mathematical models to directly reflect timeframes-based conceptual foundations, the act of describing the conceptual foundations in terms of discrete timeframes should have served to build technical knowledge that is shared between a wide range of expert and lay stakeholders.

14.6 So what?

This research has suggested to me that it will be extremely difficult to build a single consistent platform of shared knowledge for environmental decision-making that will serve all needs equally well. However, the attempt to do so will develop very valuable opportunities for dialogue and relationship building that will support the decision-making process well. The process of deliberation is as important as the material outcome of the deliberation. This means that practitioners would be wise to focus their attention on process throughout all stages of the decision-making process.

It is always dangerous to offer sweeping generalisations about different groups of people. Any group is not homogeneous and inevitably individual characteristics and specific organisational situations will exert a very strong influence over practice. Nevertheless, in order to highlight some of the significance of the research presented above, I have outlined below some of the implications for different groups of people involved in environmental decision-making.

14.6.1 The significance for Earth scientists

A key thrust of these conclusions is a greater focus on qualitative descriptions and conceptual hypotheses about environmental processes. These provide an opportunity for Earth scientists to claim a leading role in the knowledge building process. In particular, there are three characteristics of Earth science that place it in a good position to facilitate shared knowledge building about the environment:

- Earth scientists have a grasp of the timescales under consideration when dealing with risks from radioactive wastes. The focus of Earth scientists on the evolution of the Earth over many millions of years in the past gives them subliminal yardsticks which can be used to delineate and differentiate between timescales for millions of years into the future (Chapter 5).
- Additionally, Earth scientists work in an essentially descriptive manner – a key difference between the Earth sciences and other physical sciences. Earth scientists seek to identify hypotheses about the way the Earth behaves that unify environmental observations. These hypotheses can rarely be proven and are often non-unique because of the high levels of uncertainty about environmental conditions. This non-uniqueness and lack of certainty equate very well with the difficulties of predicting what will happen to the environment in the future.
- Finally, Earth scientists work with the Earth and its environment. In that respect, Earth scientists have knowledge that is tangible to people's experiences, which ought to provide many opportunities for dialogue.

However, if Earth scientists are to grasp this opportunity and take a central role in enabling shared knowledge building for environmental decision-making, they need to adopt an outward focus, rather than concentrating on their own epistemological community. This is difficult as it tends to detract from the scientific principles which scientists are trained to adopt (Chapter 5). Also, active dialogue outside a specialised audience will challenge mindsets and require individuals to re-appraise the way they work, the content of their work and the context for their work (Chapters 5 and 8). Individual characteristics will determine whether and how individual Earth scientists rise to these challenges. If enough seek to do so, then there is a chance that Earth scientists could regain a position as expert, innovative and informed voices in the environmental arena.

14.6.2 The significance for social scientists

As the scientific community becomes more receptive towards the idea that cultural influences affect their work they may become more receptive to the constructive criticism offered by social scientists. Social scientists may then be challenged to work constructively towards changing practice in response to that criticism. A recognition of the magnitude of the cultural change being requested of the scientists would be of great assistance, as would an understanding of why the scientific culture is as it is. Understanding these issues will be fundamental to developing mutual respect between scientists and social scientists, a prerequisite for real change to occur. In itself, this may require a change in attitudes on the part of the social scientist and a willingness to move beyond theoretical ideas of process and legitimacy to the practical aspects of implementation.

14.6.3 The significance for decision-makers

Those accountable for making decisions that affect the environment are, in a way, the sponsors of the decision-making process. The idea that a shared platform for knowledge building could be developed using the conceptual understanding of environmental cause and effect provides a focus for the decision-maker to begin weighing up the environmental knowledge available to inform the decision. Since the notion is that this shared knowledge platform is qualitative and used in dialogue, the decision-maker should have a decision-focus that is understandable and comprehensible. This should serve to reduce his/her reliance on the expert interpretation of expert processes such as risk analysis.

However, as discussed earlier, there is still a need in any legitimate decision process for independent expert regulation and review. The development of a shared knowledge platform in no way changes this. Neither does it inhibit it since the idea is that risk analyses can be developed from the shared knowledge platform and regulated according to legislation. The decision-maker therefore still has access to an independent expert voice about the environmental implications and risks associated with the decision. However, the foundations of the risk analysis may be more readily accessible to him/her which should increase the meaningfulness of the risk calculations.

14.6.4 The significance for stakeholders and public constituents

The ideas offered in this thesis will only affect stakeholders and public constituents if they engage in opportunities for dialogue about environmental decisions. Additionally, it is probable that debate about the conceptual understanding of environmental processes will only occur once such stakeholders and public participants are quite extensively and actively engaged in dialogue about a decision. However, once so involved, the idea of being involved in building a shared knowledge platform based on qualitative knowledge and experience will engender a feeling of empowerment and involvement in the decision-process. It is also possible to speculate that it may also lead to an increased level of lay interest in the risk analysis itself, something that I originally conceived as a desired endpoint of this thesis.

14.6.5 The significance for campaigners

Those campaigning against a project will seek for weaknesses in both the decision-process and the knowledge on which the decision is being built. The development of a shared knowledge platform will not change that. However, it may act as a focus for the challenges of such campaigners. Such challenges are, of themselves very valuable for knowledge building. This may be a way of enabling more constructive dialogue between those who otherwise could be considered opponents. It is not possible whether this will be seen as a good thing or a bad thing by the campaigners – that depends on the motivation behind the campaign.

14.6.6 The significance of individuality and specificity

As the empirical work described in Section 3 has progressed, I have become increasingly aware that the success of using conceptual understanding as a shared knowledge platform to enable dialogue will be very dependent on:

- The personal characteristics of those involved in its development; and
- There being a very clear contextual relationship between conceptual knowledge, risk analysis and the different stages of the decision-making process which it is seeking to inform.

These issues are themselves the subject of active and extensive research and are very dependant on policy frameworks, organisational structure and culture. Therefore, there appears to be no single definitive recipe for developing a legitimate knowledge base for environmental decision-making. However, the hypothesis that we seek vehicles that enable shared knowledge building at a conceptual level should at least get different stakeholder groups talking with each other about environmental processes in a meaningful manner. In this way, a knowledge platform may be built that can support both the detailed technical and quantitative calculation (analysis) and the contextual dialogue (deliberation) called for an analytic-deliberative approach to decision-making. The proposed framework for scientific knowledge building around conceptual models showed signs of this emerging for the issue of radioactive waste management despite the very ambiguous context for radioactive waste management prevalent in the UK at the time of the research.

14.7 Concluding Thoughts

This uncertain policy framework fuelled my ambition to undertake this thesis in the first place. The ambiguity of policy in the nineties meant that although people talked to each other, it is difficult to conclude that true dialogue occurred. As I write now, the Department of the Environment, Food and Rural Affairs is in the middle of a six-year policy development process for managing radioactive wastes safely. Until policy is decided, little progress can be made with finding a solution for the problem of our radioactive wastes. Although frustrations with this policy vacuum are now emerging in many different ways, it does provide an opportunity to reflect on how to improve the quality of scientific dialogue in the future. If by doing so we can prevent failure of decision-processes in the future then we will have made our own contribution to managing the present day (and increasing) risks from radioactive wastes.

As in so many areas, it is no longer possible to impose ideas on society by claiming superior knowledge and training. Whilst society still wants to have experts and expertise, and continues to be happy to be guided by such expertise, the relationship between society and experts has changed significantly over the past few decades. Experts no longer command authority by virtue of being experts – they need to demonstrate personal credibility and integrity at the same time. Such characteristics emerge from the way experts behave, amongst other experts, in the public arena and in their personal lives. It is no longer enough to state that rigorous procedures have been applied to an analysis. In the contemporary social arena, the analysis will stand or all based on the thinking that has gone into defining its scope – in particular, the clarity with which the analysis is fit for the purpose for which it was intended. If that purpose was decision-making on behalf of society, then society has a right to opportunities for involvement in defining the scope of the analysis.

Without acknowledging this change, scientific expertise runs the risk of being relegated to "supporting information" in the environmental decision arena – information that may or may not be taken on board depending on the predilections and knowledge of the decision-maker. This concerns me greatly since I believe that the natural sciences hold the key to our best achievable understanding of possible environmental futures. I also believe that arrogance about the supremacy of scientific practice over social theory will not help science to retain its rightful place in consultative decision-making.

My argument is for conceptual and descriptive models about environmental processes to act as bridges between quantitative analysis and social learning. By combining conceptual descriptions with a willingness to trade precision for tangibility and comprehensibility we may rebuild the notion of science as a valuable contributor to social debate. Earth science has a formative role to play since the subject is the earth itself, a complex system of which people are a part and which they can observe in their daily lives.

The implications of this approach vary. Not least, it makes demands on scientists to present their science in a manner which will appear very vulnerable to those used t the cut and thrust of peer review and academic rivalry. By arguing for qualitative, rather than quantitative analysis, I am asking scientists to accept that non-expert audiences are significant and important. However, I am not advocating that analytical rigour and accuracy be sacrificed o the alter of dialogue. They remain as important as ever in demonstrating the credibility of the experts involved in dialogue and in facilitating dialogue between experts. The trick is about opening up the conceptual development behind the analysis – developments which have traditionally taken place well before publication and often in the head of the expert analyst.

In speaking with social scientists about this research, they tell me that I have been on a "personal journey" as I have developed my understanding and arguments. Initially, I adopted a fairly technocratic approach to the issue – what can "we" scientists do to enable others to contribute to "our" work. This rather parochial attitude has a place since often the most effective evolutions are from within. However, over the past few years I have found myself becoming more of a translator – seeking to convey the concerns and challenges of the social sciences into the scientific arena in a non-threatening manner. I realise that I have accepted many of the challenges arising from the social theorists and believe that scientific practice can be enhanced by rising to those challenges. My internal questioning has subtly altered – how can I engender change in scientific culture so that science can learn from other sources of expertise.

At the end of the day, I doubt that any individual can engender such a widespread change in thinking. It has to arise as a result of a great many individuals all making personal journeys similar to my own. I sometimes wonder whether my own evolution means that I have "gone over" and forfeited my scientific status. However, I think it merely reflects a very uncomfortable position sitting at the interface of two very different cultures – science and society. Since so much has been written about the relationship between these two cultures, I cant be the only one sitting on this uncomfortable interface. If I am merely one in an ever increasing number of people considering these issues and willing to learn and adapt from them then there should be a lot of hope that time will bring about the cultural change that I believe is necessary.

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Appendix A

INTERNATIONAL APPLICATION OF CONSULTATION AND DIALOGUE IN RADIOACTIVE WASTE MANAGEMENT UP TO 2001

Countries included in the study are Belgium, Canada, Finland, France, Germany, the Netherlands, Spain, Sweden, Switzerland, Czech Republic, United Kingdom and the United States. Given the wealth of detail associated with various radioactive waste management programmes internationally, this analysis focuses on particular sites and aspects of waste management programmes that provide the most useful lessons with respect to stakeholder dialogue and consultation. The analysis was undertaken in 2001.

A1. BELGIUM

Low-level and short-lived intermediate waste

Since 1999 the Belgian radioactive waste management organisation, ONDRAF/NIRAS has taken novel steps forward to address the question of public acceptability within its programme for establishing suitable sites for low and short-lived intermediate level waste.

This has involved the development of local "partnerships" in areas where there is a measure of local interest in hosting a facility.
The partnerships depend upon independent mediators from a local University working with local stakeholders in the development of increased understanding of the issues surrounding proposals for disposal. Membership is specific to the individual partnership and including representatives of the local political parties, the various economic, social, cultural and ecological stakeholders, and local industry.

To date two partnerships have been signed. The first was signed on 30 September 1999, between ONDRAF/NIRAS and the local community of Dessel. The second partnership was signed on 9 February 2000 with the local community of Mol, where the national nuclear research centre CEN/SCK is located.

The partnerships have their own budgets provided by ONDRAF/NIRAS and operate at four levels:

- The "general assembly" (or Partnership Council), which involves all the parties and formally represents the "Partnership";
- The management committee which is appointed by the general assembly;
- Project Co-ordination on a day-to-day basis; and
- Working Groups which are the active basis of the partnerships.

The working groups review and develop draft project proposals with the support of ONDRAF/NIRAS acting as "partner and expert", but they also have access to independent expertise paid for by the company. The partnerships as a whole will:

- decide on priorities and take decisions;
- organise dialogue; and
- be responsible for keeping the local population informed.

Final proposals will have to be approved by the local councils concerned prior to submission to the Federal Government in 2001–2002.

High-level and long-lived intermediate-level waste

ONDRAF/NIRAS are investigating Boom Clay and Yper Clays for the disposal of high-level and long-lived intermediate-level waste. The Mol/Dessel nuclear zone is regarded as a methodological R & D site and the Doel nuclear zone as an alternative R&D site.

ONDRAF/NIRAS intends to publish a report (SAFIR 2) by the end of 2001, on research undertaken to date. This report will be subject to independent peer review. An accompanying strategic document will address potential approaches for stakeholder dialogue on high-level waste and long-lived intermediate-level waste in Belgium.

A2. CANADA

Low-level waste

The LLW inventory in Canada mainly comprises historic wastes, consisting of contaminated soils (1 million m^3) for which the original producer is no longer responsible. Most of this waste is located at two waste management sites in the Port Hope area of Ontario. In 1982, the Government established a Low-level Radioactive Waste Management Office to assume responsibility for these wastes. Subsequently, in 1988, the Federal Government appointed an independent Siting Task Force to carry out a voluntary siting process to find a disposal site. In 1995, the Task Force issued its final report to the Minister for Natural Resources, identifying Deep River in Ontario as a likely site.

Deep River's interest was supported by a 72% majority in a municipal referendum. It was based on a Community Agreement in Principle (CAP) negotiated between the Siting Task Force and the town. An important part of the Agreement was a guarantee for employment. The population of Deep River is heavily dependent on employment from AECL, and plans announced in late 1996 to downsize that organisation, as a precursor to privatisation, caused uncertainty about long-term employment prospects in the area.

In July 1996, the Minister for Natural Resources Canada announced the Federal Government's intention to proceed with negotiations to develop a legal agreement establishing the terms and conditions under which the town would agree to host the facility. The government's urgency to tie the community into a legal agreement was met with negative reaction. Negotiations subsequently ceased and the Community Agreement in Principle lapsed at the end of 1996. In late October 1997, the Deep River Council voted to withdraw from the process completely, although Natural Resources Canada has still not ruled the community out. In August 1997, Hope Township asked to be considered as a potential repository host location.

Spent fuel

Over the last thirty years, spent fuel from Canadian nuclear utilities has been stored at reactor sites in pools and concrete containers. It is likely that final disposal will take place in a deep geological repository. To meet engineering requirements, the facility must be sited in igneous rock of the Canadian Shield. The Shield is located in the northern parts of several provinces including Ontario.

In 1988, the Minister of Environment established the terms of reference for an environmental impact assessment (EIA) of the disposal concept proposed by AECL and Ontario Hydro. The results of the EIA were reviewed by a government appointed Federal Environmental Assessment Review Panel (FEARP) prior to the start of work on siting.

The terms of reference for the EIA comprised four key components:

- A requirement for review and evaluation of the safety and acceptability of the nuclear fuel waste disposal concept and a range of other nuclear fuel waste management issues;
- A requirement for comparison of the concept with other long-term management options and with the management of hazardous waste;
- Scientific review; and
- An instruction to the FEARP to refrain from discussing Canadian energy policy and the construction and operation of nuclear power plants.

Several stakeholder groups criticised the terms of reference on the grounds of lack of public input. Many also held the view that the proponent's credibility regarding future waste projects was inseparable from the safety and management records of current operations. The ability to consider and address this concern was denied through the limitations imposed in the terms of reference. Moreover, objections to the composition of the scientific review panel resulted in a stipulation by the panel itself that a peer review by social scientists and ethicists would be required to evaluate social acceptability of the proposed concept.

Over the course of the following seven years, opportunities for stakeholder participation in the EIA included numerous open houses, scoping meetings, hearings, written briefs and roundtable sessions. Public participation occurred throughout the five provinces of Saskatchewan, Manitoba, Ontario, Quebec and New Brunswick. Participants included invited speakers (both pro- and anti-nuclear), environmental professionals, engineers, Aboriginal groups, professional associations, industrial and technical specialists, government ministries, social and physical scientists, women's groups and private citizens.

One of the drawbacks of the public consultation process within the EIA framework is that the role of participants is limited in that they have no decision-making power. The extent of the influence of opinion is dependent on the will of those with political authority. This was of particular concern to the Aboriginal inhabitants since the disposal facility would probably be sited on land claimed by them as their traditional territory.

The submission of the EIA by AECL in 1992 was followed by a series of *public* hearings between March 1996 and March 1997, covering a broad range of issues. The hearings, held in numerous communities across Ontario, took place before the FEARP as stipulated in the terms of reference, and was managed by the independent Canadian Environmental Assessment Agency (CEAA). Included in AECL's EIA were recommendations for the siting process, which included volunteerism and shared decision-making.

Stakeholders from organisations and individual members of the public who wished to make submissions to the panel were able to apply for 'intervenor funding', for the use of external consultants and advisors. 'Participant funding', to allow individual

stakeholders and members of community councils to attend hearings in their localities, was also made available.

The range of views that the FEARP attempted to balance represented a continuum from total endorsement by members of the nuclear community, to total rejection by various non-governmental organisations (NGOs). The latter contended that the existence of irreducible uncertainty in areas such as modelling and long-term predictions requires an inclusive political arena in which to debate and resolve issues.

The FEARP released its public report on 13 March 1998. The FEARP concluded that although AECL's plan appeared technically sound, *"in its present form it does not have the required level of acceptability to be adopted as Canada's approach for managing nuclear waste."* The FEARP recommended that a new Nuclear Fuel Waste Management Agency (NFWMA) should be established. By May 2000, the utilities had signed a Memorandum of Understanding to create a Waste Management Organisation. A draft plan for long-term options is being developed.

A3 CZECH REPUBLIC

Low-level waste and short-lived intermediate-level waste

LLW is currently stored in one of three near-surface repositories: Dukovany, Richard and Bratrství. Dukovany, being the biggest of the repositories can hold 30 000 m^3 waste. It is the most modern repository – in operation since 1995 - and reportedly complies with advanced European standards. It is situated near Dukovany power plant in the Třebíč district. Richard is situated in a disused limestone mine, near the town of Litoměřice, and has been in operation since 1964. This repository has a total volume of 16 000 m^3 but has a capacity of half that figure, due to waste storage in 100 litre drums. Bratrství is solely for the disposal of natural radionuclides and has been in operation since 1974. It is developed in a mining shaft with 5 disposal chambers from which discharged water is drained into retention tanks.

Disposal of all radioactive waste is the responsibility of RAWRA (the Radioactive Waste Repository Authority), who seek to develop active and responsive co-operation with the communities affected by the waste repositories, as well as with the general public and non-government organisations. To this end, they have had personal meetings with representatives from the communities and initiated publication of information as well as production of a comprehensive website. They have also organised visits for Swiss and French groups to tour processing and disposal facilities.

High-level waste and spent fuel

The Czech Energy Board in Prague is responsible for the programme dealing with the management of spent fuel and wastes from Czech nuclear power plants. Research institutes, such as the Nuclear Research Institute (NRI) and universities participate in research supporting this programme.

The Czech Power Enterprise (EZ) has conducted several studies concerning spent fuel management in the Czech Republic. Alternatives include:

- interim storage followed by final disposal in the Czech Republic;

- re-processing in another country with return of the wastes to the Czech Republic, or
- final waste disposal in another country.

In 1993, development for a deep geological repository began, with the aim of producing at the end of five years, a plan for: a) a generic design for a repository in granitic rock and b) a generic plan for geological activities to be performed leading up to a siting consultation. Owing to the facility being the first site within the Czech Republic to be designed and organised under a democratic society, expectations are for a lengthy, complicated process. Procedures considering site selection have included technological development of engineered barriers, experimental data from selected test sites, natural analogue studies, and underground research laboratories for safety and performance assessments. The latter issue has included international collaboration with ENRESA (Spain) and NAGRA (Switzerland). Results from the individual projects will be compiled for the use of the National Concept of Radioactive Management, a strategic document that will direct future activities. This document will be subject to EIA evaluation including a public hearing.

Following on from the 'Concept', RAWRA plans to initiate public discussion on the matter of national policy for radioactive waste management. Firstly, RAWRA plan to disseminate information to the media, politicians and technical experts. Secondly, they plan to hold discussions with students from technical, economic, sociological, environmental and legal University departments. RAWRA plan to invite the media to monitor the discussions. The final stage of public consultation will conduct public surveys within different social groups.

Czech radioactive waste management is based on the Atomic Law approved by Parliament in 1997. This law established RAWRA, the state organisation charged with the mission of assuring safe disposal of all radioactive waste, present and future. RAWRA took over the co-ordination of the development of a deep geological repository in 1998. Much of the development of a deep geological repository is contracted out to NRI who have extensive experience with repository development. Along with development of a national deep repository, RAWRA are also considering plans for long-term interim storage procedures, reprocessing, transmutation and the possibility of a European repository.

Public attitudes in the Czech republic have changed markedly over the last 10 years or more, from support in the early 1990's when people approved of the move away from 'dirty' coal-fired power stations, to anti-nuclear attitudes, emphasised by increasing pressure from near-by Austria, who are nuclear-free. In the period from 1993 to 1997 NRI conducted opinion polls with different social groups and began to aid the public relations arm of RAWRA. Following the Atomic Law, RAWRA have involved the public, including 4, out of 11, representatives from the public on the Board of members.

A4 FINLAND

Spent fuel

Prior to the establishment of Posiva Oy, in 1983, TVO identified 101 potential disposal sites and undertook a consultation process with the communities affected. By 1985, 5 potential volunteer sites remained. It was proposed that further detailed investigations were carried out at these sites. In 1992, following further safety and geological assessments, TVO announced that further investigations would only be carried out at Romuvaara in Kuhmo, Kivetty in Äanekoski and Eurajoki (near the Olkiluoto nuclear site). Interim reports on these sites were produced at the end of

1996. An additional site at Loviisa (host to an existing nuclear site) was added to the list in response to indications by the local community in Loviisa, that they too wished to be included.

In terms of Finland's Nuclear Energy Act, the first authorisation step towards a final repository of nuclear waste is the *Decision in Principle* (DiP). This requires the Government to consider whether the "construction project is in line with the overall good of society". In particular, the government should consider the need for the facility, the suitability of the proposed site, and its potential environmental impact. Legislation subsequently requires that the Radiation and Nuclear Safety Authority (STUK) should make a preliminary safety appraisal of the DiP. The proposed host municipality must state its acceptance or rejection for siting the facility. The decision has then to be endorsed by the Finnish Parliament. The application for the DiP also includes an Environmental Impact Assessment (EIA) report for the planned facility.

An EIA report to the Ministry if Trade and Industry (MTI) and a DiP application to the Government were submitted by Posiva Oy in May 1999. The EIA covered the four candidate sites and incorporated a number of consultation methodologies including open meetings, dissemination of printed materials and videos, an opinion survey, theme interviews, small group discussions and analyses of written feedback. The submission of the EIA was followed by a series of public hearings. During the hearing period, 15 authorities and public bodies, 5 civic organisations and communities, and 23 municipalities submitted their statements on the EIA report to the MTI. In November 1999, the Ministry gave its statement, which completed the EIA process

The authorities and municipalities were mainly positive and the EIA report was generally regarded as having been wide ranging and thorough. Of primary concern was the issue of social stigmatism - the potential deterioration in the self and external image of a municipality. This was particularly in relation to the inland sites (Romuvaara and Kivetty), where there are no existing power utilities and small-scale tourism and agriculture are regarded as important components of the local economy. The possible impact on health associated with the transport of spent fuel and potential transport accidents were also of concern.

Private individuals' and civic organisations' opinions on the EIA, as well as on the whole disposal project, were critical and opposing. Their viewpoints tended to focus on issues outside the scope of the EIA. There appeared to be some confusion regarding the purpose of the EIA, which was to assess the impacts of the programme rather than to identify a specific site.

Nevertheless, the MTI concluded that the EIA was sufficiently comprehensive and detailed and fulfilled the requirements set by the EIA legislation. The MTI did request however, that a construction licence application for the disposal facility, scheduled to be submitted by 2010 at the earliest, should include an updated EIA report.

Posiva Oy plans to construct an investigation shaft at the chosen site in 2003, and to apply for a construction permit in 2010. The first emplacement of spent fuel could not take place b
before 2020.

A5 FRANCE

High-level waste

The 1991 Waste Act redirected the French deep site investigation process following the abandonment of an earlier high-level waste (HLW) programme which sought to identify promising disposal sites primarily by reference to geological considerations. This methodology resulted in strong opposition and, in 1990, a moratorium was declared on drilling activities by the Government. The 1991 law contains several provisions aimed at a more equitable siting process including a requirement that local officials and members of the public from the affected sites be consulted before any site investigations begin preliminary to Underground Research Laboratory (UGL) construction.

The creation of URLs is a key requirement of the 1991 law. M. Christian Bataille was appointed as a mediator and specifically charged with leading public involvement prior to the selection of URL sites. His mediation mission had three objectives:

- information provision to the public,
- open dialogue, and
- decision facilitation.

The siting process for the URLs began in January 1993. By December of that year some 30 sites had volunteered for consideration. Ultimately, four potentially suitable sites were recommended by M. Bataille. Two were subsequently merged so that three locations were then under consideration:

- a clay geology in north-eastern France on the border of the Meuse and Haute Marne Departments (the Bure site);
- a clay geology beneath the Marcoule nuclear site in the south of the country in the Gard Department;
- and a granite geology in the Vienne Department in western France.

Surface-based investigations at these sites, including drilling between two and four boreholes and geophysical measurements, were completed in April 1996.

The Council of Ministers authorised ANDRA to submit requests for the installation and operation of URLs at each of the three sites in May 1996,. Authorisation of the URLs was scheduled to have been completed in 1998, following review of the submissions by the Division of Nuclear Safety (DSIN) within the Ministry of Industry, and the Ministry of Research. The reviews were to take place in conjunction with public hearings and local consultation. The hearings at the sites ran from January to May 1997. The following December, the Government advised that investigations should continue at the Bure site and that further research should be undertaken towards identifying a suitable site in granite. A decree was issued in August 1999 allowing ANDRA to commence construction of the Bure URL, providing for the establishment of a Local Information Committee at Bure, and launching a consultation exercise to select a granite site.

The selection process for a granite site was initiated with a geological screening process that began in February 1999. This resulted in the identification of 180 plutons in the country and, by July 1999, this number was reduced to about 15 sites following consideration of hydrogeology. As a result of further screening, the number of potentially suitable sites was narrowed down to seven in February 2000. The next phase of the programme is divided into five stages and is being managed by a Granite Advisory Committee comprising two international experts, two government appointees, and four members recommended by the Academy of Sciences and approved by government. The stages are as follows:

- 1 - seek consensus through consultation;
- 2 - selection by government of a site or sites where the community wishes further consideration;
- 3 - confirmation of geological suitability (by ANDRA); confirmation of safety factors by DSIN; and setting up of Local Information Committees made up of environmental groups, government officials, local community representatives, farm councils, professional associations, etc;
- 4 – *enquetes publiques* (public enquiries) and endorsement by local authorities within a 10 km radius of a site.
- 5 - decision by central government to authorise construction of a URL .

It was originally intended that the granite site selection process would be completed by 2003. However, the process is stalled at Stage 1, the objective of which is to seek consensus through consultation with the communities in proximity to geologically suitable sites identified during the Phase 1 screening exercise. A government delegation sent to consult with the affected communities was strongly opposed in all communities that were visited. The negative attitude of the community leaders could have resulted from a range of factors, including a ratcheting up of concern by NGO representatives from outside the communities, a perception that the government delegation was not sufficiently representative, and the nature of the screening phase with consultation coming too late in the process.

A6 GERMANY

Low-level and intermediate-level waste

At present a number of sites exist but are not licensed largely due to disagreements at government level. A Working Group Committee on Site Selection has been established by BMU (Federal Ministry for the Environment), membership of which includes environmental groups and nuclear experts. Use of the internet and workshops for MPs, NGOs and unions are amongst the techniques used to encourage stakeholder participation. The working group will review existing criteria and will look at international practice before proposing the "relatively best site" in the country. We understand that an Interim Report by the Committee on Site Selection has recently been issued. The sites under investigation include Konrad, Morsleben and Asse. The most detailed consultation programme has taken place in relation to Konrad.

The Konrad mine in Lower Saxony was investigated by GSF (Federal Research Centre) from 1976 to 1982 to determine its suitability as a radioactive waste repository for L/ILW. The site was found suitable for the disposal of L/ILW and, in 1982, an application was made, initiating a licensing procedure. The compliance report for the Konrad project was submitted in 1986.

In 1991, a revised version of the compliance report was made available for public comment. Due to a strong political campaign in Lower Saxony and by the Green parties, approximately 10,000 objections were raised on the compliance report.

The Federal Office for Radiation Protection (BfS), responsible for the construction and operation of repositories, consequently started an intensive preparation period prior to the public inquiry in September 1992. A team of 11 representatives with expert knowledge regarding all aspects of the project was assembled and coached by psychologists to improve their understanding of stakeholder concerns and prepare them for discussions with the public. The public inquiry ran for 75 days and is the longest atomic law debate ever held in Germany. In the first few days of the inquiry, formal procedures were established for raising objections and discussions. Issues were categorised and an agenda was devised stipulating time frames and who would be allowed to participation in discussions.

A range of issues were debated, many of which were not directly relevant to the licensing procedure but were, nevertheless of public interest, for example, risks associated with the transport of wastes and reasons why the Konrad site was selected. These issues were dealt with in detail by BfS. Other key issues included safety aspects, waste origin, waste amount, and how the waste acceptance criteria for waste returned from other countries would be met.

Despite a highly charged atmosphere during the inquiry, the public appeared to trust the proponent's team and were generally satisfied with the manner in which issues were addressed. The licensing process is still continuing but a stand off exists between BfS and the State Government.

A7 THE NETHERLANDS

Low-level and short-lived intermediate-level waste

LLW and ILW are currently stored at COVRA's central facility. In 1982, a Committee (HVRA) was established to investigate the issue of long-term storage of radioactive waste. The HVRA Committee included representatives from environmental and industrial organisations. Following a report by the HVRA Committee to government, a Radioactive Waste Storage Facility Site Selection Committee (LOFRA) was established and asked to identify suitable sites where all types of radioactive waste could be processed and stored. LOFRA was asked to give particular consideration to the willingness of provincial and local authorities to co-operate.

Twelve sites were initially identified by LOFRA and discussions held with local and regional authorities, planners and politicians. Following further screening, the number of technically feasible sites was narrowed to three.

In 1985, LOFRA identified the Sloe area as the most suitable location and a site close to the nuclear power station at Borsele was chosen. A second site was subsequently identified by the Tijdens Committee (named for the alderman of the municipality of Borsele). This was the site already occupied by COVRA at Vlissingen Oost. An EIA was produced for each site. Although public meetings and working groups did form part of the process, communication with stakeholders was not effective (see below). A licence for the second site was, however, granted and the storage facility was constructed between 1990 and 1992. Compensation for the host community by COVRA was restricted to employment, benefits from the sale of land, and purchasing of local goods and services.

Recently an inquiry into perceptions around the establishment of the COVRA storage facility has revealed a number of stakeholder issues and concerns. Four categories/groups of stakeholders were identified: directly aggrieved parties, indirectly aggrieved parties, advocates and environmental lobbyists. The concerns of these groups are briefly summarised below:

Directly aggrieved parties

This group is still actively objecting to the COVRA facility. Their grievances are based largely on issues around safety, location of the facility on the river-banks, and the effect on property values. The specific objections of this group tend to focus on the consequences of events, such as an accident or flooding of the river, rather than the likelihood of occurrence of the events. Concern was also expressed with regard to compensation and liability issues.

Indirectly aggrieved parties
Indirectly aggrieved parties are mostly concerned about the fact that the COVRA facility is yet another example of a development which affects the community without, as they see it, community members being adequately involved in decision-making. They are satisfied that it is in COVRA's own interest to meet requirements and standards that would minimise the likelihood of accidents, but would like to see an integrated approach to planning of future developments and possible expansion of the facility.

Non-aggrieved parties / advocates
Many of those whom were not necessarily against the establishment of the facility followed the argument that it is logical to have a storage location in the vicinity of a nuclear power station. However, this group has also criticised the procedure followed and lack of consultation in decision-making. Some claim that at one time people in Borsele took pride in the presence of the power station and people's perceptions and regard for COVRA have subsequently changed.

Environmental lobbyists
In their objections to the storage site, the anti-nuclear movement have disassociated themselves from the local community's perceptions and grievances. Anti-nuclear and anti-COVRA demonstrators come from outside the community and many local residents feel that the presence of lobbying groups enhances a negative perception of the area.

A8 SPAIN

Low-level and intermediate-level waste

L/ILW waste was initially stored at a facility sited at El Cabril near Cordoba. Characterisation work to assess the suitability for disposing of waste there began in 1986. In 1989, the local planning authority approved a disposal application and the facility came into operation in 1992. The area surrounding El Cabril has a low population density.

The Spanish radioactive waste management organisation, ENRESA, pursues a "good neighbour" policy with the local villages and has studied social and economic needs in the area around El Cabril. Training courses have been held, and locals are employed as contractors. ENRESA has also stated their willingness to help improve the local road infrastructure in order to encourage investment in the area.

Interestingly, for high level waste and spent fuel, Spain's General Radioactive Waste Plan of 1999 states that research on separation and transmutation of radioactive waste should be supported in addition to geological disposal options.

A9 SWEDEN

High-level waste and spent fuel

A programme to site a deep repository for high-level radioactive waste and spent fuel was initiated by SKB in 1992. It was envisaged that first-stage operation would begin in 2008. The concept suggested for disposal is abbreviated to KBS-3, and comprises a bedrock repository at a depth of approximately 500 m where spent fuel will be encapsulated in copper-steel canisters surrounded by layers of bentonite clay.

The Government gave broad approval to the initial proposed siting process but emphasised the importance of a well-defined and transparent programme that incorporated the following steps:

- publication of siting factors, covering safety, technology, land and environmental impact, and societal aspects;
- content and publication of countrywide siting studies;
- undertaking largely desk-based feasibility studies of between five and ten sites, followed by more intensive surface-based investigations at two or more sites;
- a final application for construction of a shaft and/or tunnel for detailed investigation at a preferred site.

The updated R&D programme presented to the government by SKB in 1998 was reviewed by a large number of national organisations, including the Swedish Radiation Protection Institute (SSI) and the Swedish Nuclear Power Inspectorate (SKI). In April 1999, SKI delivered its recommendations to the government, following which the government stated, in January 2000, that the programme fulfils the requirements contained in the Act on Nuclear Activities.

Feasibility studies have been conducted at eight sites chosen on the basis of municipalities volunteering to allow the study and subsequently being provided with up to Euro 250,000 per year from the waste funds for its own costs related to relevant activities. In addition, a National Co-ordinator was appointed by the Government in 1996 to promote information exchange and co-ordinate liaison between local authorities.

The first two feasibility studies were conducted for sites at Malå and Storuman, both situated in the far northern part of Sweden. Following completion of the studies, both the communities held a referendum and voted against continuing with the next step in the programme, namely site characterisation. An overview of the referenda timetables is provided in Table B1 below.

Table B1: An overview of referenda for Storuman and Malå.

Procedures	Storuman	Malå
Decision, overview study	June 1993	November 1993
Decision, referendum	February 1995	November 1993
Referendum	September 1995	September 1997
Interviews	November 1995	November 1997

Despite the absence of specific legislation governing siting in Sweden, SKB has agreed to respect the results of local referenda in municipalities. Any local veto, however, has no statutory force and the Swedish Government could override local objections and grant permission for further studies to be carried out. This did not happen with respect to Malå and Storuman and no further investigations have been undertaken at these localities. KASAM has requested the Government to specify the circumstances in which local objections may be overridden.

Feasibility studies have now been undertaken at sites in four other municipalities, namely Nyköping (near the nuclear research centre at Studsvik), Östhammer (near the Forsmark nuclear site), Oskarshamn (site of encapsulation research laboratory) and Tierp. Each of these communities had volunteered to take part in the process in 1996. SKB has recently proposed that surface-based characterisation activities, including deep drilling, should proceed at three of the sites (Oskarshamn, Östhammer and Tierp). If regulator reviews are favourable, and the municipality and the government agree to the work, then drilling could commence as early as 2002.

Of the four municipalities, the consultation process at Oskarshamn provides the most useful example of community involvement in decision making. This process is referred to as the Oskarshamn Model and is described in more detail below.

The Oskarshamn Model

When Oskarshamn was identified as a possible site for the encapsulation plant, the municipality announced two prerequisites to its acceptance as a candidate site. The first was that the participation of the municipality in discussions and investigations was to be paid for from the Nuclear Waste Fund, and the second was that the key parties (SKB, SKI, SSI and the county) accepted the idea of an EIA Forum chaired by the Lt. Governor of Kalmer County. The municipality specifically chose EIA as the lead process for its involvement as the philosophy behind EIA, according to the municipality's understanding, provided the key elements of public involvement, i.e. openness, early involvement and identification of alternatives.

One of the first tasks of the EIA Forum was to set up a local reference group. The EIA Forum felt that the municipality council with 51 elected members should fulfill this function. Efforts were subsequently made to engage the local population through public meetings, seminars and local study organisations. Each of the neighbouring municipalities was also asked to identify a contact person. Six working groups were established to monitor the various aspects of the investigation. The elected representatives had full autonomy in terms of using external consultants and advisors when required.

The municipality was formally asked by SKB in 1995 whether they would accept a feasibility study for the siting of the deep repository. The municipality took one year to investigate the programme and engage as many stakeholders as possible in the decision-making process. To aid the discussion, two task groups were established by the municipality council, and were asked to report back to the full council with recommendations. One group consisted of the most experienced politicians in the council and the other group comprised the youngest members of each political party. Following positive feedback from both groups, the council voted to accept a feasibility study in October 1996 with certain conditions.

To monitor the feasibility study, six working groups were set up with different areas of focus. Each group comprises two council members, one civil servant, two local citizens and one external expert. Numerous meetings have been held with SKB and various consultants and scientists involved in the feasibility study, and all the minutes of these discussions are available on request or via the internet. The main questions and concerns raised by the working groups are forwarded to the EIA Forum for further discussion with representatives from SKB, SSI and SKI.

The structure of the EIA consultation process is presented in Table A2, followed by a list of the key features of the Oskarshamn Model.

Table B2: Structure of the EIA process.

Phases in the EIA process	Participants	Activities	Product
Phase 1 EIA Scoping Study	All stakeholders	Meeting with EIA Forum Meetings, hearings at local level	Advice on EIA document
Phase 2 Proponent's work	Proponent	Project work	Licence application
Continued EIA process	All stakeholders	Hearings, seminars	Understanding
Phase 3 Final phase of EIA = 1st phase of licensing	Regulator interacting with community	Review and decide followed by hearings	Improved licence application

Key features of the Oskarshamn Model:

- Commitment to openness and participation;
- The EIA process as a framework for interaction and stakeholder involvement;
- The municipality council as reference group as a means of increasing knowledge of political decision makers;
- Local involvement through task groups and working groups;
- Regulator involvement;
- Participation by environmental groups;
- Transparency and challenging SKB.

A10 SWITZERLAND

Currently, all licensing procedures are within the remit of the Federal Government whilst the Cantons and Communities grant building licences. The Federal Commission on the Safety of Nuclear Installations (KSA) and the Federal Office of Energy, Nuclear Safety Department (HSK) draw up guidelines for disposal. Federal law also requires that Cantons be consulted before a licence is granted. This means that the public are consulted through a referendum, a ballot or a Cantonal Assembly, although the outcome is not legally binding on the Federal Government. Cantonal politics in Switzerland, nevertheless, plays an important role in that perceived procedural fairness between Cantons is essential for the legitimacy of the site selection process.

In June 1999 the Federal Government's Expert Committee on Disposal Concepts for Radioactive Waste (EKRA) was established. The Expert Committee's membership

included a specialist on ethical issues and was chaired by a geologist who was known not to be in favour of disposal. EKRA presented their final report in February 2000. They proposed monitored long-term geological disposal, which combines final disposal with the possibility of retrievability of waste.

Low-level and intermediate-level waste

The Swiss radioactive waste management organisation, NAGRA, has developed a concept for the disposal of short-lived L/ILW in a repository mined into a mountainside. NAGRA began the process of site identification as long ago as 1978. By 1993, one hundred locations had been identified as having potential from a geological perspective. As a result of further screening processes, the initial number of sites was narrowed down to four in three different host geologies. In 1994, NAGRA sought the opinion of the Government inter-agency body AGNEB when it proposed Wellenberg to the Government as its preferred location. AGNEB agreed that the process had been transparent and that the site was a "good choice". As a result, NAGRA made public that it recommended siting a repository at Wellenberg (in the community of Wolfenschiessen within the Nidwalden Canton). However, in June 1995, the Nidwalden Canton voted narrowly against the development of a L/ILW repository at Wellenberg, despite an outcome in favour of further investigations from the local Wolfenschiessen community.

EKRA however has indicated that it supports NAGRA's choice of the Wellenberg site and a final decision by the Federal Government should follow a Cantonal referendum which is expected to be held on the construction of an exploratory tunnel in 2001. Should approval to proceed be obtained, a Technical Group will be then be formed together with an Advisory Committee established by GNW (a daughter company of NAGRA).

A11 UNITED KINGDOM

Low-level waste

LLW waste is disposed of in near-surface disposal facilities by BNFL at Drigg, Cumbria. LLW has been disposed of in shallow pits by UKAEA at Dounreay in Caithness.

Long-lived ILW and HLW are currently in long-term storage, pending the outcome of a Government review to establish a new national waste management policy. The House of Lords' Select Committee on Science and Technology, having undertaken an investigation spanning 15 months, published a report dealing with the Management of Nuclear Waste in March 1999 (HL Paper 41). Its main recommendation was that the Government should seek to build public consensus before attempting to implement its chosen policy.

In October 1999, the Government responded to the report of the House of Lords' Select Committee on Science and Technology on the management of nuclear waste. The Government announced its intention to undertake wide public consultation on the future management of radioactive wastes, including consideration of the options, such as whether to continue storage above ground or move to deep storage underground and eventual disposal. Whilst the House of Lords' report was prepared independent of Government, Ministers have indicated that its findings will provide the foundation for subsequent Government consultation.

Citizen's Panel

Although not formally a part of the Government consultation process, a "Consensus Conference" on radioactive waste management, held in London in May 1999, provided a further input. Consensus Conferences are a method of involving the public in the assessment of key issues of science and technology. Pioneered in Denmark, Consensus Conferences create a forum for a Citizen's Panel, made up of lay members of the public, to take part in an informed debate with expert witnesses of their choice.

The panel of fifteen citizens, recruited from throughout Britain, came together in London to debate the issue of radioactive waste management, following two weekends of intensive preparation. At the end of the Conference, the Panel produced a report on its views as to what are the key issues for circulation to the Government, media and other interested parties, thus opening up the debate in an area which is usually dominated by scientists and specialists.

The key issues/questions identified include:

1. What do you see as the primary advantages/disadvantages of deep disposal? What do you see as the primary advantages/disadvantages of shallow/surface storage?
2. What is the current/future policy with regard to companies other than BNFL who produce radioactive waste?
3. Currently, what research and development is there into nuclear waste treatment?
4. Would privatisation mean that an integrated approach to dealing with the problem of radioactive waste management would be more difficult? How can you guarantee that shareholders' profits will not become more important than preserving current safety standards?
5. What is the current/future policy with regard to informing the public about radioactive waste?
6. What benefits does the UK gain from importing spent fuel for reprocessing?
7. What is your opinion on the continuation of nuclear power? What are the financial, environmental and social costs?
8. Who supervises the military? How do we deal with decommissioned submarines? What research into "lost" waste is currently being undertaken (e.g. in the ocean, on Ministry of Defence land)?
9. What are your opinions on the current terminology used for the classification of radioactive waste?

The key conclusions of the Citizen's Panel were:

- Radioactive waste must be removed from the surface and stored underground, but must be monitored and retrievable. Cost cannot be an issue. We must leave options open for future solutions.
- A neutral body should be appointed to deal with waste management including site selection.
- Public awareness must be raised. Decision-making must be open and transparent.
- Research and development must be continued on a much larger scale.

National Consultation

It is envisaged that the Department of the Environment, Transport and the Regions (DETR) will issue a Consultation Paper on future radioactive waste management in 2001, setting out options for public consultation. It is possible that the Consultation

Paper may include a proposal for "consultation about consultation". This would be a so-called "Front End" process of consultation which is designed to enable all stakeholders to enter into early dialogue and potential consensus regarding the manner in which consultation about substantive and procedural/ planning issues should be undertaken.

In addition, it is likely that the nuclear industry will itself initiate an open dialogue process about the state of scientific research knowledge regarding radioactive waste management and disposal. This so-called "Science Review" is also likely to incorporate a "Front End" process.

A12 UNITED STATES

Low-level waste

A small number of essentially national low-level waste (LLW) repositories had been operating at Barnwell, South Carolina, and Richland, Washington, and at several other locations across the US prior to 1985. However, The Low Level Waste Policy Act of 1985 instructed each state to solve the problem of disposing of its own LLW. The legislation encourages States to join together and form so-called "compacts", and to develop joint facilities. Although the Act specified that the new facilities should be operational by 1992, not one new facility has been developed to date.

Many compacts have engaged in detailed siting programmes. The most advanced programme at present is for the Southwest Compact in California, where a site selected by the Decide-Announce-Defend (DAD) method has met with intense public opposition.

Other compacts have introduced volunteerism, with detailed programmes around financial incentives. For example, in the Northeast Compact, it was announced that a town that decides to participate would be paid $250,000, and that the first town to volunteer would receive an additional $100,000. If the town stayed in the programme for six months, identified a site and continued negotiations "in good faith", it would receive a further $250,000. A town that approved a site and facility development agreement by referendum would then receive $1 million. Despite these significant financial incentives, no final site has yet been selected in any State in the Northeast Compact.

Transuranic waste

The Waste Isolation Pilot Plant (WIPP) for the disposal of transuranic (TRU) waste opened for disposal in May 1999. It was constructed between 1980 and 1990, following siting studies which commenced subsequent to a 1957 report by the National Academy of Sciences recommending disposal in salt formations. WIPP is located in a salt formation at 650 m depth, some 50 km from Carlsbad, New Mexico. Less than 100,000 people reside within an 80 km radius of the facility.

In 1996, the Department of Energy, (DOE) submitted a Compliance Certification Application (CCA) to the US Environmental Protection Agency (EPA) to demonstrate that the WIPP complies with the EPA criteria. EPA public consultation, including public hearings in New Mexico, began in February 1997.

The EPA concluded in October 1997 that, subject to certain provisions, WIPP complies with its disposal standards and should be certified. This action initiated a 120-day public consultation period involving further hearings. The details of the EPA

CCA and the Resource Conservation and Recovery Act (covering hazardous waste components of the WIPP inventory) consultation and permitting processes, including the relationship between the State of New Mexico, Carlsbad and the US DOE, are extensive and complex. Suffice to say that the licensing of the WIPP facility was subjected to some of the most innovative and transparent methods of stakeholder review to have been applied in the US if not elsewhere.

Key features of the approach included:

- Enhancing realism, reducing uncertainties and simplification of conceptual and numerical models;
- Responding to public concerns in terms that are non-technical and readily understood;
- Active encouragement and participation in joint international collaborative efforts in the USA and abroad.

High-level waste and spent fuel

Following the Nuclear Waste Policy Amendments Act (NWPAA) of 1987, the US siting programme for high-level waste and spent fuel has been centred on Yucca Mountain in the State of Nevada. A number of locations in various geological settings across the US had previously been under consideration, but the Amendments Act directed the DOE to examine *only* the Yucca Mountain site. The 1987 legislation was criticised by the State of Nevada as unfair, although the Act specified that if studies showed the site to be unsuitable then investigations would cease. The legislation also provides for a benefit package for Nevada of $10-20 million per year provided the State waives its right to object to the proposal, not surprisingly, this condition has not been accepted by the State.

Under US Law, the DOE takes title to the spent fuel from utilities prior to final disposal. For the interim, the DOE proposes to store the spent fuel at the surface in a centralised facility known as the Monitorable Retrievable Store (MRS). To enable the siting of the MRS, the 1987 NWPAA established the Independent Office of the Nuclear Waste Negotiator to try to find a willing host in exchange for certain benefits. However, although some progress was made with a number of Native American Tribes, the negotiation process was terminated without result.

Despite the assurances of the DOE that Yucca Mountain can never become a repository without reasonable assurance of its ability to contain and isolate the waste, the Nevada public remains sceptical. Much of this scepticism is based on previous experience where the government had assured stakeholders that there would be no adverse effects associated with weapons testing in the 1950s. Trust in the government was seriously undermined when people were exposed to radiation doses downwind of the atmospheric testing area. High-level nuclear waste disposal at Yucca Mountain is unlikely to pose the same threat, but the choice of a site with a history of radiation exposure does affect public opinion.

A "Viability Assessment" (VA) was published by the DOE in 1998. The purpose of the assessment was to provide Congress, the President, and the public with information on the progress of the Yucca Mountain Characterisation Project, as well as to identify critical issues that needed to be addressed before a decision is made by the Secretary of Energy on whether to recommend the Yucca Mountain site for a repository. The assessment comprised a collection of largely technical documents aimed at stakeholders with different levels of understanding.

The VA report identified the main advantages of the Yucca Mountain Site as being its previous use as a nuclear weapons testing area, and the desert environment (no significant water sources in proximity to the site). From a health and safety perspective the report predicted that maximum radiation exposure from the repository is expected to occur after about 300,000 years. People living approximately 20 km form the site at that time might receive additional radiation exposures equivalent to present-day background radiation.

Six months after the publication of the VA, an Environmental Impact Statement (EIS) was produced. The purpose of the EIS was to provide information on potential environmental impacts throughout the life cycle of the proposed repository at the Yucca Mountain site. As a baseline for comparison, the No-Action alternative was also considered in the EIS. Public input to the EIS included fifteen Public Scoping Meetings between August and October 1995. Of the issues identified, a number were addressed in the EIS, including aspects of the characterisation programme, construction, operating and monitoring, consistency with existing land-uses, effects of earthquakes and volcanism, health and safety, long term and cumulative impacts and possibility of sabotage. Other issues raised were considered to be unrelated to the proposed action. These included general statements in support of or in opposition to a repository at Yucca Mountain, geological repositories in general and nuclear power; lack of confidence in the Yucca Mountain Programme; perceived inequities and political aspects of the siting process; the constitutional basis for waste disposal in Nevada, perceived psychological costs and effects; risk perception and stigmatization; and legal issues involving Native American land claims and treaty rights.

The EIS did not identify significant adverse effects associated with the long-term performance of the site. Peak doses of 1.3 millirem per year over 10,000 years are predicted to a maximally exposed individual hypothetically located 5 km from the repository.

The cultural issues associated with the Native American Tribes in the Yucca Mountain region were identified as an "area of controversy". The tribes consider the intrusive nature of the repository to be an adverse impact to all elements of the natural and physical environment. In addition, one Native American ethnic group (the Western Shoshone) continue to claim title to land at Yucca Mountain.

In the next year or so, it is possible that the site will be recommended by the DOE for approval by the President of the United States. However, the NWPAA provides the State of Nevada with veto powers over the President's decision. If exercised, however, the State veto can itself be overturned by a two-thirds majority vote of the US Congress.

If the site is approved, the DOE considers that a repository at Yucca Mountain could become operational by 2010. However, the siting issue, as indicated above, is as much a political issue as technical issue. A decision by the Federal Government to proceed with the repository at Yucca Mountain is likely to severely test the constitutional framework of the United States.

Appendix B

RADIOACTIVE WASTE MANAGEMENT IN THE UNITED KINGDOM – A SHORT RUN THROUGH HISTORY

B1. UP TO 1982

The management of radioactive wastes from nuclear power in the United Kingdom was addressed through initial legislation in 1954 (the Atomic Energy Authority Act) and subsequently in 1960 (the Radioactive Substances Act). The latter Act was based on the 1959 White Paper 'The Control of Radioactive Wastes' [HM Government, 1959]. This legislation enabled the United Kingdom Atomic Energy Authority (UKAEA) to provide a national disposal service for (what are now termed) low- and intermediate-level wastes. Disposal of these wastes was achieved through near-surface disposal and sea dumping.

In 1976 the Royal Commission on Environmental Pollution published its sixth report (the Flowers Report) [RCEP, 1976] on the management of radioactive waste. The report identified that the increased volumes and diversity of wastes brought about by the envisaged expansion of nuclear power in the UK would require new means of disposal. The report suggested that plans to dispose of nuclear fuel reprocessing wastes (now classed as ILW) at sea would be inadequate. The report called for research into the disposal to geological formations on land and under the ocean bed. However, it was duly noted that a decision on the acceptability of sub-ocean bed disposal might lie outside the jurisdiction of a British Government.

The Flowers report made recommendations to allow a strategy on long-term radioactive waste management to be drawn up and then implemented. In particular, the formation of a 'Nuclear Waste Management Advisory Committee' and a 'Nuclear Waste Disposal Corporation' were advocated. The Government responded in 1977 setting out its basic principles [Hansard, 1985] and, in 1978, creating the Radioactive Waste Management Advisory Committee.

Meanwhile, HLW disposal on land was being investigated through a European Union (then European Economic Community) funded research programme that had started in 1975. The work was performed by the United Kingdom Atomic Energy Authority (UKAEA) and the British Geological Survey (BGS, then called the Institute of Geological Sciences). A number of sites were investigated through desk studies but, despite a number of planning applications for permission to drill, the only place where any drilling was done was at Altnabreac in Caithness, Scotland (1978-79). Early in 1980 the Natural Environment Research Council (the parent body of BGS) took over responsibility for this HLW research from UKAEA but made slow progress and met with a lot of opposition. The dumping of HLW at sea (which had never taken place) was prohibited by the London Dumping Convention of 1975.

In response to the lack of progress regarding the HLW programme, the Radioactive Waste Management Advisory Committee suggested in its second annual report that solidified HLW might be usefully stored above or below ground in a suitably engineered facility for at least 50 years. Accordingly, in 1981, the programme of research into HLW disposal was to be abandoned. A policy of

surface storage of HLW for at least 50 years was subsequently confirmed in the 1982 White Paper [HM Government, 1982]

Although there was an existing route for the disposal of LLW, the capacity of the existing LLW disposal site at Drigg, operated by BNFL, was limited. Incineration and supercompaction of LLW were considered as methods of volume reduction for these wastes. However, in the 80s, neither was properly tested. There was therefore a need to identify additional routes for the disposal of LLW.

These considerations had the effect of defining the remit of Nirex, formed in 1982 as NIREX, the Nuclear Industry Radioactive Waste Executive. This remit was to work with other parts of the nuclear industry to develop and implement solutions for the long-term management of ILW and LLW. The Company had many of the functions of the Nuclear Waste Disposal Corporation envisaged by the Flower's Report [RCEP, 1976], but in some respects the framework diverged from the recommended model. For instance, Nirex was directly responsible to its shareholders (taken from the nuclear industry) and the Department of Trade and Industry rather than to an independent Radioactive Waste Disposal Commission.

B2. 1982 - 1997

Nirex was, and still is, owned and financed by the nuclear industry. In 1985 the organisation became a limited company – United Kingdom Nirex Limited (Nirex). Currently BNFL/Magnox is the major shareholder with a 74.5% share of the company, contributing 69.3% of the funding. Other shareholders are UKAEA (14.7%), British Energy (10.8%) who contribute 14.8% and 7.7% of the funding respectively. The MOD is not a shareholder but contributes 8.2% of the funding. Additionally, the government holds a special share giving it power of veto over some decisions. The shareholdings and financing arrangements relate to the amount of waste owned by each customer.

In the eighties and early nineties, Nirex was responsible for finding long-term management solutions for all intermediate-level waste (ILW) and also for low-level waste (LLW) unsuitable for disposal at the Drigg near-surface disposal facility operated by BNFL in Cumbria. After its formation in 1982, Nirex began a process of site selection for disposal facilities for low level waste (LLW) and intermediate-level waste (ILW). Broadly speaking, Nirex was considering the option of deep disposal for ILW and shallow disposal for LLW. In 1983 it announced an interest in a site at Elstow in Bedfordshire and a disused anhydrite mine at Billingham.

At Billingham, Nirex was considering a deep disposal facility for ILW. As a result of strong local opposition, ICI, the owner of the Billingham site, withdrew its offer of sale. Consequently, the Government announced its intention to focus on shallow disposal and noted that there was 'less urgency about the identification of a deep facility [Hansard, 1985]. The Government also requested that other sites for shallow disposal should be investigated in addition to Elstow.

By 1987, four sites had been identified. Despite strong local opposition, on-site investigations in support of a shallow disposal facility for LLW were commenced. Just before the 1987 general election the Secretary of State for the Environment in May 1987 announced that both LLW and ILW should be disposed to a deep facility. This decision was justified on the basis of the rising costs of a near-surface disposal facility brought about by the need to respond to public perception. Studies had shown that, if the LLW could be added to the wastes already allocated for disposal at depth, the cost of deep disposal of LLW would be 'broadly similar' to the cost of near-surface disposal in a new facility [Baker, 1987].

This switch in policy prompted a new search for a site for a deep geological repository to take all ILW and LLW. Around one third of the UK landmass was considered to have potentially suitable geology. By 1989 Nirex had compiled a shortlist of ten land-based potential sites plus two generic offshore options. From these Dounreay and Sellafield were selected for detailed study. Sellafield was then chosen as the preferred site for continued investigation in 1991. Nirex considered both sites to have potentially suitable geology but a large percentage of the waste was already located at Sellafield so that risks and costs associated with transport of waste would be lower there. Also, an existing nuclear industry presence at Sellafield was expected to provide a measure of local support for a deep repository.

An extensive programme of geological investigations was focused on the Sellafield site. Twenty-nine deep boreholes were drilled to investigate the properties of the geology around the site, and considerable modelling work carried out to assess the suitability of the site for a repository. In 1992, a need for a Rock Characterisation Facility (RCF), an underground laboratory was identified. The purpose of the RCF was to investigate further the detailed properties of the potential host rock. Nirex applied for planning permission to build the RCF in June 1994. Cumbria County Council rejected the application in December 1994. Nirex appealed against the decision and this resulted in a public inquiry that took place between October 1995 and February 1996.

The result of the public inquiry was that the rejection of planning permission for the RCF was upheld. The Secretary of State for the Environment announced on 17th March 1997 that he supported the decision not to allow the construction of the RCF and consequently Nirex terminated its work at Sellafield.

B3. 1997 - 2000

The RCF decision ended serious pursuit of any specific long-term management option for solid ILW radioactive wastes. In a report summarising the national situation with regard to radioactive waste management [Parliamentary Office of Science and Technology, 2000], the Parliamentary Office of Science and Technology concludes that:

"The refusal of the planning appeal by the last Government brought to an abrupt halt a process started as long ago as 1976 and which has involved investments of approaching £450M over the intervening years – now with little to show for it. While site characteristics and the way in which Nirex was perceived to operate no doubt contributed to the particular problems, the experience does throw up many serious questions over the mechanism for determining the appropriate approach to what would have to be a unique and national facility."

The report was the first in a series of comments about the future of radioactive waste management in the United Kingdom from influential organisations. Following the RCF Public Inquiry decision and the election of a new party into government in May 1997, the House of Lords' Select Committee on Science and Technology launched an enquiry into the management of nuclear waste, inviting evidence from a wide range of experts and stakeholders. Their report, *The Management of Nuclear Waste* [HoL, 1999] was published in March 1999. An extract of the executive summary of the report, is presented below:

II. The bulk of nuclear waste that exists now and is certain to arise in future originates from past military and civil nuclear programmes. The problem exists and has to be solved. It could not be avoided by deciding today to discontinue nuclear power production or the reprocessing of spent fuel.

IV. The long time-scales involved might be thought to be a reason for postponing decisions. The contrary is the case, since existing storage arrangements have a limited life and will require replacement and eventually the repackaging and transfer of stored waste. Reliance on supervision for very long periods increases the probability of human error.

V. We received a great deal of evidence on the technical issues and conclude that phased disposal in a deep repository is feasible and desirable..... The phased approach which we recommend would allow decisions to be taken in a considered way as technical confidence and experience develop, and would avoid premature decisions which may be difficult to reverse.

VI. The future policy for nuclear waste management will require public acceptance.... Central to this is the need for widespread public consultation before a policy is settled by Government and presented to Parliament for endorsement....

VII. Present policy for nuclear waste management is fragmented. There are wastes for which no long term management option has yet been decided and there are a number of significant materials, for which no use is foreseen, which are not categorised as waste at all. This leads to uncertainties in the planning of future facilities and to the continued storage of hazardous materials in an essentially temporary state...

VIII. These problems require changes in the present organisational structure for nuclear waste management.....

B4: 2000 – present

Since the House of Lords report, the Department of the Environment, Food and Rural Affairs have launched a consultation process to develop a new policy for the United Kingdom on Managing Radioactive Waste Safely. An initial public consultation has been undertaken and response collected and collated. As a result of this, DEFRA has established a Committee on Radioactive Waste Management (CoRWM) to steer DEFRA's policy development process through the next stage – the development of options for consideration.

Appendix C:

UNPACKING THE NIREX PERFORMANCE ASSESSMENT FOR THE DEEP DISPOSAL OF RADIOACTIVE WASTES

In this appendix, the analysis which goes into the post closure performance assessments used by Nirex to examine the risks associated with a deep geological repository is summarised. The aim is to draw out the rationale behind specific performance assessments in terms of fundamental knowledge, conceptual assumptions and mathematical models in order to support conclusions and analysis in the main body of this thesis.

C1 BACKGROUND

In the context of radioactive waste disposal, one form of risk analysis is the "post-closure performance assessment". This process evaluates the ability of a repository to protect people and the environment in the very long term after closure. It represents the repository system and includes features, events and processes which may affect the repository system, of order 1 million years into the future. Mathematical models are used to represent these features, events and processes and to estimate radiological risk. The modelling process can be complex and may use probabilistic mathematical modelling techniques. In consequence, post-closure performance assessment reports are commonly written with a highly technical audience (such as the regulators) in mind [EA, 1997]

C1.1 The approach taken to analysing the performance assessment

In analysing performance assessments, attention is often focussed on the modelling process. This is understandable, given the history of risk analysis as a means of capturing and quantifying uncertainty for discussion in the specialist domain. The primary purpose of the performance assessment is, after all, to quantify levels of safety for a system whose long-term evolution is bound to be subject to uncertainties. However, the approach adopted below is to move away from a strong focus on the modelling process and consider the inputs to a performance assessment in a more qualitative and subjective manner. A specific performance assessment is analysed below using different stages of "intellectual translation" of information and knowledge into modelling methods identified in Chapter 4:

- What standards need to be met (generally defined in regulations)
- How the proposed course of action hopes to meet these standards (the project design)
- What is known now about environmental conditions, processes and evolution
- What potentially could happen in the future
- What are the risks?

The aim of this classification is to establish the scope and complexity of the environmental issues being handled within the context of radioactive waste management.

C1.2 The performance assessments[a]

Performance assessment is a process that aims to represent the behaviour of a radioactive waste management system. In this thesis, it is used synonymously with the term "safety assessment", defined by the NEA [OECD/NEA, 1999b] as

> *"the evaluation of long-term performance, of compliance with acceptance guidelines and of confidence in the safety indicated by the assessment results".*

An assessment should therefore allow judgements about the safety of the proposed management system. Performance assessments may be used as part of the process of confidence building and decision making surrounding proposals for developing a particular facility.

Historically within the nuclear industry, both nationally and internationally, a great deal of attention has been focussed on considering how radionuclides *could* return to the surface in the future. This is a classic risk focus – if radionuclides can return to the surface then people could receive a radioactive dose which could result in harm to health. Performance assessments are used to evaluate that possibility and are an important aspect of all radioactive waste management programmes.

Appendix D presents a short summary of a range of performance assessments developed internationally. However, in order to examine the assessment process in detail, I wanted to consider a specific example and because of my familiarity with the work of Nirex, I have based much of the discussion below on post-closure assessments of the Nirex Phased Disposal Concept [Nirex, 2000a].

The Nirex Phased Disposal Concept is an example of a deep geological radioactive waste repository in which post-closure safety is provided by a series of barriers to radionuclide movement. The scientific underpinnings of deep geological disposal have been described elsewhere [Nirex, 2001a; Savage 1994]. The nature of "performance assessments" is also described in more detail elsewhere. In support of the Nirex Phased Disposal Concept, three underlying technical evaluations have been undertaken. These address: the safety of waste transport [Nirex, 2001e]; the safety of repository operation prior to repository closure [Nirex, 2001c]; and the long-term performance of the repository [Nirex, 2001d]. The assessment of the long-term performance of the repository is called the generic post-closure performance assessment (GPA). The GPA forms the initial basis for the descriptions given below.

However, the GPA is a performance assessment of a generic concept undertaken during a period of reflection and consultation regarding the future of radioactive waste management. Chapter 6 suggests that the identification of a specific site brings a number of different factors into the development of proposals. Therefore, the analysis also considers Nirex 97 [Nirex, 1997], a post closure performance assessment that was undertaken when Nirex was investigating the suitability of a site near Sellafield in West Cumbria as a potential host for a deep geological repository. As discussed in Chapter 6 and 7, this project ended following the refusal of planning permission to construct an underground "Rock Characterisation Facility" for further scientific investigations. This planning refusal led to the current period of Government consultation and deliberation about the future of radioactive waste management in the United Kingdom [Nirex, 2000a].

Juxtaposing two successive, but different performance assessments gives us the opportunity to consider trends in performance assessment, and also explore how context and experience affects the role of value judgements in performance assessment.

[a] In the context of the UK radioactive waste management industry, the term "performance assessment" is typically used for a specific risk analysis. Throughout this thesis, I have adopted this protocol when talking about risk analyses produced by the radioactive waste management industry.

C2 THE CONCEPTUAL BASIS FOR PERFORMANCE ASSESSMENT

C2.1 What standards need to be met?

Environmental standards are set out, often in legislation in order to protect the environment. They are typically established by careful consideration of cause and effect in order to determine thresholds for acceptable levels of impact. For example, the World Health Organisation identifies water quality standards which indicate concentration levels that are acceptable in potable water.

In the UK, standards that would need to be met for any long-term management option for radioactive are set out in the form of Guidance from the regulatory authorities. Both qualitative and quantitative principles are identified.

The regulatory guidance for radioactive waste disposal facilities is couched mainly in terms of :

- A dose constraint – applicable during the operation of a facility and for a period of a few hundred years thereafter. This constraint sets limits on the amount of exposure to radioactivity for any individual;
- A risk target – applicable once the repository has been closed which states that assessed radiological risk (to a "representative individual from a potentially exposed group") should be consistent with a target of 10^{-6}, or one in a million, per year. The guidance does not indicate a cut off time for this target.

Implicitly, these standards assume that risks can be controlled or limited whilst the repository is in operation and under active management. They are also based on the idea that the protection of humans will also ensure the necessary level of protection of the environment in its broadest sense.

C2.2 How the proposed course of action hopes to meet these standards

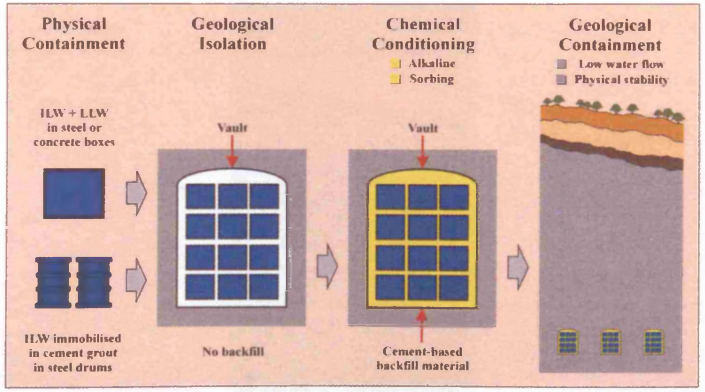
Generally speaking, regulatory standards mean that it is necessary to isolate radionuclides from humans sufficiently so that they never return to the human environment in concentrations that exceed the radiological risk target. There is broad international consensus that a good way of achieving this is by constructing an engineered repository under the ground. In this way, both man-made and natural systems can work together to contain and isolate the radionuclides. This is the concept of multibarrier containment [Bailey and Littleboy, 2001]. In essence, the concept can be considered in terms of three components which control the movement of radionuclides and the chance of exposure to ionising radiation. These are:

- The engineered system, which comprises the wastes themselves, their packaging and the engineered elements of the repository in which they are placed for long-term disposal;
- The geosphere, which is the geological system in which the repository is constructed; and
- The biosphere, which is the near surface environment in which flora and fauna exist.

Within each of these components, physical and chemical processes operate that determine the levels of isolation provided by the repository. The scientific research providing evidence for the operation of these processes is described elsewhere [Savage 1994].

Nirex has developed a Phased Disposal Concept based on the idea of multibarrier containment. This concept, illustrated schematically in Figure A1, is designed to meet the necessary safety standards and ensure long-term environmental protection. The concept includes an extended period of underground containment and monitoring (geological isolation), during which the option of retrieving the wastes will be kept open. This was included into the concept as a result of consultation with a wide range of stakeholders. The concept is generic, in that it could be applied at any suitable site.

Figure C1: The Nirex Phased Disposal Concept



The Nirex phased disposal concept is a multi-barrier system, which envisages:

- immobilisation and packaging of wastes (physical containment);
- transport to a repository;
- emplacement in vaults excavated deep underground within a suitable geological environment (geological isolation);
- a period of monitoring during which the wastes would be retrievable;
- backfilling of the repository at a time determined by future generations (chemical conditioning); and
- sealing of the repository (geological containment).

It is envisaged that such a repository would be located several hundreds of metres below the earth's surface in an area of naturally low groundwater flow.

The cementitious matrix and the steel and concrete containers in which radioactive wastes are packaged will provide a physical barrier to the movement of radionuclides by initially preventing, and thereafter limiting the access of groundwater to the wastes. Most waste containers have vents to allow the release of gases. However, even allowing for the presence of these vents it is expected that the conditioning and packaging of the wastes will reduce the release of radionuclides or up to one thousand years as the radionuclides take a long time to diffuse through waster in the pore spaces of the waste matrix.

The waste packages are to be surrounded by a cement-based backfill. This backfill is designed to evolve to create stable, uniform and alkaline conditions around the waste packages that will tend to reduce solubility – thereby limiting the extent to which some radionuclides can dissolve into groundwater. The cementitious backfill also has a high potential for "sorbing" radionuclides (capturing radionuclides on the surface of the backfill so that they are no longer mobile), thus inhibiting the movement of radionuclides away from the repository. The backfill is also designed to allow the release of gases from the repository in order to prevent any build-up of pressure.

The geological environment (geosphere) is intended to provide a stable setting and isolation from inadvertent human intrusion or disruption by natural events. The geosphere can be selected s that it is one in which there are low levels of current groundwater flow in order to reduce the rate as which radionuclides could eventually be carried away from the repository. Additionally, the longer the groundwater takes to reach the surface, the more time there is for radioactive decay to occur – a natural physical process by which radioactivity decreases over time. Any radionuclides that are released from the repository will spread out (disperse) as they are carried through the geosphere by groundwater. The movement of radionuclides will also be slowed down by sorption (adsorption onto rock surfaces or into mineral structures). So the performance of the geosphere is dependent on a combination of groundwater flow rate, decay, dispersion and sorption that will determine the concentration of radionuclides in groundwater reaching the surface. Generally speaking, these processes have been studied and observed through the practice of hydrogeology and contaminant migration studies for many years. In consequence, the assumption is that the concentration reaching the biosphere will be very much lower than the concentration leaving the repository.

Although it is assumed that the majority of radionuclides will be prevented from reaching the biosphere, those that do may be ingested or inhaled by humans, giving rise to a radiological dose. Ingestion can occur if radionuclides enter the food chain; radionuclides which become airborne may be inhaled. Additionally, radionuclides may give rise to an external dose. Many years of monitoring and research on discharges from nuclear installations means that radionuclide transfer processes in the biosphere and consequential doses are "well understood" [ICRP, 1991].

C2.3 What do we know now about environmental processes, conditions and evolution?

2.3.1 What information do we want?

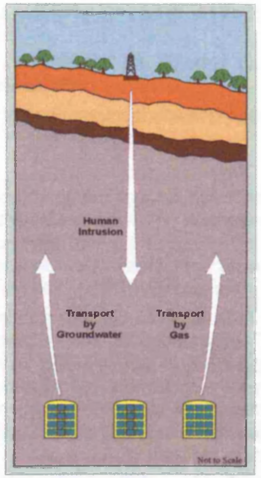
The performance assessments generally consider three main routes back to the human environment [Bailey and Littleboy, 2001]:

- the dissolution or entrainment of radionuclides into groundwater and their consequential migration back to the surface as a result of the hydrological cycle;
- the production of radioactive gas and its subsequent movement back to the surface; and
- the intrusion of humans into the repository or into surrounding rocks that have been affected by radionuclide migration (Figure A2).

The nature of the engineered and natural barriers is expected to prevent or limit of exposure by these routes. This expectation is based on certain assumptions, supported by theory, observation and practice, about the performance of the different barriers [Savage 1994].

Groundwater provides an important route for radionuclides in a deep waste repository to reach the biosphere and is often the focus of attention in a performance assessment. The groundwater must enter the waste containers, dissolve radionuclides or detach particulate matter from the wastes and transport radionuclides in solution or as suspended solids to the biosphere. Whether or not radionuclides from the waste return to the biosphere at concentrations that would pose a radiological risk exceeding the regulatory target depends on the way the various system components function together over time. More specifically, it depends on the geological system surrounding the repository.

Figure C2: Exposure pathways in post-closure performance assessments.



Current conditions provide a starting point for any analysis or discussion about how the geological system will function. For this reason, a good understanding of the groundwater flow regime at the proposed site is regarded as a prerequisite for calculating risks from the groundwater flow path. Ideally, the geosphere barrier needs to ensure low groundwater flow into and through the repository and chemical conditions (particularly in the groundwater) that do not adversely affect the engineered system. These characteristics will combine to allow time for radionuclide decay and dispersion within the near field and the geosphere, thus reducing the amount of radionuclides released into the biosphere during any given time period.

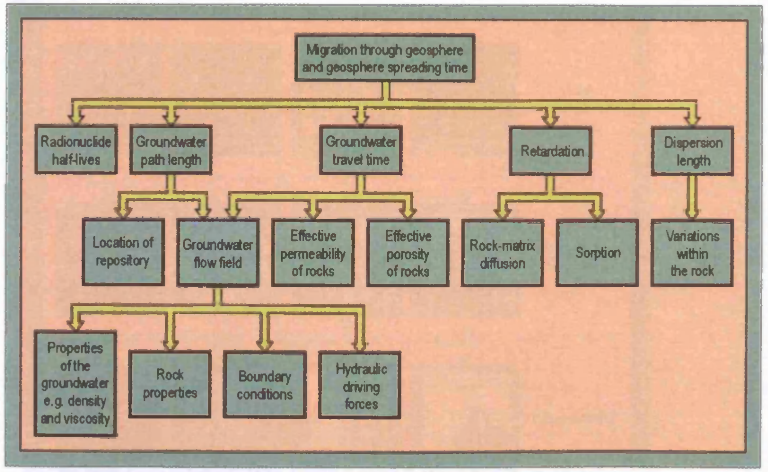
The Nirex approach to modelling the geological system under current environmental conditions is to consider the geological barrier in terms of a number of factors that govern the fraction of the initial inventory transmitted through the geosphere and the geosphere spreading time:

- the distance the groundwater must travel through the geosphere – the groundwater 'path length';
- the average time taken by groundwater to travel through the geosphere - the 'groundwater travel time';
- the extent to which each radionuclide is delayed as it travels through the geosphere (for example by sorption onto rocks) - the 'retardation factor' for each radionuclide;
- the extent to which radionuclides are spread out into the rocks as they travel along the groundwater path - expressed in terms of the 'dispersion length'.

2.3.2 The role of geological site investigations

These factors depend upon measurable physical and chemical properties of the repository and its geological setting, as indicated in Figure A3.

Figure C3: Relationship between geosphere factors and geological properties



Therefore, geological investigations are fundamental to providing the necessary knowledge for a performance assessment. Specifically, site investigations are used to build knowledge that helps to:

- understand the performance of the geosphere at a potential repository site;
- demonstrate a broad based, self consistent geological understanding of a site (this includes geology, hydrogeology, geotechnical aspects and the geochemistry of the site) to a wide audience;
- develop practical engineering designs for the construction of a potential repository; and
- enhance the generic understanding of key processes that will impact geosphere performance;
- understand the potential interactions between engineered barriers and the geosphere over long timescales; and

The broad types of information required from a site characterisation programme are therefore:

- structural and lithological information on the disposition, internal structure and inter-relationships of all of the rock formations in and around a site, to depths below the potential repository location and including surface sediment cover and soil formations;
- distribution of hydraulic properties of each formation, in terms of permeability, porosity, and nature of groundwater flow through rock units and individual structural features and the connectivity of different features in which flow occurs;
- geochemistry of rocks and groundwaters in different formations and features (e.g. faults and fractures), including hydrochemistry, fracture and pore surface mineralogy and chemical indicators of groundwater residence times and movement;
- information on the spatial variability of all the above properties and on the spatial scales over which they can confidently be interpolated or extrapolated;
- indicators of the potential variability of these properties with time;
- conceptual models of groundwater flow under current conditions and indications of how this could change in the future;

- indicators of stability or instability of the geological or hydrogeological system from the geological record, including evidence for recent (neotectonic) structural movements or environmental changes;
- indications of the resource potential of the different rock units and evidence of past drilling and excavation practices; and
- *in situ* rock stress distributions and geomechanical properties within each formation and in major structural features.

This knowledge is supplemented by other research activities to provide information on key processes such as sorption, dispersion, solubility, retardation and the potential corrosion and evolution of engineered materials and wastes within the repository. Therefore, when it comes to translating what we know now about the current conditions into model input parameters there should be a fairly large set of information.

However, determining the relevance and the robustness of data in the context of a post-closure performance assessment is not straightforward. Taking knowledge about the geosphere as an example, raw (or primary) data is generated directly by measurements in the field or on samples analysed in the laboratory. This primary dataset may require processing, either because the primary data are not directly representative of the *in situ* conditions (gaining access to the sample can disturb the natural environment) or because the measurement is correlated in some way to the data of interest. Data processing gives rise to a secondary dataset (processed data). The information of most relevance in establishing the characteristics of a site is often derived from the secondary data by interpretation. For example, models of the geological structure are extrapolated from some combination of borehole information and geophysical surveys. Groundwater compositions are often compared by examining the ratios of certain chemical species.

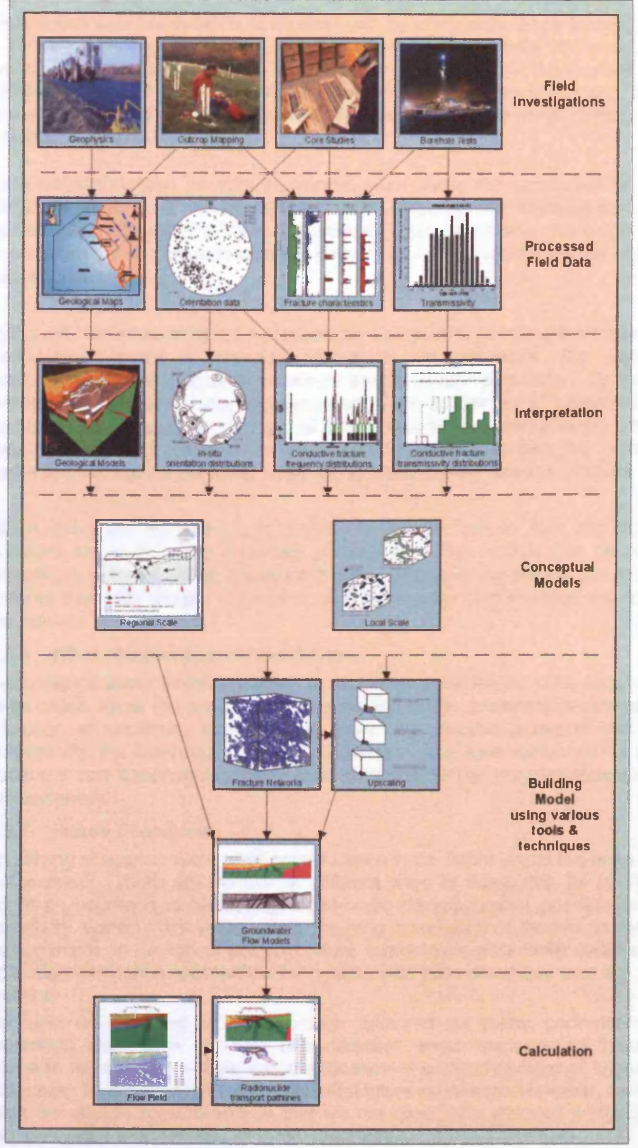
So a key aspect of the site investigation programme is the integration of many data from many different sources to provide a more comprehensive understanding. This integration can also help to reduce uncertainties arising from a single dataset and provide an independent verification of conclusions drawn from any single dataset. This all helps to increase the self consistency in any description of the current environmental conditions at the site, and hence increase confidence in conclusions drawn from independent data.

A key output from a site investigation programme is a conceptual description of what is known about current environmental conditions and processes and how they have evolved. This conceptual description helps develop conceptual models – the key staring point for the risk analysis (Figure 9.1).

2.3.3 The role of models

An assessment of the groundwater flow pathway requires credible groundwater flow models. The conceptual description itself is not sufficient to capture the geological system in a form suitable for calculating risks from the groundwater flow pathway. Models must be used to derive the factors that describe the geosphere behaviour – the groundwater path length, groundwater travel time, retardation factor and dispersion length. Since models will also have been used to help process the primary data and develop secondary datasets (for example in the interpretation of borehole test data, chemical composition or geophysical information), there is a hierarchy of models that contributes to knowledge about current environmental conditions. This hierarchy of model-based information is illustrated in Figure A4. An important issue is to keep the consistency between these models since that is the only way that the parameters going into the risk model can be related back to observation and measurements.

Figure C4: Information flow: site investigations to groundwater models



2.3.4 Integrating investigations and modelling.

Figure A4 implies a linear process for developing knowledge about current environmental conditions and groundwater flow. However, since measurement, modelling and expert judgement combine at all stages of the process, it is generally not undertaken in a linear manner.

Knowledge evolves as information becomes available. The ability to review information against identified aims to see how understanding is developing and where there are key remaining uncertainties is important to any research programme. Therefore, developing an understanding of current environmental conditions is generally developed by iterating between data gathering, interpretation and groundwater modelling [Littleboy, 1995]. Each iteration provides an evolved understanding of the area. [Littleboy et al, 1998].

The main elements of this cyclical process are:

- An initial hypothesis is constructed for the behaviour of the site, or a specific feature, event or process contributing to the overall system;
- Data are gathered to test this hypothesis;
- By considering these data, areas of uncertainty in the hypothesis can be identified, and numerical models (with associated uncertainties) can be developed to produce results that indicate the possible range of behaviour of the site that is consistent with the hypothesis;
- Using an iterative process, remaining areas of uncertainty in the hypothesis are addressed by obtaining additional information from specifically designed tests;
- A measure of the validity of the models is obtained by comparing predictions from models of the test with actual results. Tests for which the model does not adequately predict results highlight those areas where further work is required to improve the model; and
- A new cycle then commences with a revised hypothesis.

A greater level of understanding of the site is achieved during each cycle of model development. On completion of each cycle, the opportunity to refocus characterisation activities, or improve groundwater flow models in a structured manner is provided.

2.3.5 Integrating uncertainty and expertise

There is never going to be complete knowledge about the geological system or the environmental processes that operate. In translating knowledge about current environmental processes into modelling methods, expert judgements are used to supplement sparse data (data uncertainty) and ensure that knowledge about heterogeneity and uncertainty are captured within the models.

There are a number of possible approaches for dealing with uncertainty. At the level of modelling primary data and deriving secondary datasets from site investigation, precedent practice can be drawn on – state-of-the-art processing and modelling techniques for the interpretation and processing of geological, hydrogeological and geochemical information. The tools and techniques are available for application but experience and expertise in these particular techniques is called on to determine which method is most suitable for the matter in hand. Additionally, experience is required to interpret the output of these techniques. Hence at this stage in the process experience and modelling work together to deal with uncertainty, guided by fairly well established precedent practices.

However, further down the process described in Figure A4, many different types of information are being integrated into an overall understanding. At this point – where conceptual models are being developed and turned into numerical models - a number of complex issues and key uncertainties are being drawn together. Precedent practice no longer provides a useful benchmark since the requirement is to model a complex system of interelating environmental features and processes. Both conceptual uncertainty and data uncertainty are significant.

Conceptual uncertainty tends to be dealt with by using experience and expertise to identify a range of conceptual models that could be consistent with the available information. During the iterative process of investigation and modelling, conceptual models maybe refined and some maybe eliminated as conceptual uncertainty is reduced. Hence expertise is used to ensure that uncertainty is encompassed within the range of proposed conceptual models.

Data uncertainty can be very significant. Data about the parameter of interest and its variability can be obtained but needs to be extrapolated and modelled for a volume of rock. At any point within that volume, the property could adopt one of a range of values. The potential range of values is affected both by natural variability and by uncertainty due to lack of information.

In the UK, Nirex has adopted a probabilistic approach to handling the numerous sources of uncertainty inherent in knowledge about the site conditions. The approach seeks to establish the range of possible values for each uncertain parameter. Typically this range is based on measured values, supplemented by the judgement of suitably qualified experts, and takes into account any sparsity of data or bias from measurements. The uncertainty is described by a 'probability density function', which describes the probability that the parameter will have a particular value within the assigned range of possible values.

When doing the modelling it is possible to sample values from the probability density functions for each of the uncertain parameters. The models can be run many times, sampling a different set of values each time. The rationale behind this approach is that it ensures that wide ranges of possible parameter value combinations are considered within the models.

2.3.6 What could happen in the future

Performance assessments evaluate behaviour into the future. This requires assumptions to be made about the possible future evolution of the repository (scenarios). This future evolution is uncertain, and so more than one possible scenario can be envisaged. Additionally, the likelihood of people receiving a dose from radionuclides returning to the surface is very dependent on living conditions. This will be very dependent on the nature of the biosphere.

2.3.7 Future Scenarios

Identifying scenarios about what could happen in the future lies at the heart of performance assessment. There are number of different ways of doing this, all of which essentially adopt an approach of identifying broad-brush descriptions of possible evolutions of the repository system. However, given the long timescales of interest in radioactive waste management, the range of possible future scenarios is essentially unlimited. Two distinct and often competing approaches for dealing with this non-uniqueness are worth a special mention.

Scenario development is an approach favoured by many performance assessment specialists working in the field of radioactive waste management (see Appendix D). Scenario development entails the identification of a select number of future scenarios that essentially bound the full range of potential future scenarios. However, with this approach, there are always some scenarios that are not specifically included within the assessment, leaving it open to challenges of incompleteness.

Simulation seeks to identify a more complete representation of the range of potential future scenarios and to incorporate them into the assessment. With this approach, the modelling

complexity increases significantly and it is possible for some incredible scenarios to be included in the assessment (leaving it open to challenges of unreliability). Additionally, given Wynnes work on ignorance, it is naïve to claim that all possible futures have been taken into account.

Both approaches have been developed in an attempt to provide systematic and transparent means by which the features, events and processes included in a performance assessment can be selected and documented. However, the methods have been developed for application by experts and can appear complex and full of jargon and mystique. For example, Nirex has developed a systematic approach to the identification and consideration of the factors that could affect the performance of the repository [Nirex, 1998b]. These factors are often referred to as FEPs (features, events and processes) and are combined together to form scenarios. Examples of FEPs include waste package corrosion, groundwater movement, climate change, earthquakes and potential future human actions.

The FEP analysis approach links those FEPs that are almost certain to occur (such as climate change and fundamental physical and chemical processes) into a "base scenario" which is intended to represent the likely natural evolution of the system. Those FEPs which are less likely or unlikely to occur (such as large earthquakes and certain human actions) can be explored via "variant scenarios".

For each of the variant scenarios it is possible to calculate the probability that it will occur, based upon the probabilities of the FEPs which define the scenario. For example, it is possible to estimate the probability of a large earthquake occurring, based upon the historical frequency of such events.

The FEP analysis methodology developed by Nirex seeks to identify a manageable set of scenarios that embraces all significant and relevant repository evolutions. Less harmful scenarios are enveloped ("subsumed") into those likely to give higher risks. However, this can mean that the visibility of issues captured by the scenarios is reduced.

However, because scenario development is concerned with the future, and because it operates at a conceptual and descriptive level, is an opportunity to reflect stakeholder concerns about "what would happen if…". Alternative evolutions can be considered by conducting sensitivity studies. For example, parameters within the models can be varied. These studies should indicate the model assumptions and data that the performance is most sensitive to. Additionally, alternative "what if" scenarios can be explicitly considered. The early identification of the "what if" studies to be undertaken could be used as a focus for debate and dialogue with stakeholders, and "what if" studies explicitly addressing their own particular concerns could be considered.

2.3.8 Representing future biospheres

Whatever the scenario under which radionuclides return to the biosphere, the affect they may have on human health depends on the manner in which people are exposed to radiation. The manner in which people are exposed will depend on the nature of society and the standard of technology. There are huge ethical questions raised by thinking about future societies. For example:

- Are we worried about exposure to individuals or collectives? The manner in which risk is calculated and risk results are analysed varies significantly depending on this choice.
- Should we take into account the possibility of technical progression or technical regression? The scenarios that come into play for these two situations are entirely different.
- How do we represent the response of societies to future environmental change – either anthropogenic or natural? Predicting global change is a highly complex field in its own right. The assumptions about future societies vary significantly for different climate change scenarios.

The performance assessments analysed here and describe in Appendix C tend to avoid these issues by making the assumption that we are concerned with collective risk, we cannot rely on a technologically based future for society and we need to consider risks under a range of different climates. Hence the assessments look at representative subsistence communities whose main risks of exposure arise from the mixing of groundwater with waters at the surface. Scenarios whereby humans intrude into the deeper environment potentially contaminated by radionuclide migration from the repository are also considered, as are scenarios whereby society is exposed because of the emission of gas from the repository. However, for the purposes of this thesis, we will focus on natural explore to radiological risk as a result of groundwater movement.

Contaminated groundwater will be diluted as it discharges into surface water. However, the risk is that humans could receive doses by drinking this water, and since animals could drink it also radionuclides could enter the food chain. Radionuclides will also be removed from solution and bound onto soils and sediments. Once in the soil, radionuclides may be transferred into plant matter, and from plants into the food chain. Particulate matter may be blown into the atmosphere and once there, respiration can lead to the inhalation of particulate matter. Evaporation of water and transpiration ('breathing') by plants can also lead to radionuclides entering the atmosphere.

The standards raise the issue of risk to human health. Therefore, various assumptions are made about how people may live in the future - diet, occupation and general lifestyle – and how they might receive a radiological dose arising from the migration of contaminated groundwater. Due to the long timescales of consideration for a repository system, these will change from current behaviour and future trends are highly uncertain. Therefore, conservative assumptions that would tend to increase the received dose are adopted when calculating doses. For example, the following conservative assumptions are made concerning the individuals who define the potentially exposed group:

- they live in an area (known as the resource area) which includes the location of highest radionuclide concentration;
- they spend all their time in this resource area; and
- they only eat foodstuffs gathered from the resource area.

The unpredictability of human behaviour, particularly over the long time scales appropriate to post-closure performance assessment, means that wide-ranging assumptions need to be adopted, for example on future land-use, farming practices and population distributions; these may be strongly influenced by climate change. The need to make such assumptions places a limit on the extent to which it is appropriate to make detailed predictions of the long-term evolution of the environment, as recognised in the advice received from the National Radiological Protection Board (NRPB) and the Government [EA, 1997].

These assumptions are translated into modelling methods using the concept of a biosphere factor - that converts the flux of radionuclide entering the biosphere into a radiological dose. This dose can then be converted to a radiological risk. The biosphere factor is very dependent on natural processes governing radionuclide transfer between different components of the environment. These components include:

- surface fresh waters (streams, rivers and lakes);
- surface-water catchments, including soils, sediments, plants and animals;
- estuaries, including channel waters, unvegetated and vegetated sediments, and salt marshes;
- the marine environment, including foreshore, nearshore and offshore zones and their underlying sediments;
- the atmosphere.

Clearly there are a range of possible climatic conditions which could prevail over the timescales of concern when dealing with radioactive wastes. Therefore a range of broad

climate states are used to describe the range of possible future climatic conditions in Britain [Meadows, 1992]. These are: Mediterranean (e.g. Spain) or greenhouse-gas warmed; Temperate (e.g. UK); Boreal (e.g. Scandinavia); Tundra (e.g. Alaska); Glacial (e.g. Greenland). Different conditions characterise these different states. For example, Boreal conditions correspond to a climate similar to that of Southeast Iceland. The biosphere associated with this climate state can be described qualitatively in terms of an extended coastal plain, crossed by a number of small to medium size rivers. The climate is regarded as sufficiently mild for a range of arable crops to be grown in addition to the predominant pasture use. However, primary productivity is reduced relative to that of the current Temperate climatic conditions in the United Kingdom. Under this climate state, a global sea-level fall is predicted and much of the sea-bed is expected to be uncovered. Therefore most of the radionuclide release is expected initially to be to the terrestrial environment, rather than to the sea, irrespective of the repository's location. This Boreal climate state is expected to exist at the time when the risks in the biosphere are nominally at a peak and hence it is appropriate to adopt in illustrations of the performance of a repository under future climatic conditions.

C2.4 What are the risks?

Earlier sections outline the standards that need to be met. These standards have a controlling influence over the way the performance assessment is undertaken. This is because, fundamentally, the output of the performance assessment needs to be in a form that can be compared to the standards. Past approaches to performance assessment have tended to focus on providing output that can be compared with the quantitative risk target set out in the regulatory guidance. Hence performance assessment process calculates an average, or expected, risk value.

The expectation value of risk is generally calculated by specific models that sit at the top of the hierarchy of models discussed earlier. These top level models (risk models) use as input, the factors calculated by lower level models. In essence, the risk models have components to represent what goes into the repository in the first place (the source term), the near field, the geosphere and the biosphere. Obviously, the risk models need to address the many sources of uncertainty that could affect the safety of the repository system. A number of techniques are used in the Nirex performance assessments.

As discussed above, Nirex has typically adopted a probabilistic approach to the treatment of uncertainty whereby the range of possible values is used as model input and the model is run many times using randomly selected values from within the range in order to derive the "average" output. To ensure that a large enough range of combinations is computed in order to have confidence in the average value, it may be necessary to run the models many hundreds of times. This would not be practicable for detailed, highly computer-intensive models. Hence a probabilistic safety assessment (PSA) model cannot contain the same level of detail as the underlying models and the individual components are highly simplified representations of the complexity of features, events and processes that may combine in actuality. It is therefore inappropriate to consider the risk models in isolation from the underlying models and understanding on which they are based.

This means that risk models often need to make a number of simplifying assumptions, either because insufficient data are available or the modelling capability cannot represent some feature of the repository system in full detail. The aim is to address issues as realistically as possible, whilst erring on the side of caution. Therefore, many simplifications involve taking a conservative view, *i.e.* the assumption is made such that radiological dose will be over- rather than under-estimated. Conservative assumptions are often the best way of addressing issues without introducing unnecessary complexity into the models, which could by itself increase the modelling uncertainty.

Another technique that is used to address uncertainty within the risk models is to undertake "what if" calculations. In this situation, the parameter values going in to the model are fixed to represent a certain set of conditions so that the model will calculate a risk result for a particular scenario. Such "deterministic" calculations are useful guides for considering worst case situations, but tend to be used to supplement the probabilistic calculations since they assume a certain future and hence ignore uncertainty about the future.

Appendix D

REVIEW OF INTERNATIONAL PERFORMANCE ASSESSMENTS

Around the world most disposal agencies, and in many cases also their regulatory bodies, have conducted performance assessments as part of their repository development programmes. In each case the approach adopted will depend on the context of the PA and any national preferences or requirements, for example those set out in regulatory guidelines.

This appendix summarises reviews of a number of important international PAs, focussing on their context, the general approach and key elements of the methodology and any particular issues raised. The following performance assessments are considered:

1. Japan, H-12
2. Belgium, SAFIR 2
3. Sweden, SR 97
4. Sweden, SITE-94 – A Regulatory PA
5. Switzerland, Kristallin-I
6. Finland, TILA-99
7. US, Yucca Mountain Viability Assessment
8. US, WIPP compliance certification Assessment
9. Canada, AECL 1994 Post-closure assessment of a reference system
10. UK, Nirex assessments

D1 JAPAN, H-12

D1.1 Context

H-12 [i] is described as being a progress report on research and development to establish the concept of geological disposal in Japan in a generic context, that is prior to any site selection and decisions on other key factors such as safety criteria. It documents progress since an earlier report, H-3 [ii] and aims to confirm the basic technical feasibility of disposal of vitrified HLW in Japan. H-12 consists of five volumes, including an Overview report. One of these volumes is devoted to performance assessment and this also forms a major component of the Overview report.

The Japanese disposal concept aims to find a deep geological environment where volcanic activity, earthquakes, fault activity and influences of uplift, subsidence, climatic and sea-level change would cause no perturbation to a repository. However, because of the geologic tectonic instability of much of Japan, the disposal concept also incorporates a highly engineered near-field barrier. The vitrified waste would be encapsulated in a thick steel overpack and surrounded with a mixture of highly compacted bentonite and quartz sand. Various waste emplacement configurations are being considered, based on either horizontal or vertical disposal tunnels. All waste would be placed at least 100 m from any major water-conducting features and would be sufficiently spaced to ensure the temperature in the

bentonite-sand buffer would not exceed 100°C. The Japanese aim to dispose of 40,000 packages of vitrified waste by the year 2015.

As well as providing a technical basis for promoting understanding of the disposal concept, the purpose of the H-12 assessment is to provide an input to the repository siting programme and to assist in establishing a regulatory infrastructure.

There are as yet no formalised regulations for HLW disposal in Japan. However, the Japanese regulator, the Atomic Energy Commission, has set some guidelines (included as an appendix in the H-12 Overview report) which have acted as the specification for the H-12 assessment. These guidelines specify radiological dose as the primary safety indicator and refer to internationally accepted dose limits and the need to follow regulatory guidelines used in other countries. The groundwater pathway is identified as the main 'scenario', but there is also a recommendation to follow a systematic scenario development methodology to identify other scenarios. There is a recommendation to distinguish between sudden and gradual phenomena and that low probability scenarios need be assessed only semi-quantitatively in terms of their perturbation on existing models or model parameters.

There are no specific guidelines regarding a time cut-off for the assessment, other than that the assessment should be undertaken to identify when the effect on humans reaches it maximum and to determine how long this period lasts. There is also a requirement to confirm that a repository would not cause any significant increase in background radiation long-term. The assessment is also required to consider natural analogues and be presented in a form which "is widely understood and accepted by the public".

D1.2 Approach

The H-12 assessment focuses on the performance of the engineered barriers. Relatively realistic models are used for the near-field, where the system is considered to be well-characterised, whereas the geosphere modelling is simplified and more conservative (solute transport using a one-dimensional model).

The calculations are all deterministic, with the exception of the use of PDFs to represent heterogeneity in the transmissivity of the host rock. Uncertainties in key parameters are assessed by considering a range of alternative calculation cases. The rationale for this largely deterministic approach is to give a transparent assessment of the uncertainties.

The assessment is presented as a systematic approach to scenario development. The first step is the preparation of a FEP list, developed from international FEP lists from which irrelevant FEPs are screened. The remaining FEPs are grouped into sets of 'groundwater scenarios' and 'isolation failure scenarios'.

The 'groundwater scenarios' include a base scenario – in which the geological environment is assumed to remain stable and present day geological conditions persist indefinitely; and a number of perturbation scenarios – which take account of natural phenomena, future human activities and any initial defects in the engineered barriers.

The base scenario includes a 'reference case' and a number of alternative cases, which address alternative geological environments and repository designs, as well as uncertainties in the models and data. The main assumptions of the reference case are that:

- the waste package overpack fails at 1000 years post-closure;
- solute transport occurs through channels within a network of fractures in the rock mass; and
- linear reversible sorption occurs within the rock matrix, but not on the fracture surfaces.

The base scenario alternative cases examine the impacts of the following identified uncertainties in the data and models:

- the value of the glass dissolution rate;
- the groundwater flow around the engineered barriers (controlled by the transmissivity distribution and hydraulic gradient);
- sorption properties and geosphere transport times (represented by host rock distribution coefficients); and
- the contribution of colloids to radionuclide transport.

The perturbation scenarios arise from natural phenomena and human activities. These scenarios are selected using influence diagrams to examine the potential impacts of external FEPs on the safety functions operating in the base scenario. The perturbation scenarios include:

- uplift and erosion – leading to a decreased depth of the repository;
- climate and sea-level change – including intrusion of saline waters;
- incomplete overpack sealing (e.g. due to welding errors) – causing early water ingress and radionuclide release;
- poor backfilling of the repository tunnels and plug defects – causing fast radionuclide transport along the tunnels and increased groundwater flux around the repository, leading to the direct release of the contents of one disposal tunnel (i.e. 200 waste packages);
- drilling of a well and water abstraction near the repository.

The main H-12 assessment only addresses the 'groundwater scenarios', that is the base scenario and the perturbation scenarios. Additionally, a number of 'what if?' calculations have been performed. These are referred to as 'isolation failure scenarios' and are treated qualitatively, they include:

- direct human intrusion into the repository;
- uplift/erosion such that the repository approaches the ground surface;
- seismicity/fault movement in the repository vicinity – this scenario was assessed to give rise to doses that exceed overseas safety standards but are not significantly greater than natural radiation levels in Japan; and
- volcanic activity.

Overall, H-12 is very much a preliminary, generic assessment that is aiming to build the case for deep geological disposal in Japan. It is, however, a very detailed assessment in terms of the scenarios considered and is written in a convincing style. The disposal concept focuses on the engineered barriers and the need to find a stable geological environment, although the potential impacts of geologic instability are considered in 'what if?' calculations. The H-12 assessment draws heavily upon other international assessments, particularly those from Sweden and Switzerland, for its approach and for appropriate assessment standards.

D2 BELGIUM, SAFIR 2

D2.1 Context

SAFIR 2 [iii] is a safety and feasibility interim report conducted by ONDRAF/NIRAS, the Belgian agency responsible for the management of radioactive waste and enriched fissile materials. It follows the SAFIR report , published in 1989, which concluded the first phase of

research into the long-term management of radioactive wastes in Belgium. SAFIR 2 synthesises all the technical and scientific knowledge available from the second phase of the Belgian programme of methodological research and development. The research is described as 'methodological' because it is not part of any licensing application, but aims to inform relevant Government ministers and safety authorities of the progress made regarding the technical feasibility of radioactive waste disposal in a deep repository and the assessment of long-term radiological safety. The stated three objectives of SAFIR 2 are to:

- provide the authorities and other interested parties with a structured synthesis of the available technical and scientific information to enable them to assess progress made in terms of technical feasibility and long-term safety;
- promote interaction with the Belgian nuclear safety authority, AFCN/FANC, so as to reach closer agreement on outstanding research and principles of safety assessment; and
- provide one of the technical and scientific bases for broad dialogue on radioactive waste management.

SAFIR 2 discusses the disposal of long-lived and heat-emitting wastes (Belgian waste categories B and C) in poorly-indurated clay formations with an overlying aquifer. The majority of the waste under consideration is vitrified HLW. This waste would be placed in a primary stainless steel package (0.5 cm thick) with a 3 cm thick stainless steel overpack. This in turn would be placed within a 1 cm thick stainless steel disposal tube in a concrete-lined disposal gallery. The galleries would be backfilled with a hydrated mixture of bentonite clay, sand and graphite. Spent fuel would be disposed in a similar manner to vitrified waste, with some design changes to accommodate longer package sizes. The third waste category considered in SAFIR 2 is hulls and endpieces, for which a simpler concept, omitting the overpack and concrete lining, is considered.

A network of disposal galleries is envisaged, 240 metres underground in a clay host rock. The galleries would be accessed by two shafts, with a connecting tunnel between them. A co-disposal repository is planned, with HLW and spent fuel disposed in galleries on one side of the connecting tunnel and the other wastes (hulls and endpieces) on the other side.

SAFIR 2 focuses on a reference host rock, the Boom clay in the Mol-Dessel nuclear zone, using data from an underground research laboratory at Mol (the site of ONDRAF/NIRAS's main technical contractor, SCK-CEN). An alternative host formation, the Ypresian clay in the Doel nuclear zone, is also considered, but in less detail. Although the basic choice of a clay host formation is not in question for a disposal option, the report is very clear that it is not a licensing application and is not, at this stage, part of any decision-making process between options, as it does not, for example, include societal aspects of deep disposal. ONDRAF/NIRAS plan to produce a strategic environmental impact assessment by 2010 that would address these wider issues and contribute to a national decision-making process.

The Belgian regulatory criteria are based on the following three fundamental principles, derived from the IAEA and ICRP:

- The principle of justification of practices – requiring a cost benefit analysis.
- The principle of optimisation of protection – requiring that impacts are as low as reasonably achievable (ALARA).
- The principle of limitation of individual doses – requiring that doses must be within prescribed limits.

The dose constraint for a Belgian radioactive waste repository is 0.3 mSv/yr, which is an order of magnitude below the doses from background radiation in Belgium of 3.6 mSv/yr. Other factors specified in the regulatory guidance include the need to demonstrate flexibility to new wastes or conditioning practices, and the ability for the wastes to be retrievable over a limited period of time without compromising the long-term safety.

D2.2 Approach

The disposal system is based on the multi-barrier concept and aims to have partial redundancy between the barriers. The main barriers are identified as the engineered barriers, the geological (clay) barrier and the aquifer. The system offers four main safety functions: physical containment; delaying and spreading radionuclide releases; dilution and dispersion; and limitation of access.

The assessment approach is based on a systematic scenario development process, established in 1999-2000. The first stage of the scenario development is the identification of relevant FEPs. This was carried out by reference to the NEA FEP list. Screening out those FEPs not relevant to the Belgian concept, left 60 FEPs (excluding biosphere FEPs, which are addressed within the dose conversion factors). The aim is to identify a 'normal evolution scenario' and a number of alternative evolution scenarios, each scenario being described in terms of its evolution over time and the main processes by which radionuclides migrate from the repository to the biosphere.

The scenarios were identified by assuming that each of the three main components of the repository system (the engineered barriers, the geological clay barrier and the aquifers) is either intact and operating as planned or 'short-circuited' in some way. Taking all possible combinations, this leads to eight main system states, of which the state with all three components intact is the normal evolution scenario.

The assessment of the scenarios has four steps:

1. Conceptual modelling
2. Mathematical and numerical modelling
3. Impact calculations, including uncertainty and sensitivity analyses
4. Interpretation of results and confidence building, including qualitative arguments.

The SAFIR 2 assessment focuses primarily on the normal evolution scenario and the reference Boom clay host rock, with only partial assessment of the alternative evolution scenarios and the alternative, Ypresian clay, host rock. SAFIR 2 also includes preliminary assessments of criticality and the impacts of toxic chemicals present in the wastes.

The normal evolution scenario describes the expected sequence of events in the evolution of the repository system and includes all those FEPs which are judged to be certain, or almost certain, to occur. However, for the purposes of modelling, it is assumed that the current characteristics of the disposal system remain constant over time. A range of assessment codes were used to simulate the release or migration of radionuclides in different components or groups of components of the system. The end-point of the calculations are dose estimates to individuals of the reference group, but intermediate results give a number of other safety indicators, including radionuclide flux densities, total radionuclide flux and radionuclide concentrations in the aquifers and different parts of the biosphere. The calculations are primarily deterministic, using best estimate parameter values, but are supplemented by stochastic calculations to take account of parameter uncertainty for sensitivity analyses. Doses are calculated in three steps:

1. Simulation of the radionuclide migration in the near field and the Boom clay to calculate the radionuclide flux at the interface between the clay and overlying aquifer. These calculations used different source-term models for each of the three waste classes, namely, vitrified waste, spent fuel and hulls and endpieces.

2. Simulation of radionuclide migration in the aquifer to calculate the concentrations of radionuclides in water assumed to be pumped from a well just above the disposal facility, and the radionuclide fluxes entering rivers.
3. Modelling of transfers of radionuclides in the biosphere to calculate exposures to radiation and doses received.

To reduce the number of calculations required, migration calculations are only performed for those radionuclides with long enough half-lives and/or sufficient mobility to reach the overlying aquifer, namely:– carbon-14, chlorine-36, nickel-59, selenium-79, zirconium-93, niobium-94, technetium-99, palladium-107, tin-126, iodine-128, caesium-135 and samarium-147; and the curium-248, neptunium-237, plutonium-242 and uranium-235 decay chains. Several safety indicators are identified whose calculation is virtually independent of the evolution of the disposal system. These include:

- Decayed fractions and containment factors – comparison of the total cumulative radioactivity in the overlying aquifer over 100 million years with the initial disposal inventory to give a ratio of disposed activity to cumulative released activity in the aquifer.
- Total activity flux at the interface between the Boom clay and overlying aquifer.
- Total uranium inventory – comparison with natural levels present in the Boom clay.

The altered evolution scenarios address possible FEPs that are unlikely to occur and yet, if they did occur, would be capable of significantly altering the disposal system in terms of leading to poor performance or failure of one or more safety barriers. From consideration of FEPs with the potential to lead to barrier failure, the following eight altered evolution scenarios are identified:

1. Exploitation drilling (aquifer bypassed)
2. Greenhouse effect (aquifer bypassed)
3. Fault activation scenario (geological barrier bypassed or geological and engineered barriers bypassed)
4. Severe glaciation (all barriers bypassed, or geological and aquifer bypassed)
5. Poor sealing scenario (geological barrier bypassed)
6. Premature failing of engineered barrier (engineered barriers bypassed)
7. Transport by gases (geological (and engineered) barrier(s) bypassed)
8. Exploratory drilling (all barriers bypassed).

On the basis of an initial, primarily qualitative assessment, the above scenarios are shown not to lead to a significant increase in the overall expected radiological impact of the disposal facility.

The full SAFIR 2 report is available on CD-ROM with a single volume technical overview of some 270 pages. This overview report includes, as an appendix, the complete final opinion of the 'Scientific Consultative Reading Committee', a panel of thirteen independent Belgian experts who were commissioned to review SAFIR 2. Their 87 recommendations are listed, some of which ONDRAF/NIRAS had the opportunity to address prior to publishing SAFIR 2 in its final form. Overall, this review committee confirmed that deep disposal within poorly-indurated clay was a viable option, but recognised that there is a need to reduce a number of uncertainties before actual implementation of disposal could be envisaged.

In addition to the technical overview, a brochure summarising the key messages for the wider public and a short document putting SAFIR 2 into the context of sustainable development have also been published.

Overall, SAFIR 2 focuses on explaining the disposal concept and presenting the scenario development methodology. There are also substantial details on the ONDRAF/NIRAS planned forward programme to address outstanding issues. The report is written in a clear, common sense way, without giving the impression that it is strongly pushing the deep disposal option. Although it has some very helpful side panel definitions, the technical overview has relatively few illustrations, and is clearly aimed at a relatively expert audience.

D3 SWEDEN, SR 97

D3.1 Context

SR 97 [iv] is a performance assessment conducted by SKB, the Swedish Nuclear Fuel and Waste Management Company. It is an assessment of the Swedish 'KBS-3' disposal concept for spent nuclear fuel. In this concept spent fuel would be sealed in copper canisters with a high-strength cast iron insert. The canisters would then be placed in individual deposition holes drilled from tunnels excavated in granitic bedrock at a depth of about 500 metres. Within the deposition holes, the canisters would be surrounded by bentonite and the tunnels above the deposition holes would be backfilled with a mixture of bentonite and crushed rock (the exact proportions being dependent on the groundwater salinity at the chosen site). The layout of the deposition holes within the repository, in particular the distances between adjacent holes, would be chosen to ensure that the surface temperature of all the canisters remained below 90°C. The primary purpose of the KBS-3 concept is to isolate the waste by keeping it within the copper canisters. If this isolation fails, the secondary purpose of the concept is to retard the release of radionuclides back to the environment. SKB are looking to dispose of about 8,000 tonnes of spent nuclear fuel, which would require approximately 4,000 canisters.

The KBS-3 concept was designed to satisfy the following safety principles, as laid out by the Swedish regulatory authorities:

- long-term safety should not be dependent on monitoring or maintenance;
- the repository should be designed so as to permit possible future retrieval of the waste or future repository modifications, if required;
- the repository should use multiple engineered and natural barriers which contribute to the overall safety of the repository via different functions; and
- the repository should use natural materials for the engineered barriers, to enable comparisons with analogues and to minimise the disturbance of the natural conditions in the rocks, in particular limiting the chemical impact of the repository.

Swedish regulatory criteria also specify a risk limit of 10^{-6}, or a one in a million chance of serious harm from a repository affecting an individual person. This has led to SKB adopting a risk-based approach to PA, in which the probabilities and consequences of different courses of events are aggregated to calculate the overall risk from a repository. Swedish regulations also require that future harmful effects are not given less weight than those today. Whilst recognising that the first 1,000 years is the most important period in terms of the wastes being at their most harmful, there is a requirement to evaluate safety beyond this period, up to 1 million years. There is also a requirement to consider the biological effects of radiation on natural habitats and ecosystems; and to consider the potential effects of

disruption to the repository (for example by a human intrusion incident) in terms of ongoing protection of the environment from radiation.

The SR 97 assessment was conducted against these regulatory criteria, in preparation for forthcoming repository site investigations in Sweden. It has the following aims, defined by the Swedish Government and regulatory authorities:

- to demonstrate that the KBS-3 concept has good prospects of being able to meet the specified safety and radiation protection requirements;
- to demonstrate a methodology for safety assessment;
- to demonstrate the feasibility of finding a site which would meet the requirements;
- to specify factors relevant for site selection and to determine important parameters and requirements for the site investigation programme; and
- to derive preliminary safety functional requirements on the canisters and other barriers.

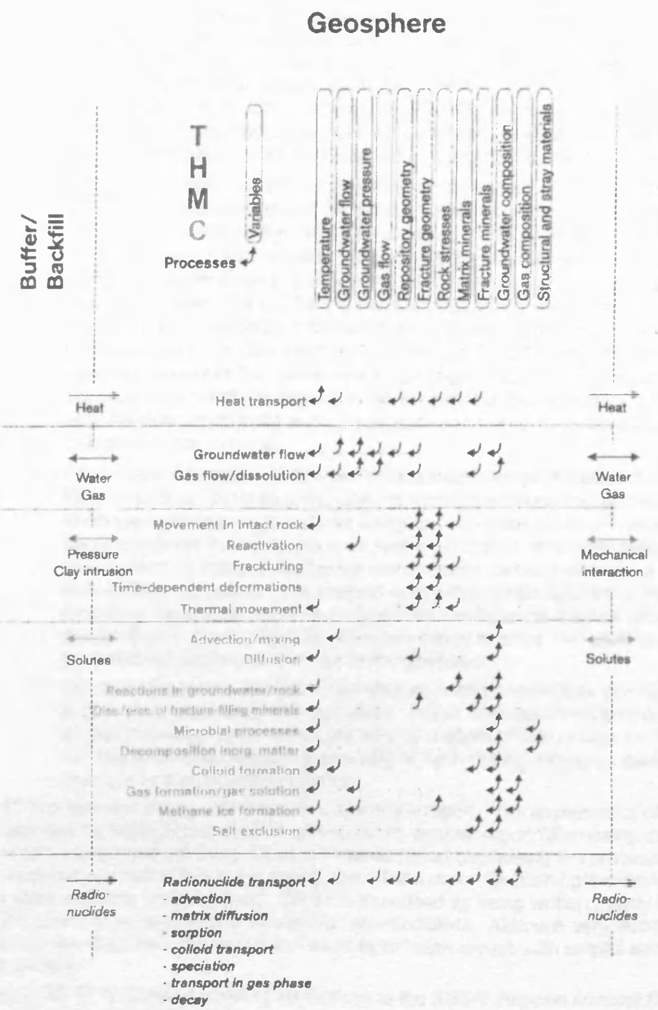
The SR 97 assessment uses geological data from three different sites in Sweden, in order to show that the PA approach can reflect geological variations and to address the requirement to identify factors relevant for site selection. These three sites are named in the report, however it is made clear that none is being considered as a potential repository location. Thus SR 97 is relevant to the conceptual stage of a specific option, the KBS-3 disposal option, as a precursor to the site evaluation stage.

D3.2 Approach

The approach in SR 97 is to consider the state of the repository system at closure and then to analyse how it changes over time as a result of both internal processes and external forces. The internal processes define a 'base scenario' and the external forces are used to derive alternative scenarios for the repository evolution.

For assessment purposes the repository system is divided into four subsystems:- the fuel, canister, buffer/backfill and geosphere, each described by a set of time-dependent variables. The evolution of these subsystems is considered in terms of thermal, hydraulic, mechanical and chemical processes. These processes and their couplings are illustrated in a graphical representation developed by SKB, known as a 'THMC diagram'. A separate diagram is developed for each of the four repository subsystems to show the couplings between the relevant variables for the subsystem (for example, temperature, water content, gas content) and the THMC processes (for example, heat transport, water transport, buffer swelling, advection). As an example, Figure D1 shows the THMC diagram developed for the geosphere.

Figure D1 THMC Diagram for the Geosphere (from SR 97 Report [iv])



The assessment approach in SR 97 then follows the following five steps:

- System description – includes defining the boundary between the repository system and its surroundings, with a description based on the THMC structure.
- Description of the initial state of the repository and its surroundings at closure.
- Choice of scenarios – a range of scenarios is selected, on the basis of identified external forces, to give a reasonable coverage of different repository evolutions.
- Analysis of chosen scenarios – using different tools and methods, ranging from reasoning and simple approximations to detailed modelling based on site-specific data. (This modelling follows the premise that the base scenario is engineered to be robust, so variations are not expected to cause dramatic changes.)
- Evaluation – this is the overall assessment of repository safety, with different scenarios weighted together into a total risk picture, including a discussion of the level of confidence in the results.

In conducting the analysis, for each input parameter two values are assigned:- a reasonable value and a pessimistic value. Calculations are then performed with different combinations of reasonable and pessimistic parameter values to investigate sensitivities to parameter uncertainties. The reasonable and pessimistic values are each assigned probabilities such that the risk will be over-estimated (generally assuming a 90% probability for the reasonable value and 10% for the pessimistic value). Hence, SR 97 adopts a conservative, probabilistic approach to PA whilst avoiding the need to elicit probability distributions for ranges of parameter values. The only exception to this is for those parameters for which statistical parameter distributions are available, for example data with spatial variability. In other words, statistical distributions are only used for parameters where there is some kind of statistical data on which to base a distribution.

Based on expert judgement, with reference to previous safety assessments by SKB and other organisations, but with no guarantee of completeness, the following five scenarios were chosen for analysis:

- Base Scenario – in which present day conditions, including climate, persist. The evolution of the repository system is described in terms of the THMC processes to identify implications for safety, with a particular focus on considering what could lead to corrosion or failure of the copper canisters. It is concluded that under the base scenario conditions, the groundwater would remain oxygen-free and that the canisters would withstand corrosion throughout the 1 million year assessment period. Research evidence is presented to support the understanding of relevant processes but no radionuclide transport or risk calculations are performed as no radionuclides are released in the base scenario.
- Canister Defect Scenario – in which it is assumed that one canister in 4,000 has a 1 mm^2 hole which is not detected in the inspection procedures. In the pessimistic case it is assumed that 5 canisters have such defects. All other conditions are the same as for the base scenario. A timeline is developed for the scenario, describing the processes in key timeframes. The THMC process analysis considers water ingress to the canister, leading to corrosion of the iron insert, which in turn leads to gas production and the corrosion products generated blocking the hole. As corrosion and gas production continue this builds up mechanical stresses in the canister, eventually enlarging the defect and releasing gas to the bentonite buffer. It is considered that by about 700,000 years the iron insert will have almost fully corroded and the fuel itself will have corroded and dissolved, the buffer will be deformed locally, but the rock will have been subjected mainly to compressive stresses and hence should not be damaged. Radionuclide transport calculations for each of the three geological environments, using a finite difference model for a stochastic simulation of groundwater flow, aim to give a simplified, but pessimistic understanding of the system evolution. These calculations predicted doses would be more than three orders of magnitude below the regulatory limit. Other variants, in which for example it was assumed that there was no geosphere retention, or no diffusion resistance in the buffer or no solubility limitation for the fuel also did not give rise to unacceptable doses.
- Climate Scenario – based on conceivable sequences of climate events, including severe glaciation, postulated for each of the three sites. These climate sequences were used to analyse the THMC evolution of the repository in comparison to the base scenario. It was considered that a glacial climate may allow oxygen-rich water to infiltrate down to the bedrock as the oxygen would not be consumed in an organic soil layer, the soil having been eroded of organic material. However this was not considered to be a sufficient effect to lead to corrosion of the copper canisters. Likewise, the canisters are also calculated to be able to withstand the pressure increases that would occur due to glaciation. By describing the climate scenario in terms of the impact on the evolution of the repository, it is explained why the canister integrity is not threatened and hence no radionuclide transport calculations are required.
- Earthquake Scenario – simulates three site-specific earthquakes by analysing fracture data at the three sites, with the assessment focusing on whether an earthquake could breach canister integrity. 100 realisations of a stochastic fracture network model for each site were generated, with earthquakes represented by fracture displacements randomly distributed within a 100 km radius of the repository. The models were used to calculate the percentage of repository deposition holes which would be subjected to fracture movements greater than 0.1 m in 100,000 years and hence to show that earthquakes are not expected to lead to any damage to the canisters.
- Intrusion Scenario – analyses conceivable societal evolutions and future human actions that could affect the repository. It was calculated that it would require 25,000 boreholes to be drilled per year to a depth of 500 m in order to reach the 10^{-6} risk limit, assuming the probability of each drilling through a canister is 10^{-7} (that is a one in 10 million chance).

SR 97 is presented in two volumes with a summary report. The assessment documentation is supported by three further reports: a Repository System report (discussing the wastes, repository design and the three sites), a Process report (explaining the processes affecting the repository evolution in greater detail) and a Data report (explaining the derivation of the data used and data uncertainties). SR 97 is described as being written mainly for experts, but with parts expected to be of interest to non-specialists. Although very text-filled, with relatively few diagrams, the report has an easy to follow layout, with helpful summaries of each section.

Overall, SR 97 focuses on building confidence in the KBS-3 disposal concept through an understanding and analysis of the processes which could affect the isolation and containment of the wastes. The thorough analysis of processes with relatively little emphasis on quantitative calculations reflects the fact that no radionuclides are expected to be released from the canisters in the base scenario.

D4 SWEDEN, SITE-94 – A REGULATORY PA

D4.1 Context

SITE-94 [v] is a performance assessment conducted by the Swedish regulator, SKI. Like SR 97, it is based on the KBS-3 disposal concept for spent nuclear fuel. SKI had three aims for undertaking SITE-94:

- to develop their performance assessment methodology;
- to demonstrate how real data could be assimilated into a PA; and
- to develop a process for the systematic treatment of uncertainties.

These aims reflect the fact that at the time of SITE-94 Sweden was preparing for a site selection stage, hence the focus on the link between site data and PA, which was also a feature of the SR 97 assessment. The geological data for SITE-94 were taken from the Äspö hard rock laboratory. For the purposes of the assessment it was assumed that a repository would be constructed beneath the island of Äspö, although it is made clear that this is entirely hypothetical, indeed Äspö is formally excluded from consideration as a potential repository location.

Given that SITE-94 is a PA conducted by a regulator, its context and focus have some important differences compared to PAs performed by disposal agencies. In particular, there is no requirement in SITE-94 to conduct a quantitative evaluation of the safety of either the KBS-3 disposal concept or the Äspö site. Rather, the focus is entirely on developing the experience and capability for PA methodology, in order for SKI to be in a strong position to evaluate future assessments submitted by the Swedish disposal agency, SKB.

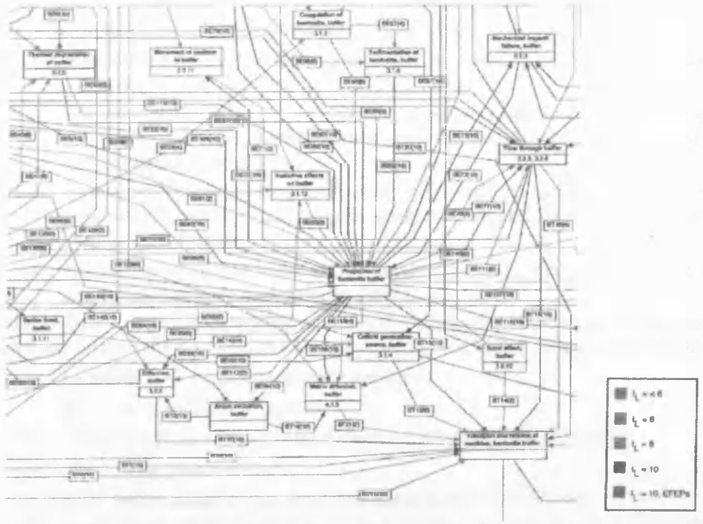
D4.2 Approach

The PA approach, and in particular the analysis of uncertainty, is central to the aims of SITE-94. A very methodical approach is adopted, based on the identification of features, events and processes (FEPs) and the following four steps, referred to as 'analysis levels':

1. System identification and definition. It is considered to be important to define a clear system boundary, in order to determine which FEPs are internal to the system and which are external. For SITE-94, the system boundary is set at the geosphere/biosphere interface, to avoid the need for biosphere modelling.
2. Scenario identification. A reference case scenario was established based on the system description and design basis assumptions, to address the 'internal' evolution of the system.
3. Modelling the repository evolution.
4. Consequence analysis.

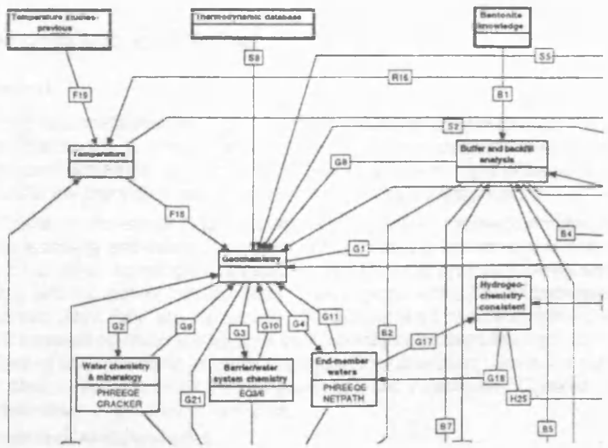
Two graphical tools have been developed as part of the PA approach for SITE-94. The first is a 'process influence diagram' (PID) which contains all FEPs relevant to the system definition, i.e. all the internal FEPs. Influences between FEPs are indicated by lines linking the FEPs and the relative importance of these influences is indicated by a classification from 1 to 10. The PID thus contains much information, but can appear quite daunting because of the number and complexity of the 'influence lines'. An example of a section of the PID is shown in Figure D2.

Figure D2 A section of the PID showing FEPs and influences (from SITE-94 Report [v])



The second graphical tool is termed an 'assessment model flowchart' (AMF). It is a relational database containing information on data sources and models and identifying a number of 'clearing houses'. A clearing house is a group of individuals responsible for specific areas of modelling, for example there are clearing houses for geochemistry and groundwater flow. All FEPs and influences on the PID are mapped onto the AMF, so that the AMF indicates the information flows that take place during modelling work and identifies interactions between different disciplines and modelling groups. An example of part of the AMF, showing clearing houses, models and information transfer links is shown in Figure D3.

Figure D3 A section of the AMF (from SITE-94 Report [v])



All internal, or system, FEPs are included within the 'Reference Case Scenario'. FEPs which are external to the system definition are termed 'EFEPs' and are used to define alternative scenarios. In total, 81 EFEPs were originally identified, but these were reduced to a more manageable number for assessment purposes by removing those which related to deviations from the repository design basis and those which were irrelevant to the Äspö site or the assessment basis (for example all biosphere FEPs were screened as outside the assessment basis). All EFEPs dealing with climate change were considered within a 'Central Scenario' and the remaining EFEPs were linked in various combinations to define eight 'supplementary scenarios'. In this way, the Central Scenario and supplementary scenarios are each developed from the Reference Case Scenario.

EFEPs are considered as modifying the process boundary conditions. Therefore, each scenario could be analysed by tracing the impacts of the EFEPs on the system PID. The impact of an EFEP would be reflected as changes to the importance levels of the FEP influences on the PID, thus leading to a new PID, and subsequently a new AMF to reflect the changed modelling requirements. This assessment process was developed not for mathematical completeness but to produce an auditable system that would allow interrogation by experts. The SITE-94 assessment follows the approach to analyse the Central Scenario only.

The Central Scenario provides a deterministic description of the likely climate state at Äspö over the next 130,000 years in the form of a climate sequence time line. It includes a description of the likely nature of the surface environment at each stage of the climate sequence and quantitative information on how these changes might affect the disposal system.

Consequence calculations focus on the Reference Case and Central Scenario, the aim being to demonstrate use of real geological and hydrogeological data in PA, rather than produce a full treatment of a comprehensive set of scenarios. The reference case design basis assumes that a single canister has an undetected manufacturing defect of a 5 mm^2

hole through the copper (note this is five times the size of the hole assumed in SR 97, showing the Regulator taking a more conservative approach), which leads to galvanic corrosion of the intact steel inner container, limited by the supply of reducible species at the copper surface. Modelling approaches and calculations include:

- radionuclide releases from the canister and near-field region;
- geochemical and rock mechanical models;
- detailed site-scale hydrogeological modelling using both a discrete fracture network model and a stochastic continuum model;
- one-dimensional flow evaluation using simple assumptions for the flow-field and boundary conditions, to identify critical factors for determining groundwater flow and transport parameters;
- modelling the effects of redox state on near-field transport, including time evolution of the redox state and its effect on the solubility and sorption properties of each radionuclide;
- time-independent modelling to explore variations in radionuclide release during the different climate states of the Central Scenario.

In addition to the quantitative modelling for the Reference Case and Central Scenario, the following supplementary scenarios were described in qualitative terms as illustrations:

- an alternative warm, wet climate evolution;
- tectonically induced seismicity;
- effect of a large mine or water well in the vicinity of the repository;
- inadequate shaft sealing;
- liquid waste injection into a fracture zone near the repository;
- liquid waste injection into a poorly sealed shaft, combined with local well/mine pumping;
- human impacts on the surface and on groundwater recharge; and
- mining impacts on the surface and on groundwater recharge.

SITE-94 is presented in two volumes, with an 85-page summary and a number of separate supporting documents. The documentation follows the 'analysis levels' of system description, scenario identification, modelling and consequence analysis. Numerical results are presented as fluxes of radionuclides from the near-field and far-field, but it is stressed that they are not predictions of actual impacts, just simple performance measures to put the releases from different cases into perspective. This is consistent with the stated focus of SITE-94 as a means of developing a PA methodology, rather than an assessment of the Äspö site.

Having said that, the assessment is quite detailed, giving the impression of rigour and complexity, above clarity. For example, the PID diagrams are very difficult to follow, but contain a lot of information and are presented as being comprehensive and systematic. There is a strong emphasis on information management, supported by the development of the AMF concept, which is seen as being an important tool for structuring the review of future SKB assessments.

Perhaps appropriately for a regulatory PA, there is rather more focus on analysing uncertainty and the use of conservative assumptions, than building confidence. Stakeholder confidence in a Regulator is likely to depend much more on scientific credibility, and in contrast to an implementor's PA, stakeholders may even derive confidence from the complexity of the approach, even if it lacks some clarity.

D5 SWITZERLAND, KRISTALLIN-I

D5.1 Context

Kristallin-I [vi] was conducted by Nagra, the Swiss National Cooperative for the Disposal of Radioactive Waste, which is responsible for research and development work associated with the final disposal of radioactive waste. Kristallin-I is an assessment of the final disposal of vitrified HLW in the crystalline basement rocks of Northern Switzerland.

Kristallin-I builds on the earlier Nagra project Gewähr [vii], which demonstrated the engineering feasibility and safety of a repository, but was not based on real site data. Kristallin-I is based on a geological dataset derived from the synthesis of regional deep borehole and seismic survey investigations. Two regions with different geologies, known as 'Area West' and 'Area East' are discussed. The project is an important milestone in the Swiss HLW disposal planning programme as it formally completes the regional investigations of potential siting areas in the crystalline basement. Since the publication of Kristallin-I, Nagra have continued their research role and investigated Opalinus clay as a potential alternative, sedimentary, host rock.

The stated aims of Kristallin-I are to:

- re-evaluate the crystalline basement using both moderately conservative and robust arguments;
- improve understanding of the roles of the engineered and geological barriers through quantitative analysis and sensitivity studies;
- identify key geological characteristics and desirable parameter ranges, to provide guidance for additional field work and site identification and to provide a basis for comparisons between crystalline and sedimentary host rock options; and
- develop and test a more complete safety assessment methodology, including a scenario development methodology.

Kristallin-I assesses the disposal of 2693 stainless steel flasks each containing 150 litres of vitrified HLW. Each flask would be placed inside a massive steel canister, surrounded by compacted bentonite clay and placed in tunnels excavated at around 1,000 metres depth in low permeability crystalline basement rock. The steel canister is expected to remain intact for at least 1,000 years and its prime role is to prevent water reaching the wastes whilst they are still generating heat. The wasteform itself is an important barrier as the glass will corrode very slowly over 150,000 years following contact by water. The role of the bentonite is to provide long-term stability, both mechanically and as a chemical buffer providing a stable chemical environment. As bentonite saturates it swells to prevent fissures for water ingress and its fine pore structure also prevents colloid movement, meaning that aqueous diffusion is the only significant radionuclide transport mechanism through the bentonite. It is these engineered barriers that provide the principal constraints on radionuclide release and migration in the Swiss concept. The main role of the geosphere is to provide mechanical protection to the engineered barriers, favourable geochemical conditions and sufficiently low groundwater flow. Therefore in the Kristallin-I assessment the geosphere is represented by conservative assumptions.

The Swiss regulatory criteria and principles are issued jointly by the Swiss Federal Nuclear Safety Inspectorate (HSK) and the Federal Commission for the Safety of Nuclear Installations (KSA). Three protection objectives are specified:

- Releases depending upon processes and events that are reasonably expected to happen shall at no time give rise to individual doses exceeding 0.1 mSv/yr.
- The individual radiological risk of fatality arising from unlikely processes and events, not taken into consideration in the above objective, shall at no time exceed one in a million per year.
- After the repository has been sealed no further measures should be necessary to ensure safety. The repository must be designed in such a way that it can be sealed within a few years.

The regulations do not specify any time-cut off for post-closure assessments, but state that assessments must be carried out at least until the maximum potential consequences have occurred. However, distant dose calculations are to be interpreted only as indicators and should be based on the use of reference biospheres and a population group with realistic living habits based on those observed today. There is a requirement to derive potential evolution scenarios but processes and events with extremely low probability or with considerably more serious non-radiological consequences, as well as intentional intrusion into the repository, are not required to be considered in the safety analysis.

D5.2 Approach

The performance assessment approach in Kristallin-I is entirely deterministic as there was judged to be insufficient data to justify parameter distributions. Nagra believe that there is greater uncertainty associated with the selection and representation of relevant processes than with scenario and conceptual model uncertainty. Therefore the use of deterministic calculations, by avoiding unrealistic sampled parameter combinations, is considered more instructive for the Kristallin-I context as it provides a more transparent illustration of system performance and sensitivity. With the use of conservative assumptions in Kristallin-I, the deterministic calculations tend towards upper bound estimates of the performance for the stated assumptions of a particular scenario. It is recognised that with more site-specific data and the requirement to optimise repository design, it will become desirable to reduce the conservatisms and introduce explicit representations of uncertainty and variability through PSA techniques.

Kristallin-I follows a FEP-based approach, in which scenario development is used both to identify FEPs and as an active tool for managing information and handling uncertainty. Three types of uncertainty are recognised in Kristallin-I:

- uncertainty in the selection and combination of relevant FEPs (this is explored through a 'Reference Scenario' and alternative scenarios);
- uncertainty in the way FEPs are modelled (explored by alternative model assumptions within the Reference scenario); and
- uncertainty in the rate and extent of important FEPs (explored by variations in the values assigned to model parameters) .

A five-staged approach to building the assessment is followed:

1. The disposal system is defined, system understanding documented and the basic characteristics for long-term safety identified (i.e. FEP elicitation, starting from those aspects of the system intended to provide safety)

2. A catalogue of all potentially relevant FEPs is developed and audited against international experience.
3. The 'System Concept' is developed. This is a description of the behaviour of the repository and its environment, incorporating understanding and interaction of all relevant FEPs.
4. The 'Safety Assessment Concept' is developed. This is a conceptual model of all those FEPs to be considered in the calculations. The Safety Assessment Concept is compared with available models to identify any important FEPs outside the existing modelling capability. The Safety Assessment Concept is then used to define the Reference Scenario and the alternative scenarios for consideration.
5. A 'Robust Safety Assessment Concept' is developed. This includes all potential detrimental FEPs, but only those safety-enhancing FEPs that can be relied upon. It defines the calculations required for a 'Robust Scenario'.

The above process naturally leads to a hierarchy of scenarios, starting with the Reference Scenario, moving down through the alternative scenarios to the Robust Scenario.

The Reference Scenario encompasses a set of reference model assumptions and reference parameter values, but also includes parameter variations and alternative model assumptions in the form of sensitivity analyses. Together these form the 'Reference Case'. The Reference Scenario assumes degradation of the engineered barriers according to conservative design performance; constant geology and hydrogeology based on understanding of present day conditions; a constant surface environment; and a temperate climate with subsistence agricultural practices. Where alternative possible models are identified, the one leading to the highest consequence is adopted for the reference model assumptions. For uncertain parameters generally two values are defined, one that is realistic but conservative and one that is pessimistic whilst still being possible – i.e. the second value is one that can confidently be believed to yield an upper bound on the consequence. The realistic-conservative values are used as the reference parameter values and the pessimistic values are used in sensitivity analyses.

The alternative scenarios considered in Kristallin-I include those that are considered to be realistic and expected as well as unlikely scenarios. The expected alternative scenarios include a range of possible future geological conditions and alternative future climate states that would affect surface environmental conditions (for example, glacial-interglacial cycling and a continuous warm climate). The unlikely alternative scenarios include unexpected engineered barrier performance (for example, ineffective tunnel/shaft seals), unexpected geoclimatic events and conditions and the drilling of a deep water well into the crystalline basement in the vicinity of the repository.

In the Robust Scenario, uncertainty is replaced by conservatism. It is still assumed that the engineered barriers evolve and perform according to their design function, but the most pessimistic representation of the geological barriers is used in that it is assumed that any radionuclides reaching the bentonite-host rock interface are transported immediately to the biosphere.

Not all radionuclides are included in the Kristallin-I assessment. Radionuclides were selected for inclusion based on the drinking water dose that would be received from a simple analysis using the canister design lifetime, glass corrosion rate and dilution in a near-surface aquifer (i.e. neglecting any retention in the engineered and geological barriers). Those radionuclides giving rise to a dose greater than 10^{-4} mSv/yr were included in the Kristallin-I safety assessment. Additionally, no gas release scenarios are included in Kristallin-I.

Overall Kristallin-I provides a sound safety assessment, with a good description of the important processes and the sensitivity of the repository performance to important FEPs. The assessment is transparent and systematic, exploring alternative possible assumptions. Presentation of a Robust Scenario that is still well within the regulatory performance requirements and the fact that no reliance on geosphere transport time is required to make a safety case provide considerable confidence.

Kristallin-I is presented in a single volume of some 400 pages. It is well written and technically detailed, with few illustrations. It is therefore aimed primarily at expert audiences. The conclusions are also published separately in a less technical report aimed at a more general readership, including the local population.

D6 FINLAND, TILA-99

D6.1 Context

TILA-99 [viii] is a performance assessment conducted by the Finnish disposal agency, Posiva. It investigates four alternative sites for a potential repository for spent fuel. The disposal concept is based on the KBS-3 design developed by the Swedes (see Section 0above) in which the spent fuel would be sealed in copper canisters with an iron insert and placed in vertical holes in the floors of horizontal deposition tunnels, some 500 metres underground in crystalline bedrock. The space surrounding the canisters would be filled with bentonite and the tunnels and shafts would be backfilled with a mixture of crushed rock and bentonite or natural smectitic clay. The distance between the deposition holes would be calculated on the basis of thermal analysis so as to limit the peak temperature at the rock interface. The repository design is such that the spent fuel canisters could be retrieved if necessary. Posiva state that they looked at other repository designs and chose the KBS-3 design because it is robust, flexible, technically uncomplicated and offers good post-closure safety.

TILA-99 is an update of an earlier assessment, TILA-96 [ix] and has been followed by an environmental impact assessment [x] and a 'decision in principle' to construct an underground rock characterisation facility for further investigation at the preferred site. The aim of TILA-99 was to inform this decision on which of four sites should be selected for underground investigation into its suitability for a spent fuel repository. As such, TILA-99 forms part of the site investigation process, linking information from the site characterisation, engineering design and research programmes.

Finnish regulatory criteria [xi] require calculation of the potential dose rate resulting from any releases from a repository to the human environment for a period that is 'adequately predictable', extending to 'at least several thousand years' following the closure of the repository. Posiva has taken this assessment period to be about 10,000 years. For times beyond this, the emphasis is on constraints on the release rate of radioactivity into the biosphere. The release rate constraint varies for different groups of radionuclides, depending on their radiotoxicity, for example, a maximum 0.1 GBq/yr is permitted for long-lived alpha emitters, 1 GB/yr for chlorine-36, iodine-129 and caesium-135 and a limit of 10 GBq/yr for carbon-14 and technetium-99. The regulations allow the calculated release rates from the repository to be averaged over a period of 10,000 years for the purposes of comparison with these constraints. However, there is an additional requirement that on a large scale the radiation impacts from a repository should remain insignificantly low and should not exceed the level of impacts from natural radioactive substances. This focus on release rate means no benefit can be taken for dilution in the biosphere.

During the period when dose rates are calculated, the regulatory criteria specify that the most exposed individual, assumed to be a member of a self-sustaining community in the vicinity of the repository, should not receive an annual dose greater than 0.1 mSv, whereas the doses to larger groups of the public must be insignificantly low. There are regulatory requirements to consider qualitatively the importance of unlikely disruptive events and wherever practicable to make comparisons of the consequences and expectancies of the potential radiation impacts from such events with the release constraints. There is also a stated requirement to discuss the potential impacts on flora and fauna.

D6.2 Approach

TILA-99 focuses on the normal evolution of a repository, with a number of sensitivity nalyses. There is an over-riding aim that the assessment should be transparent, robust, traceable and reproducible from the data provided in the single PA report. The emphasis is on simple, conservative models and deterministic calculations. The models used are primarily compartment models in which components of the repository system are represented by defined compartments and the movement of radionuclides between compartments is represented by transfer coefficients. All calculations are steady state, there is no transient or time variant modelling.

A scenario approach is followed in which the base case is the 'normal evolution scenario' in which the spent fuel canisters are assumed to remain intact for one million years and present-day repository conditions persist, unaffected by human activity. In this scenario there is no release of radioactivity. The normal evolution of the repository system, in terms of the climatic and geological conditions, is described for five timeframes: 1) the first 100 years; 2) 100 to 10,000 years; 3) 10,000 to 100,000 years; 4) 100,000 to 1,000,000 years; and 5) beyond 1 million years. Differences in the expected evolution of the four potential repository locations are discussed.

Additionally, a set of reference scenarios which consider the effects of canister defects, namely a small hole (5 mm^2), a large hole (1 cm^2) and a totally defective or 'disappearing' canister have been assessed.

Sensitivity analyses are applied to each of the reference scenarios. These sensitivity analyses consider the following parameter changes:

- alternative source term models – using realistic instant release fractions and release from the fuel matrix at a steady rate over 10,000 yrs
- very high solubility estimates for the reducing conditions in the near field – taking all conservatisms into account
- oxidising conditions throughout the near field
- transport along the tunnel – e.g. placing a deposition hole at a fracture zone intersection
- reduced penetration depth of matrix diffusion – limiting the distance over which rock matrix diffusion operates, thereby reducing radionuclide retardation
- dispersion in the far field
- alternative dose conversion factors
- realistic data – using realistic retardation data, release fractions and diffusion coefficients, with other data as in the reference scenarios.

Further, a number of 'what if?' scenarios are included, based on issues frequently discussed in Finland and in response to regulatory review comments. These scenarios consider the effects of:

- a combination of very high flow of non-saline groundwater and saline groundwater chemistry
- very poor bentonite performance – i.e. assuming the canister is surrounded by a backfill mixture of crushed rock and bentonite, instead of compacted bentonite
- displacement of contaminated water out of the canister due to gas generation
- glacial meltwater – modelled by assuming very high flow and oxidising conditions in the geosphere and in the buffer and backfill
- postglacial faulting – which is assumed to break the canister at 30,000 years, displace the bentonite, enhance flow and transport and cause oxidising conditions throughout the near-field and geosphere.

The final 'postglacial faulting scenario' gives the highest releases of all the scenarios considered above, but is still almost order of magnitude below the regulatory limit. An additional 'multi what if?' scenario was constructed in which there is assumed to be no canister, instant fuel dissolution, oxidising conditions throughout the near field, very high flow of fresh groundwater combined with saline water chemistry, matrix diffusion limited to 1 cm penetration and strong dispersion. This scenario gave a maximum dose rate from a single failed canister of 0.8 mSv/yr. This is above the regulatory dose limit of 0.1 mSv/yr, but is presented as being purely hypothetical and therefore no cause for concern.

All the above calculations only consider failure to a single canister. Multiple canister failures were considered by calculating the maximum number of canister failures which could occur in each scenario before breaching the regulatory limits.

Overall, the approach to PA in TILA-99 is clear and easy to understand, with confidence resting on the basis of the conservative modelling approach and the range of sensitivity studies, rather than the detail and complexity of the models. There is very strong reliance on the engineered barriers, particularly the confidence in the integrity of the copper canisters. This means there is less emphasis on the natural components of the system, which makes handling uncertainty much easier. There is no emphasis on modelling the biosphere (dose conversion factors from the BIOMASS reference well-drinking scenario are used to convert release rates to doses) and virtually none on modelling the geosphere (transport through the geosphere is based on a migration pathway streamtube concept, with rock matrix diffusion).

D7 US, YUCCA MOUNTAIN VIABILITY ASSESSMENT

D7.1 Context

Yucca Mountain is about 100 miles north-west of Las Vegas, USA, on unpopulated land owned by the US Federal Government. It is adjacent to the Nevada Test Site where more than 900 nuclear weapons tests have been conducted. This is a desert environment where the average rainfall is only 7 inches per year (95% of which runs off or evaporates). Yucca Mountain is being investigated by the US Department of Energy (USDoE) as a potential location for the disposal of 70,000 tonnes of spent nuclear fuel, including highly enriched fuel from the US Navy's nuclear-powered ships and submarines and high level radioactive waste from commercial and military purposes.

The purpose of the Yucca Mountain Viability Assessment [xii] was to provide the US Congress, President and public with information on the progress of the Yucca Mountain site characterisation project and to identify any critical issues that would need to be addressed before a decision could be made by the US Secretary of Energy on whether to recommend the site for a repository. (This recommendation was subsequently made in February 2002, on the basis of a final environmental impact statement, and approved by the US Senate in July 2002. This paves the way for the USDoE to submit a licence application for repository construction authorisation.)

The Viability Assessment includes the preliminary design concept for the repository, a total system performance assessment, the project plan and cost estimate for remaining work to complete the studies and submit a licence application and an estimate of the costs to construct and operate a repository in accordance with the design concept.

The repository would be constructed in the mountain, approximately 300 metres below the ground surface and 300 metres above the water table, in the unsaturated rock zone. The waste would be placed in long-lived packages. These packages would be double canisters, having an outer layer of a carbon steel, about 10 cm thick to provide structural strength, and an inner layer of corrosion-resistant high-nickel alloy, about 2 cm thick. These packages would be placed on steel and concrete supports in tunnels excavated in the mountain, with concrete floors. Approximately 100 miles of tunnels would be excavated, including access and ventilation tunnels. This disposal concept uses multiple barriers to isolate and contain the waste. The barriers are the chemical and physical forms of the waste itself (including Zircalloy fuel cladding), the waste packages, the rock and the semiarid climate. The Yucca Mountain concept is designed to limit water contacting the waste packages and hence provide a long waste package lifetime. Any release of radionuclides from the packages would therefore be slow and radionuclide concentrations would further be significantly reduced during transport from the waste packages to the accessible environment.

Other design features to increase safety are also being considered. These include, drip shields to prevent water dripping onto the waste packages, a ceramic package coating to further prevent corrosion and the use of a crushed rock backfill around the packages to raise the package temperature and protect them from rock fall or tunnel collapse.

The Yucca Mountain area is geologically stable and has changed little over the last million years. The geology is compacted volcanic ash, known as Tuff. The site is also fairly unique in that the local groundwater is isolated in a closed regional basin and does not flow into any rivers that reach the ocean. These favourable siting factors would also contribute to the containment of radionuclides.

The regulatory criteria for the Yucca Mountain Project are established as follows: The National Academy of Sciences was directed to provide recommendations on the general standards for radioactive waste management. The Environmental Protection Agency (EPA) is developing standards specifically for Yucca Mountain, consistent with these recommendations, for the protection of the environment from radiation. The Nuclear Regulatory Commission (NRC) will then use these standards to establish technical criteria for the construction, operation and closure of the repository. One such regulatory requirement is the ability to retrieve the wastes, if required, up to 50 years from the start of waste emplacement. During this period remote sensors would be used to monitor the packages, tunnels and surrounding rock.

However, other aspects of the regulatory guidance have yet to be finalised. In the absence of final guidance, the appropriate measure of repository system performance for Yucca Mountain has been taken to be the radiation exposure rate for average members of a critical population, with present-day lifestyles, living 20 km downstream from the repository. This corresponds to the closest existing well to the site. Repository performance is formally evaluated for a period of 10,000 years, with analyses extended to 100,000 and one million years to determine the time of occurrence for the peak dose.

D7.2 Approach

The Yucca Mountain Viability Assessment is described as a 'total system performance assessment', with the following five steps:

1. Develop and screen scenarios, using event trees to link FEPs that could lead to the release of radionuclides.
2. Develop models.
3. Estimate parameter ranges and uncertainties.
4. Perform calculations.
5. Interpret results, including further development or screening of scenarios, providing guidance to further work and compliance with regulatory requirements.

The stated aim is to determine the 'probable' behaviour of the system and therefore a probabilistic approach is adopted, with Monte Carlo sampling the primary method of uncertainty analysis. Uncertain parameters are sampled from PDFs, with results presented as cumulative distribution functions, giving the probability that the peak dose will be greater than a given value. For processes that are so uncertain there is insufficient data to justify a continuous PDF over a postulated range of behaviour, a high degree of sampling is not considered to be justified, and instead a few deterministic cases are considered, with the aim of bounding the likely behaviour.

Two approaches to Monte Carlo sampling have been followed:- 'lumping', in which all uncertainty is included in a single, comprehensive Monte Carlo simulation; and 'splitting', in which separate Monte Carlo simulations are performed for discrete models. The latter approach reflects the fact that the base case model represents a limited range of uncertainties (as it represents likely behaviour) in which some possibilities are treated separately in alternative models. This approach also recognises that simpler models may be more appropriate than overly complex models which may over-represent the actual state of knowledge.

The base case focuses on six radionuclides:- technetium-99, iodine-129, neptunium-237, uranium-234, plutonium-239 and plutonium-242. These radionuclides were selected because they are present in the wastes in significant quantities, they are long-lived, soluble, mobile and radiotoxic. The base case model considers how these radionuclides could be released from breached packages, dissolve in groundwater dripping through the repository, be carried down 300 metres to the water table and then be transported 20 km downstream to a well.

The assessment results are the calculated peak dose rates to the critical group using this well. These are presented either as probability distributions during a certain time, or as time histories over 10,000, 100,000 and one million years for specific samplings of input parameters. Presenting results as probability distributions does not hide the fact that the mean values of the Monte Carlo simulations tend to be dominated by a few low-probability, high-dose realisations. Most simulations used 100 realisations. The results were shown to be similar to those from a 1,000 realisation simulation, and hence it was concluded that 100 realisations was a 'good compromise between cost and precision'.

Regression analysis was used to study the importance of uncertain variables. The Viability Assessment shows scatter plots of peak dose against these variables, to illustrate correlations. The uncertainty associated with some key parameters may swamp the effects of others, therefore sensitivity studies were conducted in which the first set of key parameters were given fixed (mean) values to enable the sensitivity of other parameters to be identified in a second round of regression analysis.

The key processes for the safety of the Yucca Mountain repository concept were found to be water movement through the unsaturated zone above and below the repository, the effect of heat from the wastes on moisture in the rock around the tunnels and the movement of groundwater beneath the repository.

The sensitivity studies explored parameter ranges excluded from the base case. In addition, the following scenarios were considered to explore events outside the base case:

- Volcanism. This is judged to be unlikely, as large-scale volcanism in the area ceased 7.5 million years ago, the last small eruption was 75,000 years ago.
- Earthquakes. Yucca Mountain is in a seismically active area (a 5.6 magnitude earthquake was recorded 12 miles away in 1992), hence the repository concept has been designed to withstand earthquakes.
- Accidental human intrusion. This is an unattractive location for exploration. However, the regulations define a scenario in which a waste package is penetrated by drilling. This would lead to increased dose rates if waste was carried down the drill-hole to the water table. In this scenario, only the consequences, not the probabilities, of human intrusion are considered.
- Criticality. Design specifications would prevent a criticality inside a package. It is considered very unlikely that sufficient accumulation of fissile material for a criticality could occur outside a package, but even if it did happen, it would only have a minor effect on the repository performance. An explosive criticality event is not judged to be credible.

The Yucca Mountain Viability Assessment is published in the form of a 40-page summary report with a CD-ROM insert containing the following five volumes:

1. Introduction and site characteristics (171 pages)
2. Preliminary design concept for the repository and waste package (325 pages)
3. Total system performance assessment (523 pages)
4. License application plan and costs (233 pages)
5. Costs to construct and operate the repository (145 pages)

The summary report is written in simple language with pictures on every page. The main volumes use more technical language, but each contains a glossary and starts with an overview of that volume. Diagrams and icons are used throughout. There is a strong focus on the practical aspects of the repository, with good descriptions of its proposed design and operation. In describing repository performance, the focus is on safety and zero releases, with an emphasis on continual seeking of improvements, summarised by the comment, 'the release of any radionuclides is reason for concern and motivation for seeking improvements in the repository design'. However, alongside this there is recognition that uncertainties can be reduced but never totally eliminated. Overall, the Viability Assessment is presented as confident, with a clear message concerning the suitability of the Yucca Mountain site, whilst acknowledging that there will always be some uncertainties.

D8 US, WIPP COMPLIANCE CERTIFICATION ASSESSMENT

D8.1 Context

The Waste Isolation Pilot Plant (WIPP) is a deep radioactive waste repository excavated about 655 metres underground in a bedded rock salt formation near Carlsbad, New Mexico.

The rock salt is around 600 metres thick and 225 million years old with no significant groundwater flow. WIPP has the capacity to contain over 175,000 m^3 of transuranic ('TRU') wastes. These are wastes containing alpha-emitting transuranic radionuclides with half-lives greater than 20 years, broadly similar to ILW.

Most of the waste is packaged in mild steel drums or standard waste boxes (thick-walled steel canisters are used for the 4% of wastes requiring radiation shielding and remote handling). The waste containers are stacked in disposal rooms and surrounded with bags of crushed magnesium oxide (MgO). This MgO acts as a chemical barrier by consuming any carbon dioxide produced, consuming significant quantities of water that may seep into the repository in the form of brine, and maintaining the CO_2 partial pressure and the brine pH within ranges that lead to lower actinide solubilities.

The disposal rooms are grouped in 'panels'. Two panels have already been excavated and a further six are planned. Each panel of disposal rooms will be closed with a rigid concrete barrier and a concrete isolation wall (creating an isolation zone between them). This panel closure system protects workers during repository operations and also limits liquid and gas migration post-closure.

The four shafts that connect the repository with the surface facilities at the WIPP site will be sealed, upon completion of disposal operations, using 13 discrete components, including a 170 m long compacted salt column. These seals are designed to limit water from the repository reaching the accessible environment, restrict water flow through the seal, protect against component structural failure, limit subsidence and prevent accidental entry into the repository.

After closure of the repository, the natural process of creep in the salt host rock will gradually crush the waste containers and bags of MgO so that the wastes become entombed within a period of 500 years. Therefore, the waste containers themselves are not an important long-term safety barrier and neither are the panel closure walls. These physical barriers are not credited in the performance assessment calculations.

The licensing process for the operation of the repository required the preparation of a Compliance Certification Application (CCA). This is an assessment of all aspects of the repository against specified regulatory criteria. The WIPP CCA [xiii] was submitted in October 1996, certification was achieved in May 1998 and the repository started to receive waste in March 1999. It is planned that the repository will be operated for 35 years, with re-certification being required every 5 years.

The regulations for WIPP are based on health and environmental objectives. They specify containment requirements, individual protection requirements, groundwater protection requirements and assurances concerning active and passive institutional controls, multiple barriers, monitoring, resource extraction disincentives and the feasibility of waste removal.

The standards and criteria for limiting radiation releases are set by the US Environmental Protection Agency (EPA), which is also responsible for ensuring that the criteria are met. The regulatory annual dose limit for an undisturbed repository is 0.15 mSv, which compares to the annual average exposure to radiation for all US citizens of 3.6 mSv. In addition, the regulations require inadvertent intrusion into the repository to be considered and define the drilling frequency to be used for such calculations, based on local historical records. The disposal system is required to provide a reasonable expectation, based on performance assessments, that the cumulative releases of radionuclides to the accessible environment for 10,000 years after disposal, from all significant processes and events that may affect the disposal system shall:

- have a likelihood of less than one chance in ten of exceeding the specified release limits and

- a likelihood of less than one chance in 1,000 of exceeding ten times the quantities calculated.

This requirement necessitates a quantitative, probabilistic assessment in order to construct a complementary cumulative distribution function (CCDF) for comparison with the above regulatory constraints on probabilistic releases. In this respect, the regulatory criteria effectively define the performance assessment approach.

D8.2 Approach

The approach adopted in the WIPP CCA [xiii] aims to provide a reasonable estimate of the expected performance of a real repository. Unlike many assessments of repository concepts, the approach is not intended to be biased towards a conservative outcome. The approach is highly probabilistic, as defined by regulations, and aims to take account of the various uncertainties in a reasonable manner. However, where realistic approaches to incorporating uncertainty are unavailable or impractical and where the impact of the uncertainty on performance is small, reasonable conservative assumptions have been adopted to simplify the analysis.

A structured process was followed, starting with a FEP list compiled from international studies. A FEP screening process eliminated those FEPs irrelevant to the WIPP repository, those excluded by regulations (for example those not expected to occur within the regulatory assessment period of 10,000 years), FEPs with very low probability and FEPs with very small consequence. FEPs arising from operational, construction or decommissioning errors were screened on the basis of the quality control procedures in place at WIPP. FEPs associated with changes in land use, demographics, and anthropogenic climate change were also eliminated as the regulations specify present day assumptions for assessment calculations. This left 83 FEPs which were grouped into three major categories: natural, waste- or repository-induced, and human-initiated. The FEPs were used to define a normal evolution scenario (containing only natural FEPs) and variant scenarios for which conceptual, mathematical and then numerical models were developed. Due to the complex, non-linear nature of many of the processes being represented, the numerical models were often iterative, approximate solutions to the mathematical models (equations).

A range of computer codes was used for modelling different system components. Within a simulation, parameter values and disposal system conditions were passed between relevant codes several times, providing a loose coupling, rather than feeding results from component sub-models into a single overall system model. This approach allows time-dependent coupling, for example, permeability and porosity values are coupled to changes in pressure as the salt creeps. The evolution of the chemical environment is modelled, including microbial degradation of cellulosic materials, plastics and rubbers and the corrosion of steel. Transport models consider the potential for brine flow down the shaft, gas flow up from the repository to the compacted salt column and upward brine flow through the shaft seal system.

Together, the computer codes consider more than 1,800 parameters. However, on the basis of sensitivity analyses, only 57 of these were varied in the assessment calculations, using Latin Hypercube Sampling. The sensitivity analyses indicate the relative importance of each sampled parameter in terms of its contribution to uncertainty in the estimate of the repository system performance. For example, one of these parameters was the potential recharge, which determines the rate at which water is added to the water table in the groundwater model. This parameter acts as a 'climate index' by representing all the climate-related factors that might affect groundwater flow. Values for this climate index parameter were calculated on the basis of 17 transient and 54 steady-state regional 3-dimensional

groundwater flow simulations, in which different recharge rates and assumptions concerning regional rock properties were applied to determine the effect on potential recharge.

In the normal evolution scenario, for an undisturbed repository, gas generation from corrosion and microbial degradation is expected to occur and will elevate the pressure within the repository, but not significantly above lithostatic pressure as fracturing within the surrounding rock will provide pathways for the gas to escape. Brine flowing out of the repository may transport actinides (both as dissolved species and colloids) but calculations indicate no significant releases to the biosphere are expected within the 10,000 years assessment period.

No potentially disruptive natural FEPs (such as large earthquakes) are likely to occur during the regulatory timeframe, therefore human intrusion provides the only potential mechanism for significant releases. The human intrusion events considered are mining and drilling. If a borehole was drilled into the repository, it has been estimated that there would be an 8% chance of the borehole also penetrating an underlying pressurised brine reservoir, thus providing an additional source of brine into the repository. This would not be a significant issue if the brine immediately flowed to the surface as it would not have had time to mix significantly with the waste. However, such a scenario could increase the volume of contaminated brine released in any subsequent drilling event. Therefore, five types of human intrusion scenario were identified:

- Mining (M)
- Drilling – penetrating a pressurised brine reservoir (E1)
- Drilling – brine reservoir not penetrated (E2)
- Drilling – an E2 event occurring after an E1 event (E1E2)
- Drilling and mining (ME).

These scenarios form a core set of idealised futures for which assessment calculations were performed. Of course, in reality, one or more of these scenarios could occur. Potential sequences of future events were generated by randomly sampling six parameters associated with the above five scenarios, namely:

- the time interval between drilling intrusions;
- the location of the drilling intrusion;
- the activity of waste penetrated by each intrusion;
- the standard to which an intrusion borehole is sealed when abandoned (regulations require plugging and abandonment of boreholes to be consistent with current practices which require protection of groundwater and other natural resources);
- whether a brine reservoir is penetrated; and
- the occurrence of mining.

This random sampling was used to generate 10,000 equally likely independent futures for assessment. In other words, potential future evolutions of the repository system were created by direct probabilistic sampling of possible events leading to uncertain futures, rather than using an *a priori* definition of possible futures. A scenario can be regarded as a subset of futures having similar occurrences.

In these human intrusion scenarios, five routes were identified by which radioactivity could be released:

- cuttings – including material intersected by the drill rotary bit;
- cavings – material eroded from the borehole wall during drilling;

- spallings – solid material carried into the borehole during rapid depressurisation of the region
- direct brine releases – contaminated brine flowing to the surface during drilling; and
- long-term brine releases – occurring after the borehole is abandoned.

The assessment results in the WIPP CCA are presented as CCDFs of repository releases. In line with regulatory requirements, these plots indicate the probabilities of the maximum radiation releases for each scenario. They do not show at what time the maximum release is expected to occur or how releases would vary over the assessment period.

The CCDF output results are obtained by combining the results of numerical simulations performed for a given set of sampled model parameters with the probabilistic futures determined by the random sampling of the human intrusion event parameters. A separate CCDF is constructed for each set of sampled model parameters. Building a CCDF necessitates calculating the consequences of each probabilistic future by scaling and interpolating the results from the core set of idealised deterministic futures (the M, E1, E2, E1E2 and ME scenarios). Each of the 10,000 randomly generated futures is assumed equally likely to occur and hence this calculation provides a mechanism for factoring scenario probability into the CCDF. Calculations were performed for 100 different sets of sampled model parameters, leading to 100 CCDFs, which were shown to be converged, thus enabling the mean CCDF to be calculated.

The WIPP CCA is a regulatory application for repository operation. It is therefore technically very detailed and mathematical with the emphasis on systematically demonstrating how each of the regulatory criteria is satisfied. It is aimed at the regulatory bodies and technical peer reviewers. A 'citizen's guide' summary of the CCA has been produced for wider public audiences, which also explains ways in which members of the public can become involved in the WIPP decision-making process.

The CCA contains nine main chapters which discuss the background to the WIPP CCA, site characterisation, descriptions of the waste and the facility, demonstrations of compliance (which includes performance assessment modelling), quality assurance aspects and the results of peer reviews. These chapters are supported by 55 appendices and in hardcopy the complete CCA contains over 70,000 pages and occupies almost two metres of bookshelf space. However, the WIPP CCA was prepared to be primarily presented in CD-ROM format, with hyperlinked text, explanatory pop-up windows and extensive search facilities.

Overall, the approach and presentation of the WIPP CCA are both largely defined by the regulatory criteria that the assessment is addressing. In particular, the comprehensive scenario analysis, in which very large numbers of possible future repository system evolutions are assessed, is possible because of the extensive FEP screening on the basis of regulatory definitions.

D9 CANADA, AECL 1994 POST-CLOSURE ASSESSMENT OF A REFERENCE SYSTEM

The AECL EIS [xiv] was judged to show a repository was acceptable from a technical point of view but not from a social standpoint as it had not been demonstrated that there was sufficient support from the public.

Deterministic calculations using median values of PDFs of input parameters, to illustrate radiological system behaviour. Probabilistic calculations were used to calculate risk for comparison with the regulatory target.

D10 UK, NIREX ASSESSMENTS

Nirex has gone 'full circle' in terms of the stages in a repository development programme. During the late 1980s and 1990s Nirex was investigating potential sites for a deep geological repository, and conducted increasingly detailed PAs, culminating in the Nirex 95 [xv] and Nirex 97 [xvi] assessments of the preferred site at Sellafield. Following the failure of the RCF public inquiry and the consequent loss of the Sellafield site, Nirex has been taking stock and seeking to learn from its own history and from others regarding the repository development process. One aspect of this learning process has been a reconsideration of the Nirex disposal concept, which now allows for a delay in the decision to backfill the repository with cement, seal and close it – referred to as the Nirex phased disposal concept. Nirex has undertaken generic assessments in support of the development of this concept. For example, Reference [xvii] describes the chemical, physical and hydrogeological processes affecting the long-term performance of a repository and provides illustrative calculations of the performance of the disposal concept in six generic geological settings. Nirex has also developed a generic performance assessment (GPA) in which the properties of the geological setting are chosen to ensure that the repository performance is consistent with the radiological risk target set by the Regulator [xviii].

i JNC, *H12: Project to Establish the Scientific and Technical Basis for HLW Disposal in Japan, Project Overview Report*, Report JNC TN1410 2000-001, Japan Nuclear Cycle Development Institute, Japan, 2000.

ii PNC, *Research and Development on Geological Disposal of High-level radioactive Waste, First Progress Report (H-3)*, Japan, 1992.

iii ONDRAF/NIRAS, *SAFIR 2: Safety Assessment and Feasibility Interim Report*, NIROND 2001-06E, Belgium, 2001.

iv SKB, *SR 97 – Post-closure Safety. Main Report, Volumes I and II*, SKB Technical Report TR-99-06, Swedish Nuclear Fuel and Waste Management Company, Stockholm, Sweden, 1999.

v SKI, *SKI SITE-94 Deep Repository Performance Assessment Project*, SKI Report 96:36, Stockholm, Sweden, 1996.

vi Nagra, *Kristallin I Safety Assessment Report*, Nagra Report NTB 93-22, Nagra, Switzerland, 1994.

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viii T. Vieno and H. Nordman, *Safety Assessment of Spent Fuel Disposal in Hastholmen, Kivetty, Olkiluoto and Romuvaara TILA-99*, Posiva Report 99-07, Finland, 1999.

ix T. Vieno and H. Nordman, *Interim Report on Safety Assessment of Spent Fuel Disposal TILA-96*, Posiva Report 96-17, Finland, 1996.

x Posiva Oy, *The Final Disposal Facility for Spent Nuclear Fuel, Environmental Impact Assessment Report*, Finland, 1999.

xi STUK, *Proposal for General Regulations for the Safety of the Disposal of Spent Nuclear Fuel into Bedrock*, Finland, 1998.

xii U.S. Department of Energy Office of Civilian Radioactive Waste Management, *Viability Assessment of a Repository at Yucca Mountain: Overview*, USA, 1998.

xiii U.S. Department of Energy Waste Isolation Pilot Plant, *Compliance Certification Application 40 CFR 191 Subpart B and C*, USA, 1996.

xiv B. W. Goodwin et al, *The Disposal of Canada's Nuclear Fuel Waste: Post-closure Assessment of a Reference System*, Atomic Energy of Canada Limited Report AECL-10717, COG-93-7, Canada, 1994.

xv *Nirex 95: A Preliminary Analysis of the Groundwater Pathway for a Deep Repository at Sellafield*, Nirex Science Report S/95/012, 1995.

xvi *Nirex 97: An Assessment of the Post-closure Performance of a Deep Waste Repository at Sellafield*, Nirex Science Report S/97/012, 1997.

xvii L. E. F. Bailey and A. K. Littleboy, *The Nirex Repository Concept: Evaluating Performance*, Nirex Report N/011, 2000.

xviii L. E. F. Bailey, S. Norris, M. M. Askarieh and E. C. Atherton, *Generic Performance Assessment*, Nirex Report N/031, 2000.

Appendix F

VISUAL LANGUAGE: EXTERNAL REVIEW

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F1 INTRODUCTION

F1.1 The review

We were invited to review the outputs to date of the visual language project. These comprised:

- The Visual Framework
- Options Diagrams
- Argumentation Maps for rock matrix diffusion and solubility

These were accompanied by a draft document entitled 'The application of Visual Language to communicating the scientific basis of deep disposal', which was provided to give background to the VL project within Nirex, but not included for review. A further argumentation map on sorption was provided at the workshop (see below). The review comments in this report refer primarily to the material provided for review; however, as will be seen, respondents emphatically contextualised this material within a wider framework of Nirex's activities and the problems of radioactive waste management.

F1.2 Objectives for review

The review was asked to consider the following:

- Does the visual language work help make science more accessible to the non-scientist?
- Does the visual language work help clarify where there are areas of uncertainty?
- would visual language contribute to the debate about radioactive waste management, and if so, how would it best be used?
- Are there any biases (obvious or hidden) within the material?
- Is the structure of the material sensible?
- Any comments about the presentational form of the material?

The review is not, however, restricted to these questions, but also reports on other issues that arose in responses to the material.

F1.3 Review participants

To contribute to the review process, a workshop was convened in the Institute of Environment, Philosophy and Public Policy (IEPPP)[1] at Lancaster University, on 15th February, 2002. The workshop was attended by nine members of the University, largely from social science and humanities faculties, and by Anna Littleboy and Rachel Western from Nirex. It was led by Jane Hunt. AL and RW were primarily observers rather than discussant, and were briefed not to participate in discussions unless asked a direct question. After discussing the material, each UL participant produced a note of their responses, which are used as a major contribution to this report.

Three further colleagues also reviewed the material and provided comments.

[1] CSEC is part of IEPPP.

The reviewers were primarily versed in social science and humanities traditions of thought, and it is this perspective which is primarily represented in this review. Some reviewers, however, have training in the natural sciences and mathematics, and the synthesis of this with a social science perspective is particularly useful. As well as the variety of intellectual perspectives represented, some reviewers have also worked professional in particularly pertinent fields, including design, provision of public information, and teaching and learning, and provided comments from these perspectives

F2 REVIEW

Responses and commentary to the VL material are grouped below under a number of headings which reflect the considerations identified by Nirex and the areas discussed by reviewers. The analysis is conducted partly in terms of considering the 'messages' implicit in particular choices about ways in which to represent the world: that is, that material is 'read' not just in terms of content, but also in terms of the way in which it is presented (as well, of course, in terms of who is presenting the material).

Notes:
- double quotation mark indicate words or phrases used by workshop participants and other reviewers.
- the term 'reader' refers to users of the material, be they literally reading it, looking at it, or other.
- individual slides are referred to in the form vl8 (8th slide in the visual language sequence), sol2 (2nd slide in the solubility sequence), etc. Slides are numbered, for clarification, on the accompanying A3 reproduction.

F2.1 Enthusiasm for the VL Project

There is considerable enthusiasm for the fact that Nirex are undertaking the VL Project. The project demonstrates Nirex's commitment to exploring ways of making the science of deep storage/disposal more easily understandable by the lay person, and this was welcomed.

The value of the VL project is not solely, or even necessarily primarily, in the product, i.e. in the production of materials which contribute to scientific accessability. There is a very significant value in the process of producing those materials – that is, in grappling with the problems inherent in such a project in the particular context of Nirex's development within the broader radioactive waste arena.

Enthusiasm for the product to date has to carry the caveat that the product is not complete and there is obviously further development work necessary.

The approach – using visual language – is also welcome: clearly there are advantages to be gained from the combination and versatility of language and visual images. The ways in which issues can be mapped, both through a combination of slides and on individual slides, is also very useful, although this potential has limited use in the materials produced so far.

The potential for use of the material to encourage and enable dialogue and two-way communication is also welcome, with the caveat that in its present form, the reader is positioned as a passive recipient of authorised knowledge.

F2.2 Scope of material

The VL project has scoped the scientific map of radioactive waste management, and selected particular topics for detailed working up. The context of these topics is presented as being the overall scientific requirements of deep geological disposal (or phased underground disposal).

The social, ethical, political and economic context is entirely invisible, either as a consideration in relation to the way science is produced, or a consideration in relation to the other dimensions of radioactive waste management. It is clear from the responses of reviewers[2], and to work with the general public, that these other dimensions are of significant importance to them, and to make them invisible (which is a de facto result of not including them), carries its own message – that these dimensions are not important to Nirex. These dimensions are, however, generally seen as significant and necessary components of discussion and deliberation.

The slide entitled 'key questions'[3] makes this very clear. In response to the question 'radioactive waste – what is the problem?' we are given a number of responses – all in terms of rock, water movement through rock, etc. Not only does this presume deep geological disposal on the Nirex model, but it makes no reference whatsoever to any non-scientific issues. The question should be 'radioactive waste – what are the scientific issues in relation to deep geological disposal', not claim the entire territory of radioactive waste problems and then define them so narrowly. As the second slide in the series, this slide is in a key position in relation to the subsequent material, defining the scope and the importance of what is to be considered. Slides vl3, 4 and 5 compound this error, and add in the idea that these scientific questions are framed within a requirement to protect humans – not the environment – from radioactivity (see discussion below). This narrow framing is off-putting, offensive, and inappropriate. A much wider 'funnel' at the beginning of the material is required, which at least acknowledges the breadth of the issues, and then goes on to focus on specific sub-areas.

It appears possible that the VL approach is also suitable for including the non-scientific dimensions – and even for relating these to scientific dimensions. Ethical issues, such as the distribution of impacts across populations, across space, and across time, and social issues, such as institutional arrangements and responsibilities, and the process of decision making, would be a valuable addition. Economic issues – from the comparative cost of different disposal options to the complexities and argumentation regarding discounting practices, would also be a worthwhile inclusion.

However, it is not essential that all conceivable parts of the issue are fully worked up before the material can be used. So long as there are indications of awareness of the other dimensions signalled in the material presented (in the overall 'funnel' and cross-

[2] Both at Nirex and at IEPPP
[3] I call this vl2a; it appears to be missing from the A3 sheets, but in the A4 sheets is the second slide in the visual framework series.

referenced/linked to existing material), this demonstrates that Nirex are aware of these dimensions[4].

The selection of detailed topics for working up into argumentation maps is a sensible exploration of the method, and to set this within the overall map of Nirex's scientific method is useful, both to communicate this to others and for the value of discussion within Nirex which articulates different understanding of the nature of the parts of Nirex and their relationship to each other.

F2.3 Messages in representation choices

The way in which something is represented carries its own message. Design and stylistic choices themselves communicate particular messages, including messages about how the authors of the material wish to present themselves. No design choice is neutral.

2.3.1 Design

The particular points regarding design can be summarised in one comment "this is crying out for a professional designer – and it's a plum job for someone"[5]. This captures the enthusiasm and potential of the project – and the recognition that the development of VL in Nirex is in its early stages.

The inconsistency of styles and use of common clip art, in particular, contribute to a message of amateurishness, which contradicts the storyline that the science of radioactive waste management is under professional control.

The use of clip art in relation to more social/philosophical issues, and of graphs in relation to 'hard science' (which most readers found difficult to grasp), trivialised philosophical questions and issues of uncertainty, and emphasised 'important, serious, but too complicated for you to understand', scientific issues.

The relatively straightforward poster of the different options was generally thought to be very good as it stands. There was enough information to absorb relatively easily; the pictures gave straightforward visual clues to what was being talked about (these pictures could be used as 'logos' for further discussion of different options – cf discussion of structure and style) and it was appreciated that this poster was only intending to provide an initial identification of the different options which have been raised as possibilities. That it was clearly stated that options were not considered further in this presentation is also positive, although it begs the question of 'why not? why the focus on deep disposal?'.

Nirex's motivation in producing this material is, and is likely to remain, suspect for at least some users. If Nirex's intentions are honourable, this needs to be more clearly and consistently indicated in the material: acknowledging uncertainty and ignorance is one means of doing this, and many other comments are also relevant to the (sub-textual) communication of intent.

[4] There could still be the criticism that Nirex has chosen to focus on the narrowly scientific issues, or that they have prioritised working up these issues: there needs to be a clear statement of where Nirex sees itself in relation to the broader issues vis a vis inclusion in the VL material.
[5] This comment was made by a PhD student working on the philosophy of aesthetics, who was a professional designer in a previous life.

2.3.2 The feel of the material

"it makes me think of sex education – it's sterile"
The analogy here was extended: we know that the complexity and multi-dimensionality of sex is not represented in standard sex education materials. The emotional content – whilst often referred to – is not invoked in the forms of representation selected. Similarly, this material makes no reference to the human dimensions, either seperately or in relation to the scientific material. This is compounded because there are no photographs or 'real' images, which would humanise and contextualise the material, making it translatable into the real world rather than an abstract exercise (when sites are identified, making material translatable in the real site will be a necessity). Translation is especially necessary as the subject matter is largely invisible. Making it visible – e.g. through photographs of real rocks, perhaps magnified in insets to show rock structure – is part of making it real.

2.3.3 Tone and intent

The referents in some images were seen as patronising by some respondents (the cup of tea was particularly problematic). The simplicity of the representation of the science (which is stylistic rather than structural) leads to an interpretation that the intent of the material is to be believable – not to be understandable, which includes the ability to be critical – as the user presumes that the science must be more complicated than is being represented. Thus, simplicity is in tension with accessibility, although this can probably be dealt with by being more explicit about the different levels of simplicity/complexity represented by the material.

2.3.4 Different messages to different audiences

As one reviewer pointed out, he (as a "binary speaker") would not take the material seriously unless it included graphs and other forms of 'mathematical language'. Whilst it is inevitable that different readers will derive different messages from both the design and content of the material, this does not mean that design choices should overlook the impacts on a variety of readers. The use of mathematical language provides a form of scientific credibility even for the non-scientific reader – but, as discussed below, it can also give rise to the suspicion that uncertainty and other assumptions are hidden within the scientific representation. This can be addressed as a question of intent – for example, is the intention to provide an insight into the scientific understanding, or to convince readers of the credibility of the scientific understanding? In the first case, mathematical representations are probably necessary, but need more explanation for the non-scientist. In the second, 'blinding with science' will disempower some readers, and alienate others, but may nonetheless assist credibility.

2.3.5 Two way communication

There is no sense in the material that questions are allowed – no clues or invitations that questions by the user are possible. Where questions are used, they are within the flow of the material, used as indicators that a logical step is being taken – and the questions are answered, rather than being left open for the reader to consider. The reader is essentially passive.

This is a major criticism. The construction of a passive reader essentially reflects the 'deficit model' approach, whereby an ignorant public is seen as in need of 'correct' information. Of itself, this approach communicates a separation between experts and lay readers, and suggests that the authors are claiming the correctness, and unchallengeability, of their statements. A more dialogic approach, by contrast, suggests of itself that the authors are open to discussion and re-consideration of their claims.

2.3.6 Mapping

The ability to map the shape of an issue, and of sub-areas of an issue, is only partially developed within the material so far, yet the visual language approach has considerable potential as a means of representing the 'landscape' of radioactive waste management. The sode vl12 was generally received as a useful contribution in giving a sense of the larger landscape of the science. The comments made regarding the invisibility of social, ethical and other dimensions suggest that the attempt to produce the 'big map', and to clarify the position of scientific and technical endeavour within this larger multi-dimensional map, would be worthwhile in terms of:

- Enabling readers to locate and make sense of the larger landscape (and, if suitably linked to further information resources, to pursue interests and questions in these areas)
- Communicating that Nirex is very conscious of the larger landscape
- Through the process of production of such a map, assisting Nirex in its understanding of the larger landscape.

F2.4 Structure and Style

2.4.1 Inconsistency

The structure of the material is not clearly reflected in the style of representation, and this adds to the readers' difficultly in navigating a pathway through the material. Using different images, fonts, colours etc consistently to indicate different sections and to signpost, as discussed below, are necessary. These stylistic choices can be used very effectively to assist clearer visibility of the structure of the material; as yet, this does not seem to have been incorporated adequately.

The green, blue and yellow boxes used in Fig 2 of the accompanying note are not used consistently even within the note (on the following page, argumentation map topics are pink) and are not reflected in the VL materials (e.g. vl10,11,12,13), yet could be applied as a structuring framework (e.g. all argumentation map main heading boxes backgrounded in yellow). These boxes change again in the third slide of the solubility AM (not included on the A3) where a theory, obvservation/investigation, and modelling matrix is presented but then, apparantly, abandoned, or at least not clearly visible in the structure of the subsequent material[6] The visual clues to the structure and interpretation of the material *must* be made consistent.

The structuring of the argumentation maps into 'general theory' 'support from general observation' and 'hypothesis' looks fine in theory, but has not been well used on the page. The slides following the title 'general theory' do not seem to provide a clear statement of the 'theory' (which theory – e.g. solubility: that things dissolve, that things dissolving is important for the repository because of x, y and z, that the wastes will dissolve – it's not clear what the theory is, although the heading on sol3 of 'water will get to the wastes' suggests that this is the theory). 'support from general observation' gives us the cup of tea analogy in sol6, and a complicated graph relying on two unfamiliar concepts in rmd6 – very different interpretations of what general observation is, and giving very different messages, neither of which, to my mind, provide an indication of what sort of support there actually is (which would include: lots of data, lots of experiments, everybody agrees this is the case, and/or it being a commonly observed phenomena e.g. in tea). In both maps, the hypothesis is phrased as a question – I

[6] This slide also includes the problematic phrase 'What isn't known?' as if this can be comprehensively identified – see comments on uncertainty.

was taught, as were my colleagues, that a hypothesis is a *statement*. There is thus inconsistency with the interpretation of the headings, and inconsistency with common understandings of terms, which does not aid understanding what the material is about or what it is trying to do and how. If the terms theory, evidence and hypothesis are to be used, they need explanation and consistent application.

2.4.2 Logic

The logic of the structure is scientific. There is, however, a visual logic to be considered – as one designer put it "I wouldn't start from here, I'd start from the village hall". That is, thinking about issues such as display space, the way people move around material, and the way the eye moves through material, are important considerations in relation to the scientific logic and communicative intent.

2.4.3 Glossary

Even at this stage of development, the materials would benefit from a glossary: the presentation of so many new words makes this essential for the reader. For electronic versions, this should be hyperlinked. A glossary provides a useful 'check' for users, and reminds them of the meaning of terms they may have forgotten, or which are explained in another section. Glossary definitions should avoid the use of specialised language, and where this is essential, that term should itself be included in a glossary.

An electronic glossary can also be linked back to the text – either to all uses of the word in question (thus doubling as index) or at least enabling that term to be highlighted on the page. Certainly the glossary definitions should be linked back to the text (both electronically and by reference in printed versions) where a fuller explanation may be found.

A glossary also serves the purpose of making it unneccessary to define every term every time it is first used in a particular section or argumentation map. However, it is important that the glossary does not become a justification for not explaining key concepts more thoroughly within the text.

2.4.4 Argumentation

'There is very little argumentation in the argumentation maps' – probably because, during the process of producing the maps, agreement was reached through dialogue between AL and RW. The result is a presentation of their agreed conclusions about the shape of the science and where uncertainty lies. Argumentation implies that the stages of this dialogue need to be captured – what are the arguments, critiques, alternative viewpoints? Are the conclusions (as derived by AL and RW) really what Nirex wish to present, or is it the points of divergence, or the identification of uncertainty?

To map out the argumentation, a different process of production is required, whereby a wider range of stakeholders with views on the topic are invited to present those views, preferably within a dialogue so points made and responses to those points can be identified. An "if this, then that" approach might be helpful to identify premises and follow lines of reasoning.

It appears that argumentation became secondary to identifying uncertainty in the production of the argumentation maps. Deciding more clearly which of these objectives are to be pursued (and they are not mutually exclusive) seems necessary before developing further argumentation maps.

F2.5 Accessible Science

In general, the material was considered successful in providing an introductory understanding of solubility, rock matrix diffusion and sorption. However, quite what this understanding was is another question. The issue of whether people understood what was being presented in terms of the content presented – whether they could then answer a test 'correctly', for example - was not a focus of this review; some informal discussion indicates that understanding in this sense was not comprehensive. Rock matrix diffusion, for example, clearly got across (or resonated with pre-existing ideas and understandings) the idea that radioactivity is carried through rock by water. That some of the radioactivity stuck to the rock along the way, and that the pattern and extent of 'blind alleys' in relation to the water movement and how much radioactivity stuck to how much rock for how long might be significant in how much radioactivity eventually reached the biosphere was not so well understood[7].

The accessibility of the science in the sense of providing introductory and/or framework understandings was considered to be patchy. The solubility argumentation map is clearer and more understandable than the rock matrix diffusion, and it is worth considering why this is the case. Firstly, solubility is a more familiar concept than the immediately incomprehensible terminology of 'rock matrix diffusion'. Secondly, the solubility AM lays out a clearer sequence of concepts and steps, whilst the rock matrix diffusion AM is more difficult to follow in terms of its internal logic, and is more sloppily produced in terms of explaining unfamiliar terms, providing an accessible sequence of ideas, and making its points clear. This provides some clues as to what makes science more accessible: familiarity is one dimension, but clarity of presentation is highly important.

2.5.1 Content: Need to know

"Too much too soon" – there are several places where a clutch of concepts are introduced simultaneously, e.g. vl20&21. Many of these common concepts (like radioactive decay) should be included in a glossary, and explained seperately in a 'primer' – i.e. a series of maps of key concepts. It is good practice when 'teaching' to introduce one concept at a time, and use or apply or give example to that concept before moving on to the next.

A reviewer pointed out that in her experience, people often confused or did not distinguish between things 'dissolving' and things 'melting'. It is important not to assume that terms in common usage are understood, or used, in the same way as they are understood scientifically. For everyday purposes, the distinction between whether things dissolve or melt is largely irrelevant ('melts in the mouth'). It doesn't matter when the sugar melts or dissolves – it gets incorporated in the tea, and that is what does matter. It is well worth considering the lay understanding of a term that is being used in a scientific sense, and identifying and clarifying possible confusions (for example by stating that the usual use of a word is x, but that you are using it in this particular scientific sense). It is also worth considering, as I do in the next paragraph, whether the more specific concept is necessary to the scientific understanding, or whether the analogous lay understanding is itself sufficient or useful.

We could represent lay understanding, for example, that some things (usually hard things, or 'solids') can become liquid, and that you can mix hard things and liquid things and get a

[7] this is my own interpretation of the material in conjunction with conversations on the subject. I make no claim to its 'correctness'.

liquid thing. The simplicity of this representation is deliberate: it intends to indicate that it is possible to translate specialist understanding into common language, and it raises the question of whether it is actually <u>necessary</u> to have a more specialised understanding of the concept.

The answer is to be found in relation to the other concepts and processes being explained. For example, the key factors being communicated in relation to solubility are (as understood by me) that:

- Solid things, which include radioactive bits, can become fluid
- The amount that becomes fluid varies with environmental conditions such as heat and acidity (e.g. if its hot then more will melt/dissolve/become fluid).
- If radioactivity (or radioactive bits) in the repository become fluid they could move through the rock and reach the biosphere.
- How much radioactivity gets to the biosphere therefore depends, in part, on how much is dissolved, which in turn depends on environmental conditions.

To me, at least, this captures as much as I need to know at this stage – and I do NOT need to distinguish between something dissolving and melting to achieve this understanding because the point is about radioactivity become fluid and therefore being able to move through the rock, and the relevance of environmental conditions to how much becomes fluid is not dependent on an understanding of whether becoming fluid consists of something dissolving or melting (melting is also, of course, dependent on environmental conditions) or distinguishing between these two concepts.

The point of this is to demonstrate that it is not necessarily necessary to have a scientific interpretation of all concepts in order to follow a line reasoning, that the building blocks of comprehension can be made quite simple and accessible, and to argue that, given the volume and necessary complexities of the material, considering what is required on a 'need to know' basis to gain a grasp of the phenomena under discussion is a viable strategy.

Another example of this is sorption, which I understand as the 'sticky' tendency of radioactive things. That is, radioactivity tends to stick to things. A more complex understanding of sorption is not necessary to grasp what is going on in rock matrix diffusion. It is necessary, though, to begin to understand the uncertainties as defined within this material.

It is, of course, also important to recognise when a more specialised or particular understanding of a building block is necessary. The conflation of dissolving and melting is shown above not to matter in this particular instance; it would no doubt be confusing to maintain that conflation when considering the topic in more detail, or in specific areas.

Thus, there is a conscious choice to be made in when it is necessary, and in what way, to present a concept or building block, and an argument that it is always worth seeing what can be excluded for the time being in order to simplify and clarify the key points being made.

2.5.2 Content: levels of explanation

This relates to the rock matrix diffusion argumentation map in particular, and the VL approach in general. The RMD AG appears to lose its thread – what is the key storyline? What is the point that is being made? What is the reader supposed to come away from it with? There is a common saw in teaching that good teaching requires explanation at several levels – a simple, accessible storyline running through, that everyone should be able to grasp, with more complexity, sophistication and detail surrounding that storyline for those that are learning more comprehensively. That storyline for RMD is not clear.

It is likely to be difficult for those trained in science and familiar with the content to identify this storyline: for the trained scientist there are both too many familiar assumptions and presumptions about concepts and their relationships, and a taken-for-granted way of thinking about a topic (that is, the loose tenets of scientific method) to be able to identify the basic storyline as it might be most understandable to a public who are not, in general, scientifically literate and have a different way of thinking. Certainly, when preparing the briefing materials for the P&T Citizens' Panel, we found it useful to have one (scientifically illiterate) member of the team continually asking questions, suggesting simpler phrasing, asking why it was necessary to know things, and trying to tease out this basic storyline. And for some members of that panel, talking about bits of atoms that fly off and hit other atoms was the accessible way of explaining what was going on – an explanation which trained scientists found unfamiliar. This is not to say that trained scientists cannot conduct this task, but that it might be helpful to use non-scientists too, in order to translate scientific understanding into a form where it is accessible by lay people, and where the storyline is clear at several levels.

2.5.3 Inherent interest

The material is inherently interesting for many. Particularly, many reviewers mentioned the diagrams of rock structure and water movement through rock: it seems that some contents of science are more interesting than others. Where concepts can be more easily related to the real world, and where that real world is itself more interesting (e.g. rocks are more interesting than fish; trees are more interesting than meteorites[8], radioactivity is neither interesting nor understandable), seem to be associated with inherent interest. Identifying the characteristics of what is deemed 'interesting' and why might provide clues to where inherent interest lies and can be capitalised on.

2.5.4 Teaching and Learning

Teaching and learning models are useful resources for what appears to be being attempted here. If the intention is to provide users of the material (who are presumed to have varying levels of knowledge of the subject matter and of science more generally) with an understanding of topic (an understanding ranging from grasping the basic storyline to a more sophisticated scientific understanding), and an understanding of where scientists generally feel confident of their knowledge of what is happening, and where uncertainties lie, then that intention is, essentially, one of teaching people about the content of the material.

There are, as in all fields, different understandings of how the teaching and learning process works. Some are based on psychological understandings of memory and so on; some are focussed on the practice and content of material, and some stress the individual learner. One potentially useful idea is that of learning styles, whereby different people have different ways of learning. Whilst this complexifies the production of material to some extent, it also makes it more accessible to a larger number of people if, similarly to the idea of providing simple and more complex storylines, if different learning styles are recognised[9].

[8] These are examples, not claims.
[9] Neuro-linguistic programming offers one way of understanding and approaching this, e.g. see Garratt. T (1997) The effective Delivery of Training using NLP: a handbook of tools and practical experience (Kogan Page).

There are also 'basics' which teachers are taught to use which are helpful. Firstly, there is the question of what the teacher wants the learner to have learnt by the end of any particular teaching event, and a course in total. Identifying this helps clarify the focus of the teaching. A pertinent second question is then how the teacher will find out if the learner has learnt this, or is misunderstanding, or is ready to take on material at a higher level. In teaching, this is done through discussion and through assessment exercises. The VL project needs to consider how it will identify and explore how users are understanding the material (the partial understanding of RMD as water movement through rock and the potential for radioactivity to reach the biosphere demonstrates that the material is open to an almost reverse interpretation – i.e. that RMD is a bad thing in that it allows the radioactivity to reach the surface, rather than a good thing which means that less radioactivity will reach the surface – thus fundamentally reversing the significance of the argument about the certainty and significance of RMD). This again points to the need for work with ordinary members of the public to examine their understanding of the content of the material (rather than their responses to the general layout and idea of visual language). Such work could also usefully identify what is remembered a week or so after exposure to the material – i.e. what are the ideas that have stuck (that it is all under control? That sugar dissolves in tea so radioactivity is like sugar?).

Summary and repetition are also common teaching tools. There will be repetition, or at least the use of common concepts, across argumentation maps. However, summaries at the end of each AM, (and also within the AM to emphasise and indicate key points) would be useful, both to clarify 'these are the key things about this' and to indicate and 'close' a particular line of reasoning.

F2.6 Clarification of Uncertainty

A key initial ambition of the VL project was to use this medium to identify and make explicit 'uncertainty' in the science. There is a question to be asked, however, as to how 'uncertainty' is being defined and represented within the VL project, and whether this is, indeed, how you wish to define and represent uncertainty.

Wynne[10] discusses four different definitions:

- risk: the dimensions (of what is not known/uncertainty) are known and can be quantified
- uncertainty: where the dimensions are recognised, but cannot be quantified
- ignorance: where the dimensions are not recognised (i.e. that which we don't know that we don't know)
- indeterminacy: things that cannot be known (e.g. because of recognition of the influence of forms of knowledge on what is known, or because of feedbacks within a system whose influence cannot be predicted, or because knowledge claims are conditional on a range of contingent factors)

Any or all of these forms of uncertainty become manifested when scientists disagree; that they do not become manifested says more about the social conditions of the production and application of knowledge than the certainty of the science[11]. Absolute certainty is, within most philosophies of science, unachievable.

[10] Wynne, B (1992) *Uncertainty and environmental learning: reconceiving science and policy in the preventative paradigm*, Global Environmental Change, June, 111-127
[11] see Hunt, J (1994) Science and Policy in North Sea Pollution (unpublished PhD Thesis, Lancaster)

It was clear that the construction of the VL material focussed on the first and second of these, particularly in relation to contested science or science where different interpretations were available. There is some allusion to indeterminacy in the final two slides of AM on solubility. The term 'uncertainty' is used generally within the text to refer to the difficulty or impossibility of getting sufficiently robust data and models12.

However, ignorance is commonly recognised by lay audiences (as well as by the reviewers). That is, people acknowledge that there are always unforeseen elements which come into play, that it is not possible to identify these unforeseen elements, and that, from life experience, things go wrong (i.e. Murphy's Law). It is important for overall credibility to acknowledge ignorance as an inevitable condition; scientific claims are contingent on all relevant factors having been identified and the possibility that some factors are not identified needs to be explicit.

Indeterminacy, too, is commonly recognised and need to be made explicit. Areas of non-knowledge are significant, and provide science with a humility which has generally been lacking.

It is perhaps clearer to provide examples from social science (assumptions about the 'strength' of knowledge claims are more embedded and less visible in natural sciences) – the claim to have identified all possible social conditions over the life time of the repository is easier to accept as nonsensical.

Particular representations of uncertainty/non-knowledge carry their own message – that is, to represent uncertainty as bounded and amenable to control is to implicitly make the claim that science can provide absolute predictions which are somehow beyond contingency and the unforeseen, and have some absolute relationship with 'reality' which is beyond the conditions of production of knowledge. Overstating 'certainty', and the possibility of achieving 'certainty', has been identified as a key factor in contested science and the public acceptability of scientific claims. Particularly, where certainty (often represented in terms of 'safety', e.g. the claim that 'it is safe to live downwind of a nuclear power station/eat beef/fly to the US') is then demonstrated to be less than absolute, trust and confidence suffer.

In terms of identifying uncertainty within the way the term is interpreted in the material, a range of uncertainties to do with incomplete data, prediction, and relationships are identified and communicated. It might well be worthwhile to identify the forms of uncertainty that exist and which are these are amenable to becoming more certain if appropriate studies are undertaken (e.g. collection of more data). It is also, I think, worth being explicit about the other types of non-knowledge which we know exist.

[12] there is a key distinction here: *difficulty* in gaining adequate data/models presumes that it is possible to aquire these if sufficient resources are applied; *impossibility* includes the possibility that it is not possible to acquire certainty, as the epistemological premises of a knowledge form are themselves constructed and conditional.

F2.7 Contexts of use and delivery media

2.7.1 Media

Three media were considered in relation to the material – A4 sheets or similar, as posters/boards, and the internet.

A4

Presentation as a series of A4 sheets obviously has serious drawbacks, most notably that the structure of the material is largely invisible, and that the sort of visual clues discussed above are largely missing. Reviewers identified difficulty in knowing when one section has ended and another begun, and in the relation of parts of the material.

Posters

Posters were only presented at the workshop, and detailed responses to them thereby limited. Apart from the obvious limitations to reproduction, transportability and display caused by the size of the posters, they did provide a much clearer sense of the structure of the material. However, there was a very large amount of information on each poster, making them unsuitable for general display.

Internet/CD

As an internet/CD presentation, the material obviously has great potential. A map of the structure is still required, but hyperlinking both through the material, to the glossary, and to external sources, gives more versatility (and the potential for more confusion if the structure is not clearly visible). The user can define their own pathway through the material in relation to their interest and existing knowledge. Electronic communication also offers the possibility of using animations (groundwater flow is an obvious candidate for animation) and sound, including voice-overs. It would also be possible to include interactive dimensions. Modelling could be demonstrated in simple terms by setting up a model with a number of parameters whereby the user could change e.g. temperature, pressure and see what happened. However, if the material is to be seriously developed for electronic communication, expertise in this medium will be essential, both to contribute to design, and to carry out the work.

2.7.2 Context

Interacting with the medium of presentation is the context of use. Reviewers reflected on the use of the posters in a 'village hall', i.e. set out on display boards for people to walk around and look at. There is a presumption here that people have an interest in the material. There is a large amount of material being presented, and more segmentation (chunking) is probably needed, as well as backup, printed material that people can take away. Selection of material, rather than presenting everything, will probably be necessary both due to space constraints and the sheer volume of material if argumentation maps are developed for all the scientific topics. Here again, maps of the larger range of issues will be necessary, perhaps accompanied by leaflet versions of individual argumentation maps. The question of how much information people actually want is again pertinent. Attention needs to be given to the direction of flow, i.e. where it is necessary to read one area of the poster in order for a subsequent section to make sense. Attention also needs to be given to the way in which people (including people with restricted mobility) will physically move around the material, and to the social context and implications of the event – e.g. people are likely to talk to each other. The posters, at present, are also too large – the distance from the top to the bottom is more than is easily readable by most people if standing. If the material is to be used on display boards or equivalent, some professional advice on the use of this medium would be worthwhile.

As electronic communication, use is likely to be individual. Setting up a number of terminals in a common space is also possible, and might well be worthwhile particularly once sites are identified, in order to provide, and to demonstrate a commitment to providing, accessible information. The material also has potential linkages to the schools' website being used in RISCOM. Use, however, is still primarily individual and this needs to be taken into account within the design.

A decision needs to be made regarding the medium in which the material is to be presented, and professional advice sought regarding the potential and limitations of these media.

2.7.3 Dialogue

The material clearly has uses in relation to dialogue and consultation, both as information provision and as a prompt to discussion. Here again, decisions need to be taken in terms of the potential use in dialogue. If the material is basically envisaged as information provision, laying out the 'facts of the matter' or 'current scientific knowledge', there are different implications for design. The material currently reads as if this is the intention. If, however, the intention is to generate discussion, then questions about the purpose of that discussion need to be answered, or at least considered. Inserting questions (of the type 'what do you think') into the material is one way of prompting discussion. However, the design in relation to dialogue uses is not the most important consideration: developing the material as information provision will not preclude its use within dialogue. That the material provides access points to discussion is itself valuable.

The material has obvious potential for use in conjunction with web-based dialogue, and at the least, some form of interactive response needs to be built in: at the simplest, this could be an email box where users could 'write-in' with questions. A discussion space is also relatively simple to set up. Decisions would need to be taken in relation to the use of queries and comments posted in this way: providing a communication channel is a valid purpose in its own right, but added value could be gained if, for example, queries and comments were analysed to find common areas of understanding/misunderstanding, where information is challenged, etc, in order e.g. to revise and improve the material and/or to identify areas of particular concern.

Some thought should be given to the potential uses of the material for dialogue and consultation, and decisions taken as to whether design is to be tailored to particular uses.

2.7.4 Users

It is not at all clear who the intended audience or readership is. If a 'general' readership is assumed then the comments on providing a 'simple story line' as well as more detailed and complex storylines is extremely pertinent, as are comments on the need for a clear map of the structure of the information. A much simpler and more straightforward 'top layer' needs to be produced – similar in tone and detail to the options descriptions poster – where users can gain an overview of the material and decide which areas to pursue.

It is worth considering who the different users might be. They are likely to include:

- stakeholders of various types, including industry and ENGOs, both of which groups are likely to be critical in stance (all criticisms should be taken seriously and discussed)

- members of the public with very different levels of interest, scientific literacy, and familiarity with the topics (the VL approach does lend itself to presenting different levels of complexity, although this is not fully utilised in the material prepared so far)
- school classes (where the material is likely to be used in a classroom setting and could benefit from the incorporation of tasks/questions for use as a teaching aid)
- local groups and individuals interested particularly in relation to the possibility of local siting of a repository (where some interpretation of the material in terms of the local site will be required)

The material thus needs to be considered in relation to a wider range of potential users and in relation to particular sites. The range of users is not yet properly incorporated in terms of both the 'layering' of the material (i.e. the provision of simple overviews with more detailed continuation/understoreys) or its range (i.e. the level of detail in relation to particular topics, and the number of topics).

2.7.5 Intent

The comments above point up the need for clarity in the choices that are being made, explicitly and implicitly,

The lack of clarity of intent/purpose is reflected in the visual component of the work – its inconsistency and ad hoc-ness, as well as in the lack of clear structure and style.

Decisions need to be taken before the material is developed much further in relation to purposes and intentions. If decisions are not taken, the material will (as it appears to be starting to do now) develop an intention of its own – that is, the design logic will drive further development, rather than being a tool to enable meeting the intentions of that development.

Some of these decisions are described above, but these are not intended to be exclusive, although some decisions imply a choice between different paths. A workshop within Nirex – possibly including external stakeholders – would be a useful starting point to identify and discuss the range of intentions, but this will need to lead to decisions and choices rather than generated ever-increasing areas of discussion (although there is of course a choice to made as to when sufficient discussion has taken place to be able to reach a decision).

F2.8 Bias

2.8.1 Rhetoric

Communicative activities carry their own particular rhetorics. Three particular rhetorical frameworks are visible:

1. That science is capable of establishing sufficient knowledge on which to base decisions, even over the very long timescales involved – and, by implication, that 'everything is under control'
2. That the nature of the problem is one that can be addressed and resolved by science
3. That uncertainty is bounded and resolvable.

All of these implicit claims are potentially 'offensive', either explicitly (for those who can articulate concerns in this area) or as a less well defined 'suspicion' of the claims that are being made. The rhetoric being adopted needs to be a conscious choice, rather than a product of the assumptions of the authors, in order to be aligned with decisions about the intent and purpose of the material.

These rhetorics give rise, inevitably[13], to bias in several ways:

1. Whilst the material does a reasonable job of identifying uncertainty (as discussed above) it does not prompt, or particularly enable, the user to make their own judgements about the science. Inevitably the material tells its own story, but this could be opened up more, for example by using 'what do you think' type questions, thereby encouraging, and giving permission, for the user to have their own views. However, most lay users are still likely to feel they do not have the expertise or authority to make scientific judgements, and the material is not sufficiently comprehensive to provide a solid basis for such judgements. There is therefore a bias towards positioning the user to accept the material – and the claims and statements it makes – rather than challenging it.
2. There is a bias towards a narrow definition of uncertainty, as discussed above.
3. The focus on uncertainty is itself a form of bias – why is uncertainty important, why is it problematic, and for whom? (an argumentation map on uncertainty, exploring these questions, would be a good example of including one of the 'other dimensions' which so many reviewers saw as lacking).
4. Who is the 'we' in the text? This seems to presume a common position which not everyone might wish to adopt. Even worse is the passive voice – 'it is known that' – who knows? The passive voice presumes an absolute, beyond human, uncontestable claim, which is not the case.
5. The focus on containment in relation to humans and the human environment contains an ethical presumption that these are the areas of concern. The exclusion of consideration of effects on the natural environment represents a bias in favour of humans[14].
6. The presentation of medical and industry waste production (vl3) implies that production of wastes is a given: the use of the term 'come from' implies the continuation of production as unquestioned. This locates Nirex not as neutral, but as supporting the continued production of wastes. This is an important question, and whilst Nirex may need to not adopt a position, this needs to be stated, and some pointer provided towards the fact that there is debate on continued production.
7. What is included and excluded from the scope of the material gives a message in itself: currently the bias is towards a narrow technical and scientific scope.
8. The conservative, standardised form of presentation gives a message of an intention to reassure, to make the user feel this is verifiable and understandable: this is a normative stance, which excludes several notions of uncertainty, and goes beyond Popperian[15] notions of science in its implicit claim for certainty and knowability. The nature of science is taken as a given – yet this could well be a fundamentally important area to open for explicit consideration and deliberation (it would also assist in the understandability of the material if the structure, premises and terminology of science were introduced).

[13] unbiased, or neutral, information, is impossible to produce – one merely provides a rhetoric of neutrality, which is not the same thing. Bias is inevitable, but one can make bias more explicit, or explain the reasons for the direction of bias.

[14] In various discussions, a large number of people have raised the point that effects on the natural environment are important in their own right, not just because of knock on effects on humans: 'fish have rights'. Ignoring this is likely to alienate many users of the material.

[15] Karl Popper understood science to make verifiable knowledge claims, which would stand until evidence to the contrary was produced. Thus, the claim 'there are no black swans' is unscientific, because it cannot be verified unless all swans are identified and none of them prove to be black – and we cannot know we have identified all the swans, and that none are hiding. The claim 'there are black swans' is verifiable by the evidence being produced – i.e. a black swan being found (I do not know if this evidence is overturned if someone eats the black swan).

9. The particular view of science being presented is another form of bias, making science separate from society and giving it a special, prioritised claim on what can be known. It can be disempowering to present the issues as scientific, in this sense, excluding the non-scientific and extra-scientific questions and concerns.
10. The simplification of complexity, and the use of everyday images, makes complexity simple and the risks everyday – a very contestable rhetoric.
11. The material is presented in terms of safety, both in content and style. The omission of 'unsafety' communicates either a patronising stance, or a lack of ability to see problems which others identify. Where, for example, are the leukemia and thyroid cancer victims, that many of us know about? Their exclusion is a form of bias.

F3 SUMMARY AND CONCLUSION: RECOMMENDATIONS FOR FURTHER WORK

It is quite clear that the VL project has enormous potential, both as a form of communication with respect to the intention of 'making science accessible' to a wide range of audiences, and as a vehicle for dialogue both with and outside Nirex.
To date, the VL project has obviously had considerable benefit in developing Nirex's understanding of the complexity of 'making science accessible'. It would be valuable to take a little time to document this learning to avoid future wheel reinvention.

The materials developed to date provide a basis for continuation of the project. However, the purpose(s) of the material need to be more thoroughly considered and defined, now that a better understanding of the potential of the VL approach has been gained. Style also needs to be defined in relation to this purpose, and the project and products would benefit from working with an appropriate[16] professional designer. The scope of the material also needs reconsidering. The overall structure needs tighter definition, the top layer needs working out in relation to this structure, and the 'simple' story lines need to be developed.

There are biases in the style of representation adopted which may prove problematic with wider, more general audiences. Particularly, the implicit safety and controllability rhetorics, and the narrow representation of uncertainty, need reconsideration.

The positioning of the reader as a passive recipient of information needs serious attention, especially in conjunction with possible uses of the material in relation to dialogue and consultation.

As a communication and information form, the VL material could well be developed as the central 'stem' of communication products (I am excluding consideration of dialogic uses for the moment, and focussing on the general requirement for Nirex to provide information in some form – traditionally as leaflets, brochures and a website). It is easy to see how the material, and parts of the material can be utilised in different media (a booklet introducing the hydrogeological aspects of a deep repository, for example).

[16] It would be essential to work with a designer who was sensitive to the intentions of the project and who was skilled in working with clients (i.e. Nirex) to identify the design choices and factors influencing these choices. Unfortunately, not all professional designers meet this specification.

It might also be viable to consider developing part or all of the material, in a consistent style, in conjunction with other agencies also involved in producing information on similar topics (e.g. NRPB, DEFRA, EA, Friends of the Earth). This would assist resourcing; more importantly, it would bring together a wider range of stakeholders to engage in the very important process of production (to gain benefit from this it would be necessary to be explicit about the value of the process, and the resist being overly driven by a requirement for products). It would, of course, be essential to include critical voices (who are likely to need resourcing) in such a group. The disadvantage of such a collective approach is that it could lead to a set of 'master' information which was more difficult to challenge, and was thus exclusionary. However, if the problem of 'agreeing' (i.e. losing the argumentation from the argumentation maps) can be resolved, a very useful knowledge map could be produced[17].

The VL project is emblematic of Nirex's developing awareness of its relationship with others. As such, it warrants a higher profile within Nirex, to encourage this awareness. The VL project embodies a positive approach to a complex and difficult situation. The creative space it occupies, however, is related to the period of (potentially) creative chaos which radioactive waste management in general, and Nirex in particular, are currently experiencing, and this should be acknowledged. There is no immediate need for closure of this period, and the creative opportunities it provides are beneficial in relation to the VL project.

[17] Such a map – and the process of collectively producing such a map - would also form a valuable contribution to the review of science being contemplated by DEFRA.

Appendix: specific comments on Visual Language

Presentation

1. All non standard images (i.e. specialist/not immediately accessible to a general audience, e.g. graphs) need to be appropriately titled or labelled.
2. The labelling of axes on graphs is problematic: to make these more understandable by the non-specialist who is already finding it difficult to work out what a graph means, non-specialist language for labelling axes is clearly preferable. E.g. the use of the word 'concentration', which is not understood (in terms of the scientific understanding) in lay usage.
3. The predominant font used is Times New Roman or similar, which gives a formal appearance. Different fonts can be used to communicate that 'this is a scientific bit', this is a summary, this is an introduction, and font selection (and colour and size) is a useful tool for identifying to the reader where they are and what they are supposed to be doing. Again, using too many different 'codes' is confusing.
4. Using too many fonts is confusing.
5. Any hyperlinks need to be clearly identified as such, using a consistent motif such as text which is underlined. This motif should not then be used for anything else.

Images

1. Images should be used consistently: if an image is used as a representation or symbol for one thing, it should not then be used as a symbol for another (e.g. the image of the people sitting around a table appears to be used as a image for people in general, and for the research community in particular).
2. Images should add something in terms of explanation, rather than being purely decorative.
3. The image of people sitting round a table appears to include only caucasians, with women in subservient positions (presenting the image in e.g. black on green bypasses racial stereotypes to some extent). Not taking account 'political correctness' of itself gives a clear message to readers that Nirex are not concerned about racial and gender issues.
4. Is crystal ball gazing really supposed to be a representation of scientific uncertainty?
5. The images of rock structure were widely liked.
6. The contested cup of tea slide sol6 presumably intends to demonstrate that (the rate of? The occurrence of?) solubility varies with temperature, but this is not spelt out, and the slide appears to be demonstrating (in relation to the preceding heading) only that things dissolve in everyday life.
7. The use of clip art was felt to be flippant, and used to present a message that these weren't important issues, and weren't anything to worry about. This message, in turn, was read as intentionally trying to trivialise the issue, and direct attention away from it.
8. The options poster was generally liked, although there were some comments related to simplicity – the rocket, especially, generated a response in several people that they wanted to see what happened next (rocket travels to sun? rocket crashes?).
9. Graphs were generally felt to be more difficult to understand.
10. Diagrams were generally felt to be very helpful.
11. Clip art was described as 'eye candy[18]' used to break up the text – there was a view that it added interest, although most felt that these common, and somewhat cartoon like images should be replaced with something more specific and more serious.

[18] There is more attractive eye candy available, if this is the intention.

Colour

1. a large number of men are colour blind, so the use of red and green should be avoided; different shades of green in combination will be illegible.
2. Dark colours on dark colours eg as used on header slides for in VM e.g. vm2, 8, 9 etc, are hard to read and illegible at a distance.
3. There are certain common cultural expectations in the use of colours in representations – water is blue, for example; complying with these expectations aids communication (e.g. where particles are blue and water is sandy coloured)
4. There are particular cultural associations for colours – red, or yellow/black, for warning, for example.
5. The expectations and associations of colours do vary across cultures: purple is the colour of royalty for some, and of goths[19] for others. White is the colour of purity in the west, and of mourning in the east. Colours should be used with an awareness of the readership.

Space

1. 'blank spaces are thinking spaces': leaving spaces should be done deliberately, to indicate to the reader where to pause and reflect on what they have just read.
2. Some slides have far too much on them: others too little. If (and this is not clear to me, as reader) the slides are supposed to represent steps in a line of reasoning, this will be unworkable in relation to the space available, as some steps are bigger than others. Steps and lines would be better indicated visually by some other means (e.g. colour, format).

House style

1. Adopting a house style is important because it enables the reader to learn how a presentation is constructed and where to look for various things (e.g. the footnotes are at the bottom of the page; the introductory bit will be in red arial 12 point). Use of a consistent style throughout will aid accessability. The current style is not consistent, and not used in any clear sense in relation to the structure.
2. It is essential that grammar, punctuation and spelling are correct (this is not always the case in this version) – otherwise a message of sloppiness comes over, and that does not inspire confidence in Nirex as a radioactive waste management organisation.

Direction

1. English is read from top to bottom, left to right, and clockwise (e.g. where speech bubbles are used). Meaning should move in these directions.

Definition/terminology/word use

1. all specialist terms should be explained when first used (this is not always the case in this version of the material), and should then be used consistently with this explanation, e.g. see rmd15 where several new terms are suddenly introduced (advection, rock face) along with a graph.
2. Not more than one term should be introduced at once.
3. the terms 'research' and 'modelling' need clarification and distinguishing very early on.

[19] Goths are a sub-group of alternative youth culture distinguished by their adoption of black and purple clothing, with a preference for velvets and lace.

4. 'diffusive flux' explanation goes straight in at a relatively complex level, and its relevance to rock matrix diffusion isn't clear – the heading 'general theory…' on rmd2 leads the reader to expect an explanation of rmd, not of diffusion.
5. Diffusion flux might be more understandable as rate of flow x number of particles x time over distance; this term certainly needs an explanation in lay language such as the rate at which particles move through rock. It could then go on to look at the factors influencing this – i.e. concentration (which is a term which is not explained, and should be).
6. Rmd 8 (concentration gradient) is a good simple explanation, but does not take account of other factors affecting the rate of diffusion, e.g. ph, temperature. This could be approached in the same way as solubility (i.e. solubility is the amount that dissolves, and the rate at which things dissolve is influenced by….)
7. Rmd8 is a good example of a bad graph – it is not clear whether the arrow points to the curve or the red line, what the red line means is unknowable to someone not familiar with curves on graphs, there are two arrows on the slide, one used as an indicator (this is a ….) and one used to indicate movement, and the term concentration is used to label an axis but is not explained (see comment below). And the bunch of flowers can be read as 'so its just like flowers, i.e. pleasant, safe, - if they are trying to tell me radioactivity is like that, they are lying….'. I do not think it is actually necessary to understand the concept of a concentration gradient to understand rock matrix diffusion (simple version) and this slide, here, with this complicated concept, is offputting.
8. Conflation of terms that have both lay and specialist meanings – such as concentration – should be avoided. Like dissolve and melt, the lay understanding of concentration is different from its specialist meaning, focussing (I think) on how much 'stuff' there is in one place (concentrated) rather than as a relationship between different concentrations. This relationship needs spelling out.
9. Examples should be identified as examples, using the sentence structure – stating 'for example….'.
10. Common symbols are useful, but their meaning can be ambiguous and changes with context (e.g. the use of the 'no entry' symbol on slide >>). If there is an emotive heading, for example, a symbol is likely to be interpreted differently than if there is a technical heading.
11. Large numbers should be written as words: lots of zeros are not comprehensible to many people.
12. Words need to be used very carefully, both individually and in relation to each other. E.g. The use of 'unique' (slide>>>) suggested unpredictability where the intention was to suggest predictability.
13. Whenever 'it' is used, the thing being referred to should be clear – sometimes it is ambiguous which of two possible referents are intended.
14. Verb tenses can be confusing. 'There is a problem of rock matrix diffusion' suggests that there is currently a problem in the physical world rather than the scientific research world. That there 'will be' or 'may be' a problem is more appropriate in relation to a future repository. 'There is' also gives the impression that the reader should already know what rock matrix diffusion is.
15. Acronyms should always be defined on first use; it may be necessary to alter text to encompass this with disruption. Acronyms should also be linked to a glossary.
16. The difference between storage and disposal needs to be explained.
17. The term 'concept' is used in relation to the Nirex concept, without explanation – and it is confusing to use this word for 'the Nirex concept' and the idea of a concept.
18. Notwithstanding the difficulties this audience had with unfamiliar graphs, simple, clearly labelled graphs are recognised as a valuable means of communication – and the

expectation that 'everyone should speak English' (rather than speaking maths) is clearly arguable. It is reasonable to make some demands, and place some expectations, on users, rather than trying to reduce everything to the lowest common denominator.

Structure

1. In the linear form (printed on A4 sheets) it is very difficult to see where different sections are, and to read in order, and to see the overall structure, and impossible to grasp where there are choices to follow the information along one line or another. If this form is to be used, reordering and 'links' will have to be incorporated.
2. The material is largely 'chunked', although this is not particularly clear in the layout and style. There is a valid emphasis on the flow of ideas, but this appears to have been emphasised at the expense of the individual 'chunks' – where the chunks are in relation to each other, and where the beginning and end of each chunk is, needs to be clear. A summary slide at the end of each chunk would achieve this, as well as providing a useful (simple) summary of that bit.
3. The beginnings and end of individual ideas and larger ideas need to be clearly marked, even (especially) when the end of one idea is the beginning of another (again, this can be done through style/visual indicators of 'this is the end of this bit and the beginning of the next bit' as well as through the text. Rmf 16, for example, suddenly introduces the idea of a model, and that the use of model involves assumptions, which is key to the whole argumentation map, but just appears half way through a section on what is as isn't known. Yes, it flows from the previous slide, but needs a clear visual and structural clue that ***this is important***.
4. Headings sometimes seem to have little to do with the subsequent slides – eg rmd 7&8
5. All slides should be numbered (discretely) – or provided with some form of identification, so that they can be referred to directly in discussion/communication.

Content

1. Where claims contradict 'common knowledge' this needs to be explicit – otherwise it is confusing and can appear to be dishonest. E.g. it is common (ish) knowledge that the ice sheets are melting, i.e. unstable, so presenting them as stable in the options poster is problematic.
2. Time and distance are in play at many points, and it needs to be clearer when either or both are important.
3. Huge timescales are notoriously difficult to comprehend in a culture where we largely do not think beyond a generation or two. It is usually more accessible to think about long periods of time projecting backwards rather than forwards ('if the Romans had produced radioactive waste, we would still be looking after it now'). One suggestion was for an image of 'security guards' through the ages, 'caring for' the waste across a historical vista and providing a visual prompt.
4. Statements such as 'since we've lived in caves' are offensive to e.g. contemporary Spanish cave dwellers.
5. The final slides in the RMF AM are confusing, particularly rmd 22 – are the Swedes and Nirex using different data? Why was different significance attached to rmd? Are 'the Swedes' and 'Nirex' equivalent entities?
6. An argumentation map on the dangers of radioactivity is essential.
7. The assumed level of knowledge of the reader is very variable – we are supposed to know what concentration is, but need solubility explaining; we can understand graphs but need picture of cups of tea. Increasing complexity as we proceed through the slides

doesn't work – it means people give up before they get to the end of the story. Rather, there should be concurrent simple and complex narratives.

8. The presumption that waste needs to be kept remote from humans needs explanation – why is it dangerous, and why is it difficult?
9. The ideas that a) radioactivity decays and b) protection is considered in terms of exposure to radioactivity, rather than 'locking it away' could usefully be explicated.
10. The lack of reference to decay chains and daughter isotopes, and how these complicate assessments, undermines confidence in the comprehensiveness of the stories being told.