Waste Isolation Pilot Plant

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A REVIEW OF APPROACHES TO SCENARIO ANALYSIS FOR REPOSITORY SAFETY ASSESSMENT

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ABSTRACT

This paper surveys approaches to scenario analysis for repository safety assessment which have been under scrutiny by the NEA Scenarios Working Group. Scenario analysis blends information on site and waste characteristics, established understanding of processes, and subjective views of appropriately experienced scientists and others. It is important to follow systematic procedures and to document each step carefully so that it is amenable to scrutiny. There is a wide agreement about the general approach that should be taken to the identification, classification and screening of phenomena that need to be considered. Three general approaches have been identified to the difficult problem of combining these phenomena into scenarios, and consideration has been given to their ranges of applicability.

EXAMEN DES METHODES D'ANALYSE DES SCENARIOS EN VUE DE L'EVALUATION DE LA SURETE DES DEPOTS

RESUME

La présente communication passe en revue les méthodes d'analyse des scénarios en vue de l'évaluation de la sûreté des dépôts, qui ont été étudiées par le Groupe de travail sur les scénarios de l'AEN. L'analyse des scénarios intègre les informations relatives aux caractéristiques du site et des déchets, les connaissances établies sur les processus en jeu, et des appréciations subjectives portées par des chercheurs et d'autres experts possédant l'expérience voulue. Il importe de suivre des procédures systématiques et de recueillir soigneusement les données concernant chaque étape, de manière à ce qu'elle se prête à un examen critique. Il existe un large accord sur la démarche générale à adopter pour cerner, classer et sélectionner les phénomènes qui doivent être examinés. On a défini trois façons générales d'aborder le problème complexe consistant à combiner ces phénomènes à l'intérieur de scénarios, et on a examiné leurs domaines d'applicabilité.

1. Introduction

This paper surveys approaches to scenario analysis for repository safety assessment, which have been under scrutiny by the Nuclear Energy Agency (NEA) Scenarios Working Group. A list of participants in this group is given in Table I.

TABLE I
PARTICIPANTS IN MEETINGS OF THE NEA SCENARIOS WORKING GROUP (SWG)

J. Alonso, Spain	D. Galson, USA/NEA
J. Andersson, Sweden	B. Goodwin, Canada
K. Andersson, Sweden	R. Guzowski, USA
D. Billington, UK	D. Hodgkinson, UK (Chairman)
T. Bonano, USA	J. Marciano, France
S. Carlyle, NEA	J. Olivier, NEA
A. Cernes, France	M. Stephens, Canada
R. Cranwell, USA	C. Thegerstrom, NEA (Secretary)
P. Escalier des Orres, France	B. Thompson, UK
D. Fehringer, USA	F. van Dorp, Switzerland
T. Foult, France	P. Zuidema, Switzerland

The objective of the group is to consider, at an international level, issues related to the identification and selection of scenarios for performance assessment of radioactive waste disposal in order to promote consistency in approaches and methodologies being used [1]. The group has met three times and its progress has been discussed at the NEA Performance Assessment Advisory Group. A preliminary report [2] was produced following the first meeting, and a final report is currently being prepared. In addition, the responses to a scenario questionnaire have been compiled into a catalogue [3] which will form an Appendix to the final report.

The plan of the paper is as follows. Section 2 presents a brief overview of repository safety assessment and the role of scenario analysis within it. The identification, classification and screening of phenomena which could affect repository safety are considered in section 3. Three general approaches to the difficult problem of organising these phenomena into a framework for consequence analysis, are considered in sections 4-6. These are bottom-up and top-down approaches to scenario formation, and environmental simulation. Finally, the conclusions of this work and the outlook for future progress are noted in section 7.

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2. Overview

The purpose of safety assessment in the present context is to evaluate potential hazards from radioactive waste following disposal.

This may be done in order to:

i) assist with the formulation of regulations, or to evaluate compliance with regulations;

ii) guide site characterisation and research programmes;

iii) feedback to repository and waste package design;

iv) evaluate trade-offs between post-closure performance, other impacts and cost;

v) assist with site selection.

An important characteristic of all environmental transfer problems is the need to quantify uncertainties in predictions, in view of the necessarily incomplete characterisation of the complex processes and structures that occur in natural systems. For pollutants which are routinely found in our environment, the uncertainties can be reduced by monitoring. However, for solid radioactive waste disposal assessments the uncertainties are increased by virtue of the long time periods which need to be considered, during which the environment will inevitably change due to natural processes and human actions. This paper reviews ways in which uncertainties arising from alternative futures are handled in repository safety and performance assessments.

In this paper, the treatment of alternative futures is termed scenario analysis. The word scenario has a wide range of alternative definitions in the literature. The Scenarios Working Group has not agreed upon a definition for the term scenario, despite extensive debate. Whilst an agreed definition might be desirable, its absence has not significantly hampered progress. This paper uses the word scenario in the sense of a generic alternative future, although scenario analysis can also take account of uncertainty in present day conditions. Thus a scenario is viewed as a high level description of an alternative future. It includes a specification of the most important events and processes, with a broad-brush description of their characteristics and sequencing.

In the view of the Working Group, scenario analysis does not encompass the definition of mathematical or numerical models or the provision of data. The specification of the calculations to be carried out for an assessment is assumed to be part of consequence analysis. Of course, there needs to be close liaison between those involved with scenario analysis, model development and consequence analysis.

A general framework for safety assessment is shown in Figure 1. The logical sequence of events is scenario analysis followed by model development and consequence analysis. These activities are supported by a wide range of information on geology, repository design, waste characteristics, physical and chemical processes, natural evidence, the biosphere, radiological protection and human behaviour. There are many interconnections and feedback loops between the elements of safety assessment and its information requirements. In particular, the whole process of safety assessment requires a number of iterations in order to converge to a consistent result.

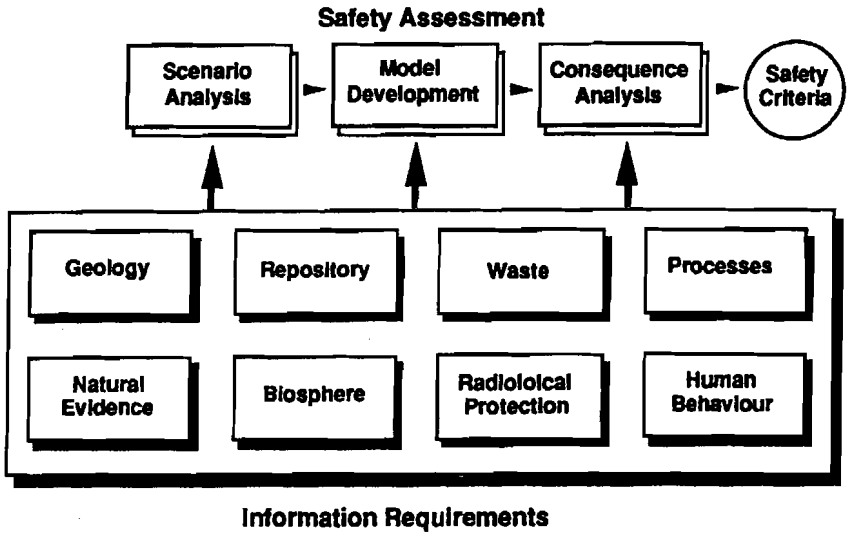
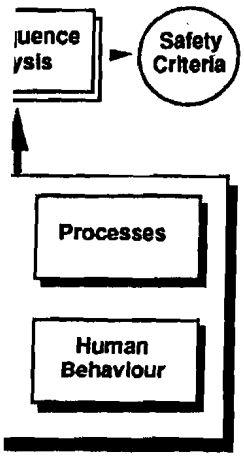


Figure 1: Framework for repository safety assessments

Scenario analysis is central to safety assessment for several reasons. First, scenarios provide the context in which safety analyses are performed. That is, one cannot analyse the long-term safety of a radioactive waste disposal system without considering future conditions at the site. Second, scenarios influence model development and data collection efforts. Finally, scenarios provide an important area of communication between repository developers and regulators, and others with an interest in repository safety. There is clearly scope for developers and regulators to have some degree of consensus about which scenarios are important and how best to evaluate their consequences. The joint SKI/SKB scenario development project [4] is one move in this direction. Also, the somewhat speculative nature of scenarios, and the relative ease with which they can be described, provide a rich and accessible means for public involvement.

The selection of scenarios and estimation of their likelihood relies on the judgement and imagination of individuals. The process can be made less subjective by following a structured procedure. Equally important, subjective judgements must be documented so that the exercise is traceable and thereby open to scrutiny. A number of early assessments have been criticised for considering a very limited set of scenarios in detail, whereas in fact a wider range of scenarios were considered and rejected for reasons which were not recorded.

One of the most difficult aspects of scenario analysis is the estimation of the likelihood of a particular scenario. The likelihood of a scenario is usually termed the scenario probability. However, this is contentious since to estimate a probability requires that the process is stochastic and that some relevant statistics are available. This is rarely the case for events and processes relevant to repository scenario analysis. Usually the estimate of likelihood is an expression of the degree of belief of a group of experts. The International Commission on Radiological Protection [5] advocate the use of the term 'subjective probabilities' for these quantities and suggest that the rules of probability theory be used to manipulate them. However, alternative formalisms such as possibility or fuzzy set theory [6] may be



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Despite the difficulties, it is important that some consideration is given to the likelihoods as well of the consequences of scenarios. Unlikely scenarios can be screened out of the analysis. A qualitative statement of likelihood, e.g., very unlikely, could be assigned to groups of scenarios; alternatively, quantitative subjective probabilities could be assigned to scenarios, as is required by the regulations in some countries. The problem is most acute when individual risk is to be calculated since then a comprehensive set of scenarios needs to be examined, with probabilities assigned in a coherent manner.

In view of the large degree of subjectivity and different purposes of scenario analyses, it is not surprising that no single methodology has emerged as being the most appropriate in all situations. The rest of the paper surveys the spectrum of approaches reviewed by the NEA Scenarios Working Group, and comments on their applicability to particular circumstances. In summary, the group considers that a scenario development procedure should:

i) take a broad perspective;

ii) provide a logical and consistent framework which can encompass alternative methodologies, models and regulations;

iii) document the reasons for analysing some scenarios in detail and rejecting others, in an understandable and traceable way;

iv) allow the judgement and reasoning power of experts and generalists to be integrated with more quantitative considerations;

v) involve people with a wide variety of expertise;

vi) provide a systematic way of compiling a comprehensive list of potentially important events, features and processes;

vii) result in a manageable number of representative scenarios through a well-defined screening procedure;

viii) be a practical tool rather than just an intellectual framework,

ix) be applicable to any type of waste repository or site;

x) provide feedback to model development, research, repository design and site investigation;

xi) be of use to regulators and developers, and be communicable to decision makers and the public;

3. Identification, Classification and Screening of Phenomena

The basis of any scenario analysis is the compilation of a list of phenomena that are potentially important for repository safety. From one perspective, this needs to be unstructured in order to compile a wide-ranging list from the imagination and experience of those involved. On the other hand, it should be structured to aid comprehensiveness and ensure that the procedure is traceable and documented. To balance these requirements it is helpful to divide the problem into three sub-tasks of identification, classification and screening of phenomena, as discussed below. The general procedure described in this section is influenced considerably by the work of Sandia National Laboratories for the US

Nuclear Regulatory Commission [7-9].

3.1 Identification

The first step is the identification of a comprehensive list of events, features and processes. The lists compiled by the IAEA [14] provide a useful starting point in this regard. A typical list for a repository located in hard rock is given in an Appendix.

In order to strive for completeness it is thought appropriate at this stage to include all imaginable phenomena that could affect repository safety. For example, there should be no time cut-off during this step, even if it forms part of the regulatory guidelines. Inappropriate phenomena can be screened out later in the procedure. Comprehensiveness is required at this stage so that interactions are not overlooked and so that the reasons for rejection are documented.

There is a need to be aware of unconscious screening due to the prejudices or lack of imagination of participants in the identification exercise. This can be ameliorated by involving people with a wide range of expertise and interests, and by using formal elicitation techniques.

3.2 Classification

Classification of phenomena under a variety of headings can be a powerful aid to bringing to light further examples. Thus it interacts closely with the identification step of the procedure. It is important for demonstrating that as complete a list as possible has been compiled. In addition, classification under certain headings, provides a framework for organising scenario formation and safety assessment.

Some examples of possible classification schemes which provide alternative perspectives of future system behaviour, are :

- natural phenomena, human activities, repository induced effects;
- release, transport, exposure;
- radionuclide transfer agent (eg. groundwater, gaseous transport);
- timescale;
- near-field, far-field, biosphere.

In any of these cases subdivision of classes is possible.

3.3 Screening

The combined effect of the identification and classification stages produces a large number of events, features and processes which are potentially relevant to disposal systems. Many of these will be irrelevant to the safety assessment of a particular repository and site. There is thus a need to screen out unimportant phenomena using a well-defined and justifiable criteria.

The rejection of phenomena should be done in a transparent and documented way. In general, consequence analysis should be avoided at this stage. However, there may be a need to perform simple scoping calculations. If so, the assumptions and data used should be clearly stated. Screening is site and system specific, and also depends on the regulations

governing disposal. At the present stage in the procedure, phenomena are considered one by one, but bearing in mind possible interactions with other phenomena. Examples of possible criteria are :

- physical unreasonableness
- low likelihood
- negligible effect on repository or environment
- beyond timescale of interest
- beyond regulatory interest

4. Bottom-up Scenario Formation

In bottom-up scenario formation, the list of phenomena formed from the activities described in section 3 are combined together to form a limited number of scenarios for consequence analysis.

4.1 Sandia Methodology

The Sandia approach [7-9] is to follow a three stage procedure.

First, in order to ensure that no possibility is overlooked, phenomena are classified according to whether they affect release or transport with the possible scenarios being formed by taking all combinations, as shown in the logic diagram in Figure 2.

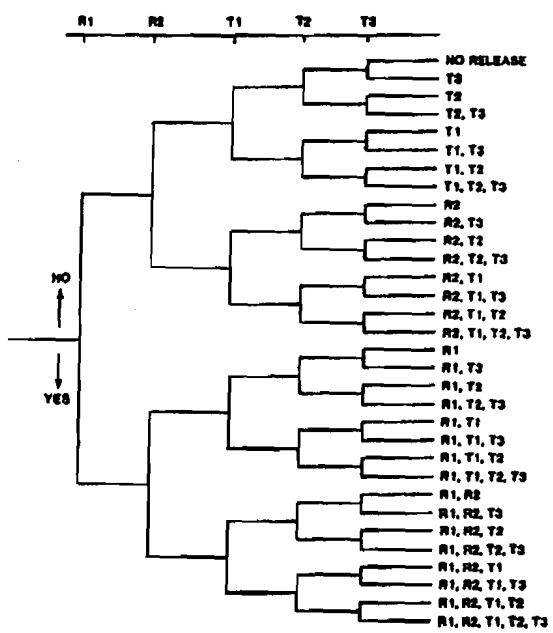

Figure 2: Logic diagram showing potential combinations of two release and three transport phenomena.

All time orderings of processes and events are implicitly included. Second, the scenarios formed are screened according to criteria similar to those used to screen phenomena. However, the criteria need to be applied more rigorously, and a greater degree of consequence modelling is called for. Finally, the remaining scenarios are grouped into a fairly small number of representative groups on the basis of how they may be modelled. This is the transition between scenario analysis and consequence analysis, and requires close cooperation between these areas of expertise and an appreciation of the scope and capabilities of modelling tools.

The recent experience of groups participating in the Scenarios Working Group who have attempted to apply this methodology is reported elsewhere in this symposium [4, 10-12]. In general, they have found it difficult to apply the procedure, principally because of the very large number of phenomena that need to be considered and the variety of potential interactions between them.

In particular, the Swedish attempt to implement the Sandia approach to scenario formation necessitated further developments of the methodology. First the concept of a *process system* was introduced. This contains all the physical and chemical processes operating in all scenarios. The remaining features, events and processes constitute the *external conditions*, and it is these which are combined to form variant scenarios, However, these are too numerous to form scenarios directly and so they have been grouped according to their cause and/or effect. This exercise resulted in external conditions comprising eleven primary phenomena and a further five which are being analysed as isolated scenarios. These are listed in Table II.

TABLE II
PRIMARY FEATURES, EVENTS AND PROCESSES CONSTITUTING THE EXTERNAL CONDITIONS FOR THE JOINT SKI.SKB SCENARIO DEVELOPMENT PROJECT [5]

1. Random canister defects - quality control
2. Backfill material deficiencies
3. Faulting
4. Saline (or fresh) groundwater intrusion
5. Stray materials left
6. Unsealed boreholes and/or shafts
7. Uplift and subsidence
8. Permafrost
9. Human modification of groundwater recharge
10. Glaciation
11. Altered surface water chemistry by humans

Isolated Scenarios

1. Non-sealed repository
2. Accidents during operation
3. Waste retrieval, mining
4. Explosions
5. Post-closure monitoring

Three methods were attempted for forming scenarios from the eleven primary features, events and processes. The first used expert judgement, the second assigned probabilities on the basis of expert judgement and then screened out low probability combinations, and the

third formed scenarios according to whether the three primary barriers (containment, near-field, far-field) performed as expected, less effectively than expected or were completely short circuited.

The conclusion from this and other recent work is that the Sandia methodology needs to be developed further in order to be practicable when large numbers of events and processes are involved. The introduction of the concept of the process system may help in this regard, although there are ambiguities as to whether some processes (e.g., glaciation) should be in the process system or external conditions; this depends on the models available for the assessment.

4.2 Event-Tree Analysis

Event-tree analysis is an inductive technique which has been used to combine failure events for components of engineered systems, such as nuclear reactors, in order to deduce potential failures of the overall system. There are a number of problems with applying event-tree concepts to repository systems [7, 13]. First, phenomena of importance to waste disposal assessments are rather slow and continuous rather than being abrupt events, and repository safety does not rely predominantly on containment by physical barriers. Secondly, feedback loops are not part of the event-tree approach but are important for disposal assessments. Thirdly, event-trees force artificial barriers between the representation of processes, whereas the important question is how the entire system behaves. Fourthly, in common with other bottom-up approaches, the number of combinations which needs to be examined becomes unmanageable unless rather drastic pruning or lumping is undertaken. The final objection to such approaches relates to probabilities, and is discussed in the next sub-section.

Nevertheless, the event-tree approach has been applied to repository systems, for example, by Bingham and Barr [14] and by Hunter et al [15]. The most justifiable application of this technique seems to be repository concepts whose safety is directly linked to the physical integrity of barriers, for example, in salt deposits.

4.3 Probabilities

Estimates of the frequencies of a number of events and processes have been compiled [16] from a variety of sources. Most of the estimates are strongly influenced by expert judgement, but in principle a number of other techniques can be used. These include extrapolation from past frequencies, simulation and worst-case analysis [7].

A comprehensive scenario probability study has recently been made at Sandia [17] covering resource exploration, climatology, tectonics, seismicity and volcanology. This identifies useful sources of information on these topics which can contribute to probability assignment. Nevertheless, the overall conclusion is that probabilities must be assigned largely on the basis of expert judgement.

In principle, probabilistic information about component events and processes could be combined to give an overall scenario probability in a bottom-up approach. In practice, problems arise because the component probabilities are assigned predominantly by expert judgement, and they are very uncertain. Combining such quantities compounds the uncertainty in the overall scenario probability to such an extent that it can be less meaningful

than if it had been elicited directly by expert judgement [16]. In addition, because extensive screening is needed to make bottom-up approaches practicable, the total probability will lie below unity.

5. Top-Down Scenario Formation

As discussed in the last section, it is very difficult to proceed in a structured fashion from a large number of events and processes to a small number of representative scenarios. Also, it is very difficult to assign 'degrees of belief' to scenarios in a coherent way in the bottom-up approach. In order to break this deadlock, it has been suggested that a top-down approach should be taken to scenario formation in an analogous fashion to the use of fault tree analysis for nuclear reactor safety. The top-down approach has been investigated within the Nirex disposal safety assessment programme [12], and a trial application has been made within the UK DoE research programme.

An extreme version of the top-down approach would be to postulate an end point, e.g. an unacceptable consequence, and imagine ways in which this might be reached. This may be a useful exercise by which to broaden the scope of scenarios to be considered, but cannot form the basis of quantitative safety assessment since the scenario set is incomplete and there is no way to assign 'degrees of belief' in a coherent way. One approach is to divide the repository, natural environment and radiological system into component elements, termed scenario elements, and then to postulate a comprehensive set of alternative states which each scenario element may adopt. The stages of a possible top-down approach are as follows:

i) define potential scenario elements;

ii) construct an influence diagram showing dependencies between scenario elements;

iii) define a comprehensive set of states for each scenario element;

iv) form a scenario element state tree in which each combination of states defines a potential scenario;

v) screen the combinations of scenario element states by rejecting non-physical and unimportant combinations to arrive at a set of scenarios for consequence analysis;

vi) assign 'degrees of belief' to each scenario element state taking account of states of other elements via the influence diagram and hence derive scenario probabilities.

Stages (i) to (iii) may be iterated on in order to arrive at a most logical and appropriate definition of scenario elements and states. The list of phenomena discussed in section 3, acts as a check list for the above procedure.

Scenario elements may be defined based on: cause (e.g., natural phenomena, human activities, repository effects) which may be convenient for the construction of an influence diagram; field of effect (e.g., near-field, far-field, biosphere, or release, transport, exposure) which may be convenient as a starting point for modelling; or combinations of these. The main advantages of the top-down approach are that the scenario element states can be defined to be intrinsically comprehensive, and thus 'degrees of belief' can be coherently assigned using expert judgement.

The result of a trial run of this procedure is shown in Figure 3. The 144 potential scenarios reduce to 56 due to the effect of influences among the scenario elements. Calculations

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would first be performed for the base scenario and for combinations of the base scenario element states and one variant scenario element state, and these results would be used to judge how many further scenarios need to be examined. A trial probability assignment exercise has been carried out by a number of independent experts, for the above example.

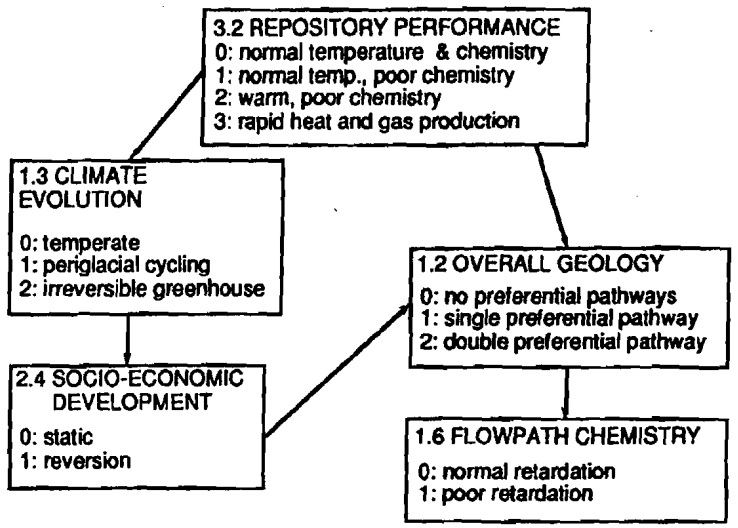

Figure 3: Potential scenario element and states for top-down scenario formation

A more direct top-down approach is to define the scenario elements to be the barriers to migration of radionuclides in fluids (solute and colloids in water; radioactive gases and aerosols in a gas stream). For example, they may be taken to be:

i) containment by a canister;

ii) transport through engineered barriers;

iii) transport through the geosphere.

Each of these could be assigned states such as: performs as intended; impaired performance; short circuit. The definitions of these states are determined by reference to the list of phenomena. This approach is one of the options considered in Sweden [4] and corresponds to the outcome of the recent scenario development exercise in Canada [10].

6. Environmental Simulation

A distinct approach to the problem of scenario formation is to construct a computer model of the evolving environment. The starting point is the list of relevant phenomena discussed in section 3. The most important phenomena are selected from the list according to prescribed criteria and coupled together in a model. It is therefore a variant of the bottom-up approach. The applications of environmental simulation to date have tended to be limited to natural processes, often climate driven, rather than including repository

induced or human induced phenomena. However, in principle the technique is more widely applicable.

The first code of this type to be developed was the Geologic Simulation Model (GSM) which applies specifically to the Columbia Plateau region of the US [18]. This models continuous natural processes and sudden events using Monte Carlo sampling of probability distribution functions (pdf's) for the input parameters. Of course, the results of GSM and similar models, deserve credence only to the extent that the pdf's are justified [18]. Since the pdf's are largely derived from expert judgement, the output results need to be treated with considerable caution. A non-site-specific stochastic environmental simulation model was subsequently developed [19] in the USA containing a far wider range of events and processes, namely: undetected features, climate, glaciation, folding, diapirism, magmatic events, faulting, regional deformation, geomorphic processes, dissolution fronts, breccia pipes, solution mining and drilling. A deterministic model, CASTOR, has been developed in France [20] and has been tested on a hypothetical site in the Fougeres region of Normandy.

The most recent developments have been made by the UK Department of the Environment [22,23]. The initial development was the TIME2 code for assessing disposal into near-surface repositories. This is a Monte Carlo simulation model of essentially climate-driven processes of environmental change in the UK up to the next glacial maximum. TIME2 was used to model environmental change at a potential repository site in Eastern England [22]. More recently it has been used as part of the UK DoE assessment of the low-level waste site at Drigg in Cumbria.

In both of the above cases the environmental simulation results have been used to guide radiological consequence analysis. In the former case, results were used to construct groundwater and biosphere scenarios, representing the site in each of three climate states (temperate, savannah and tundra) which were then analysed separately. In the case of Drigg, the results have been used to construct a single representative future prognosis for the site, and radiological impacts are modelled taking account of changes in environmental parameters in a realistic sequence. This latter approach is made possible by the use of the VANDAL code [22]. VANDAL includes a network representation of groundwater flow which responds to time-dependent changes in boundary conditions and material properties.

The aim of current UK DoE work is to couple directly a newly developed Monte-Carlo simulation model of environmental change over a million years (TIME4) with a new version of VANDAL aimed at the assessment of deep underground disposal. Thus the environmental model will effectively generate a very large number of realisations for a single scenario. TIME4 generates consistent probabilities for these scenario realisations from the input pdf's and allows checks to be made concerning statistical convergence of the results. However, the general caveats concerning probabilities noted in section 4.3 apply to this technique as to other bottom-up approaches.

A conceptual view of a climate-driven environmental system which conditions radionuclide release, transport and exposure processes conventially considered in consequence calculations, and the roles of TIME4 and VANDAL, is shown in Figure 4.

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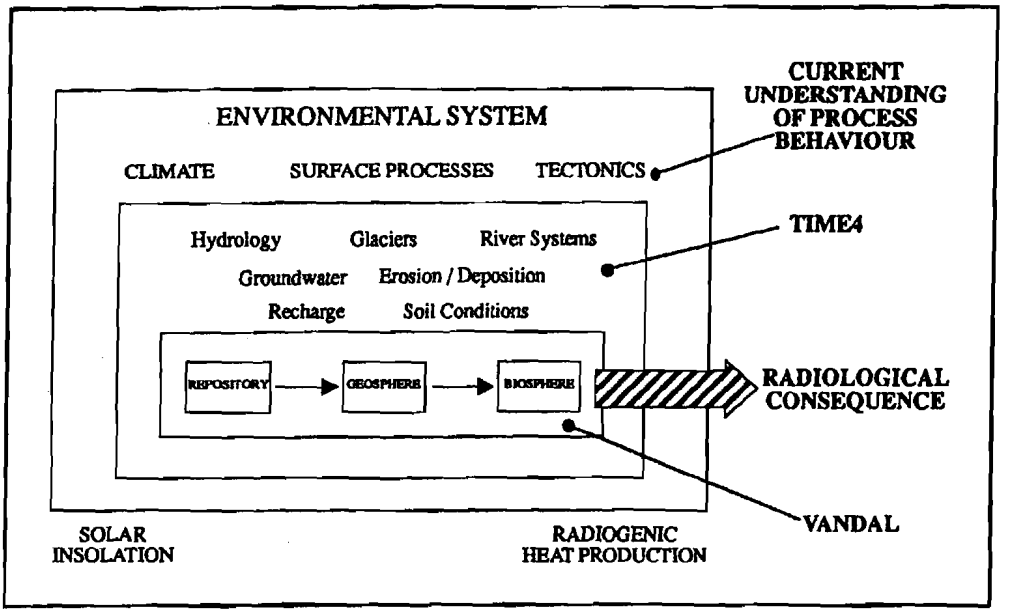

Figure 4: Conceptual view of a climate-driven environmental system, and the roles of TIME4 and VANDAL[23]

Because of the long time required to develop effective environmental simulation and radiological consequence models, it is likely that for any given assessment, phenomena will be identified that have not been represented in the available system model. Thus, additional calculations will be required and these must be sensibly related to the calculations performed by the system model.

The UK DoE work is motivated by the need to take a systems approach to the complex problem of assessing risk in situations where there are large numbers of inter-related and uncertain phenomena. A strength of the simulation approach is that the act of formulating a model forces the assumptions to be examined and documented clearly. Also, it provides a rigorous way of dealing with interactions between phenomena, and of creating coherent time sequences. Since the model is so complex, the problems of understanding and presenting the results are very challenging. The major disadvantage of the simulation approach, and the reason that the work was discontinued in the USA, is the difficulty in obtaining reliable probability density functions for the large numbers of input parameters.

7. Conclusions and Outlook

The NEA Scenarios Working Group has proved to be a very valuable forum for exchanging ideas and information on scenario analysis. It has acted as a stimulus and a focus for a number of new scenario analyses, some of which are reported at this symposium. In view of the variety of regulations and many purposes for performing scenario analyses, it has not proved possible to agree on a single approach. Rather, the attributes and uses of the spectrum of possible approaches have been examined. In this way consistency between approaches and methodologies has been promoted, as required by the objective of the group.

In any particular assessment, a combination of approaches is likely to be used.

A particular conclusion of this work is that expert judgement plays an important role in the identification and selection of scenarios and in assessing their likelihood. In view of this, it is recommended that systematic procedures are followed and that each step is carefully documented so that it is amenable to scrutiny.

Moreover, the likelihood of occurrence of scenarios and their component phenomena are rarely true probabilities and should not necessarily be combined using probability theory. In view of the large uncertainties, it may prove more reliable to assign a likelihood to a scenario rather than build it up from the likelihood of component phenomena.

There is wide agreement about the general approach that should be taken to the identification, classification and screening of phenomena, also about the range of phenomena that need to be considered. To date most attention has been paid to groundwater migration pathways. In future, human actions, gaseous migration and effects of natural environmental changes need to be considered in appropriate detail. Furthermore, there has been a tendency to consider relatively sudden events which disrupt the physical integrity of part of the system. Chemical interactions often play a vital role in securing the isolation of wastes. Thus more attention needs to be focussed on processes which could lessen the impact of chemical constraints

Three general approaches have been identified to the difficult problem of combining phenomena into scenarios: current and planned applications, especially to real sites, should give a better understanding of the range of applicability of these methods.

This work has concentrated on defining the broad range of futures to be considered in a safety assessment. There remains the difficult problem of moving from this to the definition of specific calculations where the models and data are defined.

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