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UNITED KINGDOM NIREX LIMITED

Rock Characterisation Facility

Longlands Farm, Gosforth, Cumbria

PROOF OF EVIDENCE

OF

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MULTI-ATTRIBUTE DECISION ANALYSIS FOR RECOMMENDING SITES TO BE INVESTIGATED FOR THEIR SUITABILITY AS A REPOSITORY FOR RADIOACTIVE WASTES

CONTENTS

1. PERSONAL DETAILS

1.1 I am Lawrence Douglass Phillips, employed part time by the London School of Economics as a Senior Research Fellow, with the rest of my time devoted to my own Company, Facilitations Limited, of which I am one of two directors. At the LSE I teach behavioural decision theory (the study of how people form preferences, make judgements, deal with uncertainty and take decisions) and decision analysis (the art and science of how people can be helped to make better decisions). I also supervise the research work of PhD students. My work through Facilitations Limited involves applications of decision analysis to strategic and operational management, risk analysis, options evaluation, prioritisation, resource allocation and crisis management. I work mainly as a process facilitator of work groups and decision conferences, helping individuals and teams to use their different perspectives on the issues of concern to create a shared understanding of the issues, to build a sense of common purpose and to arrive at an agreed way forward.

1.2 My first degree, from Cornell University, is in Electrical Engineering. A brief spell in the US Navy aroused an interest in the interaction between people and machines, so I took up post-graduate study in engineering psychology, human learning and decision making at the University of Michigan, receiving in 1966 a PhD in experimental psychology. Curiosity about how people in other parts of the world make decisions and deal with risk led in 1966 to post-doctoral research in England. I was then appointed to the staff of Brunel University in the newly-created School of Social Sciences where I taught Bayesian statistics, introductory psychology, social and personality psychology, decision theory and behaviour in organisations. I trained in observation and group processes at the Tavistock Clinic and Institute of Human Relations in the late 1960s and at periodic times since then. I created the Decision Analysis Unit in 1974 as a self-funding research unit, which moved to the LSE in 1982. At the time of the Nirex site selection task, in the autumn of 1988, I was the Director of the Decision Analysis Unit.

1.3 My early research focused on how individuals deal with uncertainty, and I discovered, with Professor Ward Edwards who initiated the field of study known as behavioural decision theory, a phenomenon we called 'conservatism': the failure of individuals to become as certain in the face of data as they could(1). Then, in the mid-1970s, I found evidence, with George Wright, of cultural differences in people's assessments of uncertainty(2). My research in the 1980s shifted to aspects of decision making in groups. My research publications span organisation theory, behavioural decision theory, decision and risk analysis, Bayesian statistics and cultural differences in dealing with uncertainty. I am a member of the British Psychological Society and was elected Chairman of the Mathematical and Statistical Section of the Society for 1975. I am also a member of the American Psychological Association and Informs. I have served on the editorial boards of *Acta Psychologica*, the *Journal of Forecasting* and the *Journal of Behavioral Decision Making*. I am a founder-director of the Medical Benefit/Risk Foundation, a UK charity working for the safer use of medicines.

1.4 My interest in finding ways of helping individuals and groups realise their capabilities led me to combine my interests in decision theory and group processes, developing an approach to group problem solving known as decision conferencing. This is a two- or three-day meeting attended by key players who wish to resolve particular issues of concern, helped by an impartial facilitator and some on-the-spot computer modelling of people's judgements about the issues. Since my first decision conference in 1981, I have conducted well over 100 of these meetings for national and international organisations in the private, public and charity sectors, including, recently, the Department of Trade and Industry, the National Audit Office, the Ministry of Agriculture, Fisheries and Foods, the Ministry of Defence, Pfizer Central Research, Bristol-Myers Squibb, Janssen Research Foundation, International Federation of Health Funds, BUPA, Action Aid, Barnardos and London Lighthouse. In most of these decision conferences I applied multi-attribute decision theory in modelling participants' judgements about the issues, though each application was unique to that group.

1.5 I bring two areas of expertise to this inquiry. One is in applications of multi-attribute decision analysis (MADA), while the other is in group processes. In the mid-1970s I tested the applicability of decision analytic modelling, including MADA, to various parts of the business of Commercial Union Assurance Company, including decision making in underwriting, risk assessment, claims management and strategic management. In one major project, I developed a computer-based underwriting system that incorporated the collective expertise of groups of head-office underwriters(3). This project stimulated an interest in developing methods for obtaining risk assessments from groups of experts, each of whom has a different perspective on the risk. One of my first applications of this new approach concerned the risk associated with changing the design of a company's successful main product. A decision tree was used to model the various future scenarios and the uncertainties associated with future events, and the possible consequences were modelled using MADA. The model was presented to the company's board, whose members used it to try out different assumptions, leading them to agree about the way forward, while retaining difference of opinion about details(4). This work introduced my notion of requisite decision modelling: that models need only be sufficient in form and content to resolve the issues at hand. As I will indicate later, this approach substantially influenced my work with Nirex on site selection. Experience with MADA modelling in decision conferences showed that participants would typically find the model helped them make a decision, but the decision taken might subsequently be different from the overall most preferred option in the model. This led me to develop further the idea of requisite decision modelling, distinguishing it from other types of models such as normative (what people should do), satisficing (what people do when the cost of thinking is too great) or descriptive models (what people actually do) and showing how it could lead to new insights about important and complex issues when used in a group context(5). Later, I showed how requisite decision modelling and MADA could be applied to major technological projects(6).

1.6 My expertise in group processes has steadily grown since the late 1960s, stimulated by my work in developing group approaches to decision analytic modelling. One application that followed soon after the work with insurance underwriters involved groups of specialists assessing the potential reliability of operators in nuclear power stations experiencing emergency conditions(7). I have tried to apply much of the experience of the Tavistock Institute of Human Relations on group processes(8) to the process of decision modelling in groups(9), often assisted by my wife MaryAnn who is a specialist in group processes. Our work together in facilitated work groups and decision conferences, and in training decision conference facilitators, led to the publication of a paper discussing the theory and practice of working with these types of groups(10). Most recently, we have been applying this approach, along with MADA modelling, to creating and managing the research and development portfolios of drugs in pharmaceutical companies(11).

2. SUMMARY

2.1 This proof of evidence provides further information and technical detail about the selection of a short list of sites recommended in the autumn of 1988 to Nirex for further investigation.

2.2 Five meetings, conducted as facilitated work groups and facilitated by myself, were held during which a multi-attribute decision analysis was carried out of 12 potential sites. Participants represented perspectives on the information and judgements needed to draw up a short list. The modelling process was conducted in the LSE Pod, a special room designed to increase the productivity of meetings, and the model was implemented in the computer program HIVIEW, which provided instant playback of results that were displayed on a screen in the Pod. The final MADA model created was considered by the group to be sufficient in form and content to allow participants to agree a short list of sites to recommend.

2.3 The MADA model consisted originally of 12 potential sites as options, 30 attributes or criteria that distinguished the sites in varying degrees, evaluations of the sites on the attributes and weightings of the attributes to reflect their relative importance. The group identified the attributes and organised them hierarchically clustered in four main groups, costs, robustness, safety and environment. Performance measures, rating scales or directly-assessed preferences were determined for all sites on all attributes. Performance measures and rating scales were linearly converted to preference scales, and for one attribute a non-linear transformation was developed. Ranges of possible values of performance measures, ratings or preference scores were agreed for all attributes, and the differences represented by these ranges were judged for their relative importance when participants assessed attribute weights. Preference scores represented 'best guess' evaluations of the options on the attributes. Uncertainty in many of the best guesses was taken into account by establishing high and low values that represented 90% intervals of confidence around the best guesses.

2.4 The 'swing weight' method of assessing weights was used, and many consistency checks were carried out. This method required participants to consider differences on the preference scales and how much those differences mattered as compared to one another. The group recognised that different groups might differ in the weights they assigned to the attributes, and many sensitivity analyses were subsequently carried out to test the robustness of the model's results to differences of opinion about the weights. The weights assessed by the group reflected the relative importance of the attributes, and together with the preference scores they provided a means for discriminating amongst the sites.

2.5 Considerable discussion and debate, resulting in revisions to the model, attended the process of evaluating the sites on the attributes and of assessing attribute weights. Once these were agreed by the group as a base case model, overall preference scores were obtained by multiplying preference scores by attribute weights and summing over all attributes, a simple weighted average.

2.6 The group explored the model in many ways to deepen insight into the best sites. Overall results were examined under several different weighting systems; several sites were identified that performed consistently well. Another type of analysis looked at overall scores at one node as a function of overall scores at another node, eliminating the need to consider the weights at those nodes. These analyses showed that several sites consistently were less preferred to others. Sensitivity analyses on individual weights were conducted for all the weights; these showed that a subset of sites remained amongst the best sites under wide variations in the weights. This proved to be true even when pessimistic scores were substituted for best guesses. Many 'sorts' were carried out to identify the attributes that constituted relative advantages and disadvantages of each site and to compare pairs of sites.

2.7 From these many analyses a picture emerged of three sites that could be recommended for further investigation, with possible merit in a further two. The group agreed to draw up three lists consisting of three, four and five sites, and these three lists were recommended to Nirex.

3. SCOPE OF EVIDENCE

3.1 The purpose of this Proof of Evidence is to provide further information and technical detail about the task of selecting sites for further investigation as undertaken by the Decision Analysis Unit of the LSE for Nirex in the autumn of 1988.

3.2 Section 4 sets out the context in which this task was carried out. It establishes the purpose of the task and sets out the group roles of all participants. It explains my socio-technical approach, how I applied the theory of requisite decision modelling to ensure that just the right amount of modelling was undertaken to serve the purpose of this task, and why MADA was chosen to provide a means for bringing together the data and judgements about the site options. Finally, I describe the physical setting in which the task meetings took place and indicate why this was an important contributor.

3.3 Section 5 begins with a brief description of MADA and explains the version used in this analysis, including a brief description of HIVIEW, the computer program that facilitated the MADA analysis. I indicate how the attributes were selected and modelled, and I distinguish between performance measures, rating scales and preference scores. The methods I used to arrive at preference scores directly or from performance measures are explained, as are the techniques for assessing attribute weights. I discuss the important role of social processes in arriving at agreed judgements.

3.4 Section 6 describes the process of iterating to a shared understanding within the group. I explain the various types of output displays provided by the model, the role of sensitivity analyses and the method of looking at each site's advantages and disadvantages and of comparing pairs of sites.

3.5 The final section provides detailed answers to criticisms presented in Proofs of Evidence submitted by Dr Andrew Stirling on behalf of Greenpeace and Mr Colin Parker on behalf of Cumbria County Council.

4. CONTEXT

4.1 I attended several meetings with Nirex staff and a team of specialist consultants from early June to mid-September 1988 to discuss the potential for MADA in helping Nirex reduce a list of 12 potential sites to serve as a deep repository for low- and intermediate-level radioactive waste down to a short list that could be recommended to Nirex for further investigation. I recommended the use of MADA because it is theoretically sound, proven in practice, had been used in the USA for a similar task following a recommendation by the National Academy of Sciences, separates matters of fact from matters of judgement, brings together in one model evaluations of all options on all attributes to give an overall scoring of the possible sites, and provides an audit trail of the resulting recommendations. Nirex then engaged the LSE's Decision Analysis Unit to carry out this work, and five meetings were held between September and November 1988.

4.2 Participants at the meetings included:

Mr H Beale	Nirex	Co-ordinator
Mr A Davies	Nirex	Presenting repository costs
Mr G Hickford	Nirex	Presenting pre-closure safety and robustness
Mr D Bennett	Nirex	Transport specialist
Dr N Chapman	BGS	Geology specialist
Dr T McEwen	BGS	Geology specialist
Mr C Eastman	JMP	Transport specialist
Mr D Billington	UKAEA	Post closure safety assessment specialist
Dr D Lever	UKAEA	Post closure safety assessment specialist
Mr C Balch	Pieda	Planning/Environmental specialist
Prof R Nicol	Pieda	Planning/Environmental specialist
Mrs F Graham	Pieda	Planning/Environmental specialist
Dr L Phillips	LSE	Facilitator
Dr S Barclay	LSE	Analyst

4.3 I chose to conduct these meetings as facilitated work groups. My role was to guide the process, with members participating in the discussion and contributing content as experts in their own fields. I also helped structure the model, attended to group processes and intervened as necessary to keep the group oriented on the task. My colleague from the Decision Analysis Unit, Dr Scott Barclay, served as the analyst, attending to the on-the-spot computer modelling during the meetings.

4.4 I guided the group through the stages of the analysis within a socio-technical framework. The social element involved a team of people representing perspectives that could contribute to formulating a recommended short list of sites for more detailed investigation, the interactions of the participants to create a shared understanding of the potential of the sites and the expert judgements of the participants. The technical element provided the means by which the participants' judgements and assessments were used to construct an overall relative preference scoring of the potential sites, i.e., MADA as implemented in the computer program HIVIEW.

4.5 A further guiding principle was my theory of requisite decision modelling which states that a model serving decision making need only be sufficient in form and content to resolve the issues at hand. In this case, the goal of the analysis was a short list of sites to be recommended to Nirex for further investigation, not site selection itself. Thus, the model needed to be only as complex as needed to accomplish this goal. Requisite models are created by iterative and consultative interaction between key players, with the interaction in the group driven by the sense of unease that arises between participants' intuitions and the resultant model. When the unease is gone, and no new intuitions about the issues arise, the model is considered requisite. The status of such a model is at best conditionally prescriptive, not normative, descriptive or satisficing, in that it indicates what option is relatively best *given* the input data and judgements and the agreement of the group about how much those inputs can be different yet still give the same overall results. This feature is difficult to describe adequately and has to be experienced for a full understanding. In essence, I worked with the group trying out different judgements and weightings, flexing the model, looking at the results from different viewpoints, until eventually a clear qualitative picture of the most preferred sites emerged. This enabled the group to agree unanimously on three short lists of 3, 4 and 5 sites recognising uncertainties about many of the evaluations, disagreements about weightings, and assumptions about how different interest groups would weight the attributes.

4.6 Finally, I should mention the physical setting in which the meetings took place, the LSE Pod. This is a room originally designed by ICL as a work room in which all participants are in eye-to-eye contact with each other, and have an unobstructed view of all boards and visual aids. The air-conditioned room is octagonal in shape, participants are seated in comfortable chairs at a round table, and the walls present a variety of screens, whiteboards and a self-copying board. Transparencies or hard copy can be projected onto a large screen, 35mm slides can be shown, and the output of a computer can also be projected onto a screen. All devices are switched on or off and the lighting dimmed using a hand-held infra-red controller. Thus, everything needed to facilitate a group's work is available in an instant. The room is designed to facilitate the interaction of participants without the intrusion of technology. Experience with the LSE Pod, and research on specially-designed meeting rooms in general, indicates substantial gains in group productivity over ordinary meeting rooms. The LSE Pod is a modified version of the ICL design intended specifically for facilitated work groups and decision conferences.

5. THE MODEL

5.1 MADA is a theory-based methodology that enables evaluations of options on relevant attributes to be combined giving one overall evaluation. The complete theory was first described by Keeney and Raiffa(12) who set out the various forms of MADA and provided many real-world applications of the approach. For the Nirex site selection task, I considered a simple additive form of MADA to be appropriate. Additive MADA models are compensatory: losses on one attribute are compensated by gains on another (e.g., in deciding which car to buy, you might give up some performance for a lower cost). Because a thorough sieving process had already been undertaken, as explained by Mr Folger, the sites under consideration were judged to be at least acceptable on the attributes of concern, so that additional value on one attribute could compensate for less on another. Von Winterfeldt and Edwards(13) have shown that violations of the assumption of preference independence(14) that underlies the additive model is usually of no real consequence. In any event, the objective for this task was for the group to agree on a short list of sites, not pick the best one, so the additional work of carrying out all possible preference independence checks and using more complex modelling to accommodate violations seemed not to be justified. However, I used a method of assessing weights, explained below, which usually reveals serious violations of preference independence, and none were detected.

5.2 The MADA model was implemented using the computer program HIVIEW which was developed by Dr Scott Barclay for the Decision Analysis Unit and has sold several hundred copies world wide to decision scientists and others. HIVIEW was based on earlier work carried out in the United States by Decisions and Designs Incorporated under contract to the US Department of Defense's Advanced Research Projects Agency. HIVIEW presents a very user-friendly interface for constructing a hierarchical model of attributes, entering data, viewing results in different ways, conducting sensitivity analyses and comparing options. By projecting the output of the computer in the LSE Pod, it was possible to show results as soon as data were input. This instant play-back of results helped the group to gain an understanding of the sensitivities, or otherwise, of the model, and enabled participants to develop a deeper understanding of the relative merits of the proposed sites.

5.3 In my preliminary discussions with Nirex, I indicated that the meetings would proceed through several stages:

- identifying attributes and measures of performance for the attributes;
- establishing ranges of those measures for the sites;
- constructing a hierarchical value tree of the attributes;
- agreeing values of the performance measures for all options on all attributes;
- determining value functions to transform the performance measures into preference scores;
- weighting the attributes and establishing trade-offs;
- combining the assessments and examining overall results; and
- conducting sensitivity analyses to determine the robustness of overall results to different weightings and scores.

Building the hierarchy of attributes

5.4 In the first meeting of the group, after the 12 sites had been listed, I asked participants to identify all stakeholders perceived by the group as being interested in the choice of a short list of sites. These included:

- Nirex Board
- National Environmental Groups
- Local Residents
- Local Authorities
- Treasury
- Regulatory Bodies
- Politicians
- Scientific and Technical Community
- European neighbours

I then invited participants to role play any of these stakeholders and write down five *factors* that should be taken into account in evaluating the sites. I also asked them to list *objectives* that should be met by a satisfactory site, and I asked them to consider what they individually thought were the *pros and cons* of the sites. Listing the factors, objectives, and pros and cons, and discussing them helped all of us to construct a value model showing the attributes and higher-level nodes. This is shown in Figure 1, where 30 attributes are grouped under four major nodes, costs, robustness, safety and environment. Some discussion of preliminary results from *The Way Forward*, the Nirex public consultative exercies, provided input to the selection and subsequent weighting of attributes, though because the analysis of responses from that exercise was not yet complete, there could be no formal linking of that exercise to the site selection task.

Evaluating the options

5.5 As noted above, MADA combines evaluations of options on many attributes into one overall evaluation. Evaluations of each option on an attribute were expressed as preference scores. Three methods were used to obtain preference scores:

- **Direct assessment**. Preference scores were judged directly for some attributes.
- **Rating**. Rating models were constructed for some attributes, with different features of the sites gaining points that were weighted and summed to give an overall rating on an interval scale(15). These ratings were then converted linearly to preference scores.
- **Value function**. A quantitative performance measure was established for some attributes, and the values of the performance measures for the site options were converted linearly to preference scores (always ensuring

that the more preferred performance measures were assigned higher preference scores). In one case, post-closure safety to the individual, attribute 18, the preference scores were based on a non-linear value curve (see Figure 2). Because considerable uncertainty attended the assessments of annual dose at most of the sites, an attempt was also made to accommodate participants' aversion to risk induced by this uncertainty. To do this, a utility curve, which reflects both strength of preference and risk aversion, was assessed for attribute 18, but it was almost identical to the value curve so the latter was used.

Initially, the 'best guess' evaluations were used to generate preference scores of the options on the attributes. Participants recognised that uncertainty attended most of these evaluations so I asked them to provide 90 per cent intervals of confidence around each best guess, i.e., a low and a high value of the evaluation such that there would be a 90% chance that the eventual true value would lie between those limits. For attributes that already expressed uncertainty, such as some of the robustness attributes, it was not appropriate to give confidence intervals. For three of the pre-closure safety attributes a great deal more work would have been needed for the experts to provide confidence intervals, and in light of the overall low weighting on the safety attributes, the extra work would not have appreciably affected the overall scores of the options. Thus, additional work would have exceeded the requirements of requisiteness. For the four post-closure safety attributes uncertainty was considered to be expressed entirely by intervals of confidence on attribute 18, safety to individuals, and additional work on the other three would not have been requisite.

5.6 A potential source of confusion is the ranges that were established for all attributes. These ranges were arrived at in a variety of ways and were sometimes modified during the course of the analysis. Suffice it to say that associated with each attribute was a range of possible preference scores, ratings or performance measures, whichever was the form of the input data. The original intention in defining these ranges was to ensure that any input value used in subsequent analyses, whether optimistic, pessimistic or best guess, would result in a preference score falling between 0 and 100. (Only for one site on one attribute, offshore east on capital repository costs, was the range exceeded, and in this case negative preference scores were assigned rather than changing the range and the weight on the attribute.) One consequence of this decision was that when sites were subsequently dropped from the analysis, the remaining sites did not always display the full range of difference on the attribute. For example, scores of the 12 sites on short-term post-closure safety to society were all assigned preference scores of 100 except for one site which was given a zero. That site was eventually dropped (see paragraph 6.2), leaving only sites scoring 100 on this attribute. Thus, the weight on this attribute now seems irrelevant, which it is, although it made sense with the original 12 sites. The original ranges were important because they established the difference in preference for each attribute, and these differences in preference were one consideration in assessing weights. The ranges for the attributes are shown in Table 1.

5.7 For attributes associated with performance measures or ratings, the least preferred value in the range, x_{low}, was assigned a preference score of 0 and the most preferred value in the range, x_{high}, given a value of 100. Then, when performance measures or ratings, *x*, were agreed, HIVIEW converted them linearly to preference scores, assigning values between 0 and 100, inclusive. For the remaining attributes, direct assessment of preference scores was carried out by asking the group to identify the most and least preferred sites on that attribute, assigning those sites values of 100 and 0, respectively, and then scoring the remaining sites such that differences between the preference scores reflected differences in strength of preference. I used difference scaling techniques(16) to ensure the consistency of the resulting scales. That is, if site A was given a preference score of 80, site B a 40 and site C a 20, I would ask the group if the difference in preference between A and B (i.e., 80-40) was really twice as great as the difference between B and C (i.e., 40-20). A group consensus about the preference scores was always obtained. The final input data to HIVIEW, performance measures or preference scores, for all options on all attributes are shown in Table 2. The preference scores (after performance measures have been converted to preference scores) for all options on all attributes are shown in Table 3.

The MADA model

5.8 The simple additive model that characterised this MADA approach combines preference scales by taking weighted averages. That is, letting sij represent the preference score of option i on attribute j, then the overall score Si for option i is given by:

$$S_i = S\, w_j s_{ij},$$

j

where w_j represents the weight associated with attribute j (assessing the weights is discussed next). In practice, the weighted-averaging model was applied first within each grouping of elemental attributes after the weights associated with the attributes in each group were normalised to sum to one by dividing each weight by the sum of the weights in the group. This normalisation process preserved the relative weights of the attributes and ensured that the final overall result gave averaged scores on a 0 to 100 scale, thereby easing interpretation of results. This averaging process was repeated up through the hierarchy until a single overall score was obtained for each site.

Assessing the weights

5.9 The process of weighting the preference scales (one for each attribute) is essentially a process of equating a unit of preference on one scale with a unit of preference on another, much as the ratio of 9 to 5 expresses the relationship of units on the Fahrenheit and Celsius scales, respectively. For the cost attributes weights were assigned in proportion to the ranges of costs. To start, I noted the ranges of costs for the first two attributes, capital and operation transport costs. Transport costs (over 50 years) showed the largest range, £1,650 million, so this attribute was given a weight of 100. The range for capital transport costs was £650 million, so this attribute was given a weight of 100 × 650/1650 = 40. The range on the third attribute, capital repository costs, was £1,650, coincidentally the same as transport operation costs, so this attribute was also weighted at 100. The range on repository operation costs was £3,300, so its weight was put at 200. Of course, the absolute values of these weights is of no importance since they are normalised before being used, but their relative values are important. Thus, the weights can be interpreted as reflecting the relative importance of the attributes.

5.10 For the remaining attributes, the swing-weight method(17) of assessing weights was used, but it was realised by applying different techniques depending on how much difficulty the group experienced in making the assessments. These techniques were aimed at helping the group to consider the swing in preference from 0 to 100 on one scale as compared to the swing in preference from 0 to 100 on another scale. When I was asked how to make this comparison, I replied that participants should take account of the range established earlier for the attribute to establish how big the difference on that attribute was, *and* how much they cared about that difference. There is, of course, no simple way to separate these two influences on the weights. If you are considering purchasing a car, presumably the cost of the car is of considerable importance to you and would be weighted heavily. However, if you were to draw up a short list of cars, and they differed by only £100 in cost, then it is likely that you would not give much weight to the attribute. If the cars differed by £5,000, then your weight would be more. But if you are very wealthy, then the weight might still be negligible. This illustrates that the actual difference in cost is not sufficient to assign a weight; how much you care about the difference is also a consideration, and this depends on your personal circumstances. The group recognised that different interest groups might judge the weights differently because they would care differently. I suggested that they are the group charged by Nirex to make a recommendation, so in the first instance they should assess the weights as they judge them in their professional roles. Later we would change the weights to simulate the perspectives of different interest groups to see the effect on the overall scores. Whatever the technique used to assess the weights, I made further consistency checks along the following lines. If an attribute had been weighted 100 and one site given a score, say, of 80 on that attribute, and another attribute had been weighted 80, then I asked the group if a swing from 0 to 80 on the first attribute weighted 100 was equivalent to the swing in preference on the second scale from 0 to 100 weighted 80. Often this sort of check was accepted, and helped the group to see that they were being consistent. But when the group did not agree, we went back and revised the offending scores or weights to achieve consistency.

5.11 For three of the four major grouping of attributes, one attribute was always assigned a weight of 100, and this attribute was then used as a standard against which all other weights were judged. The exception was the safety attributes, as noted below. I presented the group with many consistency checks, comparing weights on other attributes within the grouping to ensure that they also made sense relative to one another. On the few occasions when they did not, revisions were made. These methods of weighting allowed weights at higher nodes within each of the four major grouping to be determined by adding the weights from the lower levels. For example, with weights of 40 and 100 on the capital and operation transport cost attributes, the weight on the transport cost node became 140. The group was invited to judge the adequacy of these summed weights compared to each other, with the result that two slight adjestments were made, both within the robustness group. One was in geological certainty: weights on the two attributes under this node added to 82, but the group felt the node should be weighted equally with known engineering, whose weight was 100. The other was on the repository node: the lower-level weights summed to 290, but the group felt this was too high compared to the transport node weight of 60, so the 290 was reduced to 250.

5.12 Weights on the nodes representing the four major groupings could not be made by summing lower-level weights because the attributes assigned weights of 100 within each grouping were not necessarily equal in relative importance. Of course, it would have been possible to assess relative weights for those 100-weighted scales, but instead the group elected to examine the trade-offs implied by different sets of weights on the four upper-level nodes. Equal weights gave seriously unacceptable trade-offs between costs and deaths. Other weighting schemes were examined, and eventually the group agreed to accept weights of 100 on costs, 20 on robustness, 10 on safety and 10 on environment as a base case, while recognising that other weights should be looked at in sensitivity analyses. It is worth noting that the weight of 100 on costs and 10 on safety does *not* mean that costs were considered to be ten times more important than safety. What it does mean is that the difference in costs was judged to be ten times more important than the difference in safety for the sites considered. This judgement was the consequence of valuing a life at £300,000, a figure twice that recommended at the time by the NRPB(18) for valuing lives in a radiological protection context.

5.13 A consequence of the weights on all attributes and nodes can be seen in Table 4. There the attributes have been ordered by their cumulative weight, the product of the normalised weights from the top of the hierarchy down each branch to the final end attribute. In a sense, the attribute hierarchy can be viewed as a plumbing model: if 100 cl of liquid were poured in the top, then the amount going down each branch would be determined by the relative weights, with the cumulative weight representing the amount of liquid reaching the bottom attribute. These cumulative weights show the discriminating power of the attributes; cost attributes at the top because the sites are most different in ways that matter with regard to costs, and with three safety attributes at the end. It must be borne in mind that these cumulative weights are the consequences of the group's judgements given the information available in the autumn of 1988 and may not reflect the actual differences between the sites if full and perfect information were to hand.

5.14 The scoring and weighting was accompanied by much discussion amongst participants in the group. An individual reporting scores that had been developed by the organisation he represented rarely went unchallenged. For example, one person might know more about costs, and another more about geology, but the geologist might challenge the assumptions about geology that were made in arriving at construction costs. By presenting their organisation's work at developing scores for the sites on a particular attribute, each participant subjected the scores to considerable peer scrutiny, with the result that many revisions and changes were made throughout the process for nearly every score. The final performance measures, ratings and preference scores were the result of considerable discussion and debate, and represented the shared understanding of the group.

6. EXPLORING THE MODEL

6.1 A key feature of requisite decision modelling is the iterative nature of the process. Participants are reminded to keep a constant check on any features of the model while it is being created, and to express any sense of disquiet. Exploring the sense of unease usually reveals either aspects of the model that need refining, or shortcomings in people's intuitions and judgements. Once all the inputs to the model have been provided, results can be examined, and this is the stage where vigorous exploration of any sense of unease reveals inadequacies that must be resolved. It would be impracticable, not to say impossible, to recreate here this iterative process, but I will illustrate in this section the kinds of results examined by the group to give a feeling for how the final short lists were selected.

Overall results

6.2 The first, and most obvious, analysis was to look at the overall results using the base case weights. Table 5 gives the overall result in the Total row. The other rows show the weighted average evaluations up to that level in the hierarchy(19). (Note that a higher preference score on costs means lower cost.) This shows that Sellafield B is overall most preferred, and Offshore Deep is least preferred. (I have provided the overall results for all 13 sites that were at any time considered in the decision analysis process. Of the 12 original sites, two were dropped at the fourth meeting for the purposes of further investigation because they consistently scored poorly overall whatever weights were used. Two further sites were kept in reserve as surrogates for two other sites that were very similar on all scores. Of the remaining eight, offshore west was split into two, shallow and deep, resulting in nine options taken forward at the final meeting in the Pod. However, this makes a total of 13 sites that were considered at some point in the anlysis.)

6.3 The group also examined the overall results with different weighting systems intended to simulate a local perspective, which put no weight on costs, only 10 on robustness and 100 on impact, split equally between safety and environment. Another weighting system simulated a national environmental view, with no weight on costs and equal weights on robustness, safety and environment. An economic view was explored, with a weight of 200 on costs, 40 on robustness, none on safety and 10 on environment. Finally, a local community view was simulated by making changes to 23 weights in the model. Making changes to lower-level weights made it possible to take account of nuances in a local community view by differentially increasing some weights and decreasing others. The results of these analyses are shown Table 6.

Node versus node results

6.4 Another type of analysis avoided the need to consider weights on the four top-level nodes. This was accomplished by displaying the overall scores up to one node as a function of the overall scores up to another node. Figure 3 shows the overall preference for robustness versus overall preference for cost. An ideal site would be in the upper right portion of the figure, most preferred for both robustness and costs (i.e., relatively robust and relatively lower in cost). The shading defines the border beyond which no sites are more preferred. If all weight were put on costs, then site 7, Sellafield B would be most preferred. If all weight were on robustness, then site 3, Site B, would be most preferred. With equal weight on these two criteria, a 45-degree line from upper left to lower right would define the trade-off between robustness and costs, and moving that line as far to the northeast as it can go while still intersecting with a site's position, defines the search for the most preferred option, which is option 3, Site B. Since the slope of that line reflects the relative weights between the two criteria, it is clear that over a wide range of weights, site 3 will remain most preferred on these two attributes. Sites within the shaded area should be compared to sites on the border. Sites 8 and 9 are clearly well inside the curve; all the others are better in both costs and robustness, whatever the weights put on these nodes. Site 6 is also relatively less preferred, for sites 5 and 7 are judged to be more robust at no additional cost. Site 3 is both less costly and more robust than sites 1 and 2. This leaves just four sites, 3, 4, 5 and 7 as possible candidates for a short list, given only these two nodes. Repeating this sort of analysis for other combinations of nodes showed that at this level of the analysis sites 2 and 6 were consistently less preferred than the other sites, though site 2 usually fell only slightly behind site 1, Dounreay. The main conclusion from this analysis was that the weights on the four main nodes matter to the overall scores.

Sensitivity analyses on scores and weights

6.5 The group also considered the effect on the overall scores, under both the base case and the national environmental view, of setting best guess scores to their pessimistic values. This had little effect on the relative ordering of the sites; the same group of sites continued to be most preferred overall.

6.6 Another way of examining the model was to conduct sensitivity analyses on individual weights. Sensitivity analyses on the top four nodes are shown in Figures 4 through 7. To understand these, consider Figure 7. This shows the effect on the overall, top-level preference score (vertical axis) of varying the weight (horizontal axis) on the environment node from 0 (no weight at all on this node) to 100 (all the weight on the attribute). As the weight increases from zero, all other weights are reduced but kept in the same proportion to each other. The vertical line at about 7% shows the base-case cumulative weight at this node. This line intersects at the top of the figure with a sloping line that represents the overall preference score of site 7, Sellafield B. As the weight on the environment node increase, Sellafield B remains the overall most preferred option until the weight becomes about 45%; then site 1, Dounreay becomes most preferred overall. Finally, when more than 75% of the weight is placed on this node, then site 8, offshore shallow is most preferred. Sensitivity analyses were carried out for every node in the hierarchy and for all the bottom-level attributes. These kinds of analyses showed that over considerable variations in the weights Sellafield B together with a number of other sites were fairly consistently preferred.

Sorts

6.7 The 'sort' facility of HIVIEW made it possible to look at the relative advantages and disadvantages of each site. An advantage is a high score on a heavily weighted attribute. If the score of a site on an attribute is multiplied by the cumulative weight of the attribute, the result is the 'part score' of the site on that attribute. Summing all the part scores for a site over all 30 attributes gives the site's overall score. HIVIEW carries out this calculation and orders the attributes according to the size of the part score. It is also possible to compare two sites, using the same approach. HIVIEW subtracts the preference scores of two sites on each attribute, weights the difference by the cumulative weight, and sorts the attributes on the size of this weighted difference. Advantages and disadvantages of the more promising sites were checked using HIVIEW's sort facility, and all sites were compared to Sellafield B so that the group could gain a deeper understanding of the significant differences between sites.

Recommendations

6.8 Out of all these analyses, a picture emerged for the group of a short list of at least three sites that could be recommended to Nirex. The exact wording of the recommendations agreed by all members of the group is as follows (except that sites A through D were specifically named):

.	1.	Both offshore sites are overall so poor that they should be investigated only if the land-based sites prove to be unacceptable.
	2.	Sellafield-A is significantly the worst of all land-based sites and should not be investigated.
	3.	Sellafield-B is consistently good; it should be investigated.
	4.	Sites C and D are relatively good, and though Site C is marginally better than Site D, especially under pessimistic assumptions, one of them should be investigated. There is no need to investigate both because they are geologically similar.
	5.	Dounreay and Site A look relatively good and either, or preferably both (because they are geologically different), should be investigated.
	6.	Site B is as good, overall, as Dounreay and Site A, and is particularly good on robustness, but loses as more weight is given to environmental issues. Is should be considered.
	7.	It is recommended that at least three sites be investigated and there may be merit in investigating up to five:

.	If three sites:	Sellafield-B Site 6 *or* Site 7 Dounreay *or* Site 2
	If four sites:	Sellafield-B Site 6 *or* Site 7 Dounreay *or* Site 2 Site 3
	If five sites:	Sellafield-B Site 6 *or* Site 7 Dounreay Site 2 Site 3

7. REPLIES

7.1 In this section I answer some of the points raised in Proofs of Evidence submitted on behalf of Greenpeace and Cumbria County Council. It is my view that the preceding sections of this Proof answer the bulk of the criticisms in those Proofs so I will not take them up specifically. There are, however, a few remaining issues.

Dr Stirling PE/GNP/1

7.2 Dr Stirling sets out in paragraph 2.3 the proper use of MADA in public policy analysis, but I would take issue with the claim that one can ever optimise the choice of an option. Any analysis involving human judgement can be at best conditionally prescriptive: it recommends what is relatively the best option subject to assumptions. Choices, which are made by people, not MADA models, typically go beyond the restrictions of the assumptions and beyond the set of options, including relevant elements that were not part of the MADA model.

7.3 The 'spurious air of precision with attributes weightings' mentioned in paragraph 2.10 reflects a confusion between decimal places and significant figures. All weights were assessed to no more than two significant figures, but when cumulative weights were calculated after normalisation, it was necessary to display the results to two decimal places, as I did in showing the cumulative weights in Table 4, in order to show that very little weight is placed on the bottom 13 attributes.

7.4 The weighting of local experience, referred to in paragraph 2.13, was only 1.3% in the base case model. It had almost no impact on the MADA result.

7.5 Dr Stirling suggests in paragraph 2.15 that weights should be representative of those in wider society. I doubt that such a set of weights exists. Rather there are many sets of weights, reflecting the differing perspectives of different groups of people. We tried, as I indicated in paragraph 6.3, to role play and simulate different perspectives and to see their effect. We also discovered that the final recommendations of the group were robust under widely different assumptions about the weights.

7.6 I agree with Dr Stirling that 'systematic and comprehensive' sensitivity analyses should have been carried out. This document argues that we did.

7.7 In paragraph 2.22 Dr Stirling argues that the ambiguity in the meaning of the weightings undermines confidence in MADA. I would suggest that it is not possible to effect the separation he requires between the importance of an attribute and its ability to discriminate between the sites. My discussion in section 5.10 refers. The weights reflect the magnitude of the difference between *xhigh* and *xlow* on a given attribute, and how much that difference matters compared to other differences. The weightings reflect the relative importance of the attribute ranges, while the overall ability to discriminate depends *only in part* on the weightings and the differences in scores between the sites. I would like to make this absolutely clear with a simple example. Imagine two sites scoring at the opposite ends of two criteria, that is, option A scoring 100 on attribute 1 and 0 on attribute 2, with option B scoring 0 on attribute 1 and 100 on attribute 2. At this level of the analysis, these two attributes discriminate between the sites. However, if the attributes are equally weighted, then the weighted average scores of the two options are both 50. At this level of the analysis, there is no discrimination between the sites. Discrimination at the level of attributes does not necessarily imply discrimination at any given node. It is best to think of discrimination at node level as *emerging* from weighted average differences at the attributes, *and* from the effect of summing those differences over all attributes leading into the node.

7.8 If Dr Stirling is referring to attribute 18, individual post-closure safety, and attribute 21, integrity, in his comment at paragraph 2.23, these are the attributes for which a value curve converted the performance measures to preference scores. The curves were not step functions such that only values of 0 or 100 could be assigned, as would be the case if a strict threshold was imposed. The curve for mSv/yr fell gradually to zero at 0.1 mSv/yr and then leveled off (see Figure 2), so all higher values were given values of zero.

7.9 The apparent scoring of all options at 100, referred to in paragraph 2.24, is a consequence of dropping off some of the original sites, as I explained in paragraph 5.6. With this in mind, his observations in paragraphs 2.25 through 2.27 are irrelevant. We were careful always to retain the original ranges of all attributes throughout the analysis even if for the subset of nine sites the preference scores did not discriminate on attribute 19, safety to society in the first 100,000 years.

Mr C. Parker PE/CCC/6

7.10 In Colin Parker's Proof of Evidence he suggests in paragraph 1.15 that weights should be determined by assessing trade-offs. That is one way to assess weights, as I indicated in paragraph 5.11 above, and I used this approach in determining weights for the safety criteria and for the four major high-level nodes. But other methods are also acceptable, as I have explained. I agree with him that '*an attribute which turns out not to be a discriminator ... should emerge from the analysis, not be an input to it*'. Since discrimination at node level is a function of the differences in the preference scores, the weights and the effects of summing over the attributes, it has to be emergent. That is how the sorts helped.

7.11 Paragraph 1.21 does not take account of the analyses that did not require top-level weights, such as the one I showed in section 6.4. Nothing was 'sidelined' as a result of its being given too little weight without careful examination of the weight in sensitivity analysis.

7.12 Mr Folger's statement quoted in paragraph 1.22 is correct, for he was referring not to differences in performance measures but differences in preference scores.

7.13 Paragraph 1.26 unfairly suggests that only geological profile and safety should be the basis for selecting sites for further investigation. This task looked at 30 attributes, and participants examined the sites from many perspectives in addition to those two attributes. *The Green Book* [GOV/302] itself made clear the need for economic and social factors to be taken into account (Section 3.9) and for transport implications to be fully considered (Section 5.5).

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[14] Preference independence requires that preferences for options on one attribute are unaffected by preferences on another attribute, whether or not the options are correlated in the real world.

[15] An interval scale has an arbitrary zero point and an arbitrary unit of measurement, and only ratios of differences are interpretable.

[16] See von Winterfeldt and Edwards for a full explanation of how these techniques, long familar to psychologists, are used in decision analysis.

[17] [NRX/18/1]. Explained in von Winterfeldt and Edwards on pages 286-287 and in section 8.3, which also covers eliciting values on preference scales.

[18] [NRX/18/2]. Advisory Statement on Protection 9, Cost Benefit Analysis in the Optimisation of Radiological Protection, NRPB, 1986.

[19] Some of the numbers in the table differ by one point from those obtained in the original analysis. The difference is attributable to the handling of rounding numbers in the old and new versions of HIVIEW. The original table was created by the the-current DOS version of HIVIEW, whereas this table was generated by the now-current Windows version. None of these differences affects any conclusion.

NIREX

PE/NRX/18

Appellant Ref: DB/CD 8.5.1
LPA Ref: 4/94/9011
DOE Ref: APP/HO900/A/94/247019

UNITED KINGDOM NIREX LIMITED

Rock Characterisation Facility

Longlands Farm, Gosforth, Cumbria

PROOF OF EVIDENCE

OF

Dr L D PHILLIPS
BEE, PhD

MULTI-ATTRIBUTE DECISION ANALYSIS FOR RECOMMENDING SITES TO BE INVESTIGATED FOR THEIR SUITABILITY AS A REPOSITORY FOR RADIOACTIVE WASTES

FIGURES AND TABLES

Back to NRX18 Menu   Back to POE Menu   Back to Homepage

TABLE 1: PERFORMANCE MEASURES AND UNITS OF MEASUREMENTS FOR EACH ATTRIBUTE

ATTRIBUTE	MEASURE	UNITS (Min. - Max.)
COSTS		
1 Transport capital costs	Total construction cost: infrastructure + plant at 1988 prices	£60M - £710M
2 Transport operating costs	Constant value 1988 operating costs over 50 years	£350M - £2000M
3 Repository capital costs	Capital cost, investigation + construction at 1988 prices	£350M - £2000M
4 Repository operation costs	Constant value 1988 operating costs summed over 50 years, including vault excavation and closure	£1200M - £4500M
ROBUSTNESS		
5 Transport - known technology	Degree of experience with technology	Preference scale
6 Transport - flexibility	Number of available modes & routes of transport	Preference scale
7 Transport - consents	Number & type of planning & operational consents required	Preference scale
8 Repository -known engineering	Degree of past experience & precedence	Preference scale
9 Repository - flexibility	Potential to accommodate design variations	Rating model
10 Repository - potential for intervention	Scope for remedial action	Preference scale
11 Repository - invulnerability	Potential for loosing repository as a result of catastrophic events	Preference scale
12 Repository - geological certainty	Known lack of discontinuities, possible but unknown features	Rating model
13 Repository - investigability	Likelihood that investigations will provide good data, scale of investigations, availability of techniques	Rating model
IMPACTS - SAFETY		
14 Pre-closure - radiological safety to workers	Collective dose, transport & repository	Man-Sv, 30-385
15 Pre-closure - non-radiological safety to workers	Number of accidental fatalities, transport and repository	No. fatalities, 0-45
16 Pre-closure - radiological safety to public	Collective dose, transport & repository	Man-Sv, 35-330
17 Pre-closure - non-radiological safety to public	Number of accidental fatalities, transport	No. fatalities, 0-45
18 Post-closure - safety to individual	Annual dose that most exposed individual will get from a naturally evolving repository	Sv/yr., $3\ 10^{-9}$ - $2\ 10^{-4}$

19 Post-closure - safety to society, 0 to10^5 yrs	Collective dose	Man-Sv, 0- 3 10^6
20 Post-closure - safety to society, 10^5 to 10^8 yrs	Collective dose	Man-Sv, 10^3- 3 10^4
21 Post-closure - integrity	Chance that facility be disturbed by human intrusion	Probability, 10^{-9}-10^{-6}
IMPACTS - ENVIRONMENT		
22 National community	Number of urban train-km per yr.	km/yr., 8500-85000
23 Local population	Dwelling and population factors, visual and noise factors	Rating model
24 Local experience	Nearness to nuclear establishment	Rating scale, 0-2
25 Economic - local benefits	Job creation and labour availability	Rating model
26 Economic - blight	Proximity to susceptible activities	Rating scale, 0-4
27 Economic - resource sterilisation	Number & value of resources forgone	Rating scale, 0-3
28 Physical - landscape	Area & quality of effect	Preference scale
29 Physical - nature conservation	Extent & quality of habit effect	Preference scale
30 Physical - planning policies	Number & significance of policy restraints	Rating scale, 0-4

TABLE 2: INPUT DATA TO HIVIEW

	Dounreay Site 1	Site 2	Site 3	dropped Site 4	dropped Site 5	Site 6	Site 7	dropped Site 8	Site 9	Site10 Sellfld B	Site 11 Off W Sh	Site 12 Off W Dp	Site 13 Off East
Capital	185.9	186.3	441.5	477.4	176	186.6	428.6	419.3	85.9	88.6	327.5	327.5	327.5
Operation	28.8	28.6	14.6	15.6	22	20.9	13.4	13.3	15	14.3	21.4	21.4	20.9
Capital	395	375	436	436	605	380	400	400	498	444	810	1374	2731
Operation	1242	1242	1448	1448	2155	1271	1271	1271	1563	1266	2038	2595	4469
Known Tech	100	100	80	80	100	100	80	80	100	100	0	0	0
Flexibility	0	0	90	90	100	30	90	90	60	60	30	30	30
Consents	50	50	90	90	80	80	30	30	100	80	0	0	0
Known Engng	100	100	100	100	67	96	96	96	58	83	17	15	0
Flexibility	100	100	100	100	24	100	100	100	0	100	100	100	20
Intervention	80	80	80	80	100	80	80	80	60	80	20	10	0
Invulnerability	100	100	100	100	94	94	94	94	81	88	13	0	63
Predictive	65	85	100	82	92	76	65	76	0	34	63	63	92
Investigability	100	100	82	82	43	78	47	47	47	69	0	-22	13
Radiological	59	59	255	255	67.5	67.5	67.5	67.5	67.5	67.5	73.4	73.4	68.4
Non-radiolgcl	4.9	4.9	5.1	5.1	8.13	5.75	5.75	5.75	5.75	5.1	22.4	22.4	26.7
Radiological	223	223	120	120	108	108	108	108	71	71	108	108	108
Non-radiolgcl	30	30	9	9	16	16	10	10	12	10	12	12	12
Individual	25	25	25	25	60	99	99	99	60	60	25	100	0
Short	100	100	100	100	100	100	100	100	100	100	100	100	0

Long	10	10	10	10	10	3	3	3	10	10	10	1	30
Integrity	100	100	100	100	0	100	100	100	80	100	100	100	0
National	77	76	9.5	9.5	59	67	9.5	9.5	46.3	46.3	65.4	65.4	61
Population	65	80	70	80	5	65	25	0	30	25	100	100	100
Experience	100	100	0	0	0	0	50	0	100	100	0	0	0
Local Benefit	100	100	95	95	65	60	30	0	80	80	95	95	65
Blight	90	90	0	0	70	50	50	50	90	90	90	90	90
Res Sterilistn	70	100	70	100	40	70	55	70	85	85	100	100	100
Landscape	80	20	0	0	90	40	60	40	80	70	100	100	100
Nature Cons	10	0	20	10	100	50	30	30	90	80	90	90	90
Plan Policies	100	50	0	0	75	0	50	0	100	85	75	75	75

TABLE 3: FINAL PREFERENCE SCORES

	Dounreay Site 1	Site 2	Site 3	dropped Site 4	dropped Site 5	Site 6	Site 7	dropped Site 8	Site 9	Site10 Sellfld B	Site 11 Off W Sh	Site 12 Off W Dp	Site 13 Off East
Capital	81	81	41	36	82	81	43	45	96	96	59	59	59
Operation	34	35	77	74	55	58	81	81	76	78	56	56	58
Capital	97	98	95	95	85	98	97	97	91	94	72	38	-44
Operation	99	99	92	92	71	98	98	98	89	98	75	58	1
Known Tech	100	100	80	80	100	100	80	80	100	100	0	0	0
Flexibility	0	0	90	90	100	30	90	90	60	60	30	30	30
Consents	50	50	90	90	80	80	30	30	100	80	0	0	0
Known Engng	100	100	100	100	67	96	96	96	58	83	17	15	0
Flexibility	100	100	100	100	24	100	100	100	0	100	100	100	20
Intervention	80	80	80	80	100	80	80	80	60	80	20	10	0
Invulnerability	100	100	100	100	94	94	94	94	81	88	13	0	63
Predictive	65	85	100	82	92	76	65	76	0	34	63	63	92
Investigability	100	100	82	82	43	78	47	47	47	69	0	-22	13
Radiological	92	92	37	37	89	89	89	89	89	89	88	88	89
Non-radiolgcl	89	89	89	89	82	87	87	87	87	89	50	50	41
Radiological	36	36	71	71	75	75	75	75	88	88	75	75	75
Non-radiolgcl	33	33	80	80	64	64	78	78	73	78	73	73	73
Individual	25	25	25	25	60	99	99	99	60	60	25	100	0
Short	100	100	100	100	100	100	100	100	100	100	100	100	0
Long	69	69	69	69	69	93	93	93	69	69	69	100	0
Integrity	100	100	100	100	0	100	100	100	80	100	100	100	0
National	10	12	99	99	34	24	99	99	51	51	26	26	31
Population	65	80	70	80	5	65	25	0	30	25	100	100	100
Experience	100	100	0	0	0	0	50	0	100	100	0	0	0
Local Benefit	100	100	95	95	65	60	30	0	80	80	95	95	65

Blight	90	90	0	0	70	50	50	50	90	90	90	90	90
Res Sterilistn	70	100	70	100	40	70	55	70	85	85	100	100	100
Landscape	80	20	0	0	90	40	60	40	80	70	100	100	100
Nature Cons	10	0	20	10	100	50	30	30	90	80	90	90	90
Plan Policies	100	50	0	0	75	0	50	0	100	85	75	75	75

TABLE 4: ATTRIBUTES ORDERED BY CUMULATIVE WEIGHT

Node	Attribute	Cum Wt
REPOSITORY	Operation	32.47
TRANSPORT	Operation	16.23
REPOSITORY	Capital	16.23
TRANSPORT	Capital	6.49
REPOSITORY	Known Engng	4.08
GEO CERTY	Predictive	3.27
POST CLOSE	Individual	3.18
POST CLOSE	Integrity	3.18
LOCAL	Population	2.60
TRANSPORT	Known Tech	1.63
REPOSITORY	Flexibility	1.63
REPOSITORY	Invulnerability	1.63
LOCAL	Experience	1.30
GEO CERTY	Investigability	0.82
PHYSICAL	Landscape	0.78
PHYSICAL	Nature Cons	0.78
ECONOMIC	Local Benefit	0.78
TRANSPORT	Flexibility	0.41
TRANSPORT	Consents	0.41
REPOSITORY	Intervention	0.41
SOCIETY	Long	0.38
COMMUNITY	National	0.26
PHYSICAL	Plan Policies	0.26
ECONOMIC	Res Sterilistn	0.26
WORKERS	Non-radiolgcl	0.14
PUBLIC	Non-radiolgcl	0.14
ECONOMIC	Blight	0.13
WORKERS	Radiological	0.05
PUBLIC	Radiological	0.04
SOCIETY	Short	0.03

TABLE 5: OVERALL RESULTS AND RESULTS UP TO THE LEVEL OF COSTS, ROBUSTNESS AND IMPACTS

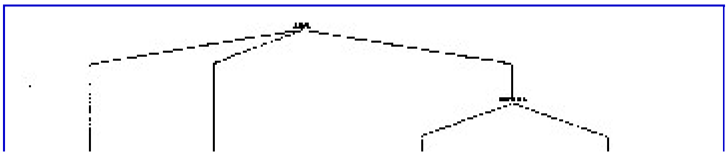
	Wt	Dounreay Site 1	Site 2	Site 3	dropped Site 4	dropped Site 5	Site 6	Site 7	dropped Site 8	Site 9	Site 10 Sellfld B	Site 11 Off W Sh	Site 12 Off W Dp	Site 13 Off East
COSTS	100	82	82	85	84	71	87	89	89	87	92	68	53	9
ROBUST	20	87	92	96	91	76	88	82	85	46	75	34	30	32
IMPACT	20	67	65	54	56	35	71	69	57	69	71	70	87	38
TOTAL		81	81	82	81	67	85	85	84	79	87	64	55	16

TABLE 6: RESULTS OF SENSITIVITY ANALYSIS ON WEIGHTS, SIMULATING DIFFERENT PERSPECTIVES

Weights for the different perspectives					
	Base	Equal	Local	National Environ.	Economic
Costs	100	100	0	0	200
Robustness	20	100	10	20	40
Safety	10	100	50	20	0
Environment	10	100	50	20	10
			& others at lower levels		

Overall results	Base Case	Equal Weights	Local View	National Environ.	Economic View
Dounreay	81	76	60	74	82
Site 2	81	76	56	74	83
Site 3	82	72	57	68	85
Site 4	81	72	58	68	83
Site 5	67	54	54	49	71
Site 6	85	80	68	77	86
Site 7	85	77	66	73	86
Site 8	84	72	57	66	85
Site 9	79	68	69	61	80
Sellafield B	87	77	71	72	88
Offshore West Shallow	64	60	75	58	63
Offshore West Deep	55	64	83	68	50
Offshore East	16	29	58	36	15

FIGURE 1: THE VALUE MODEL SHOWING THE ATTRIBUTES AND HIGHER-LEVEL NODES
Click on image to see larger picture



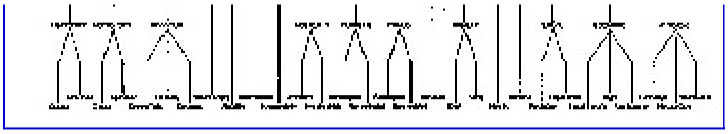


FIGURE 2: THE VALUE CURVE FOR POST CLOSURE SAFETY TO THE INDIVIDUAL
Click on image to see larger picture

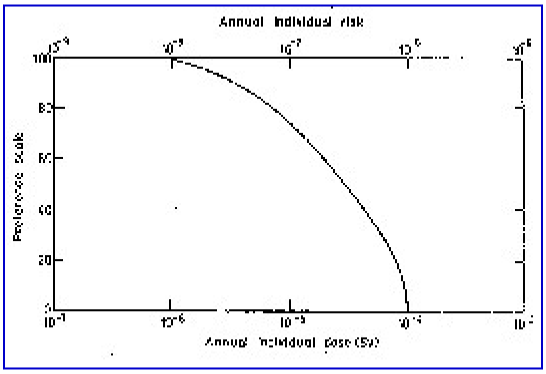


FIGURE 3: OVERALL PREFERENCE FOR ROBUSTNESS VERSUS PREFERENCE FOR COSTS
Click on image to see larger picture

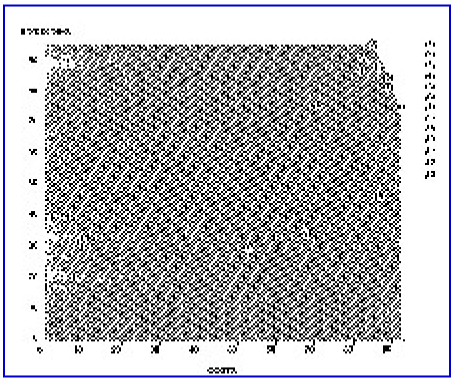


FIGURE 4: SENSITIVITY ANALYSIS ON THE WEIGHT FOR COSTS
Click on image to see larger picture

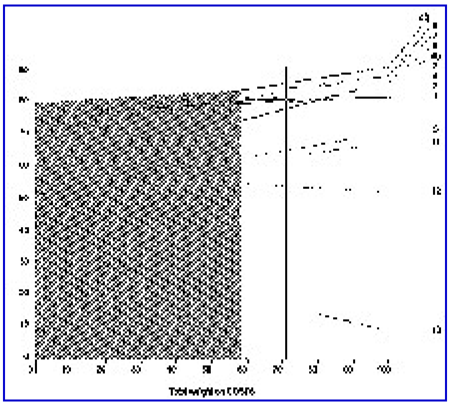


FIGURE 5: SENSITIVITY ANALYSIS ON THE WEIGHT FOR ROBUSTNESS
Click on image to see larger picture

FIGURE 6: SENSIVITY ANALYSIS ON THE WEIGHT FOR SAFETY
Click on image to see larger picture

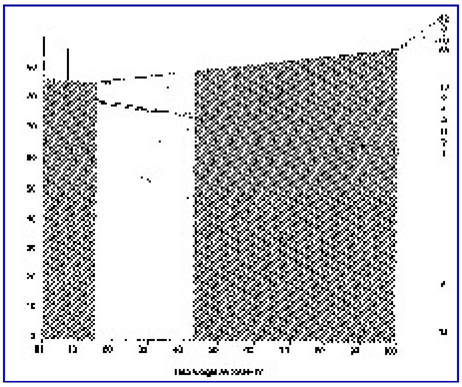
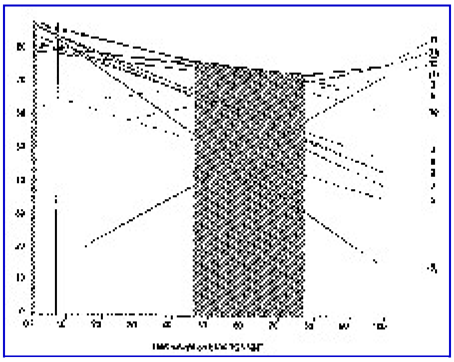
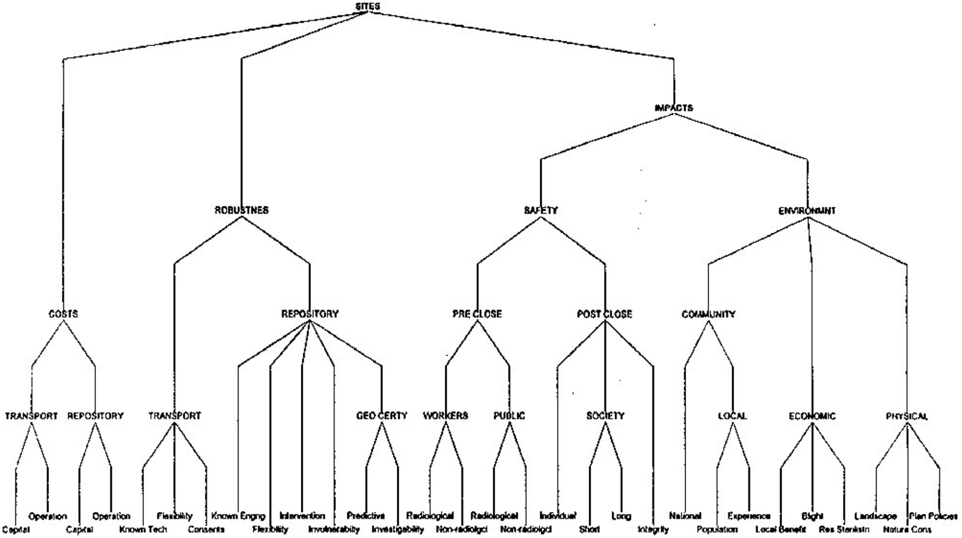
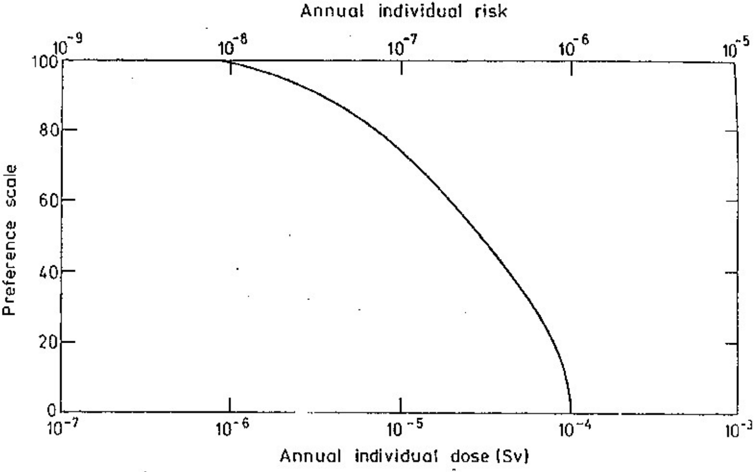


FIGURE 7: SENSITIVITY ANALYSIS ON THE WEIGHT FOR ENVIRONMENT
Click on image to see larger picture

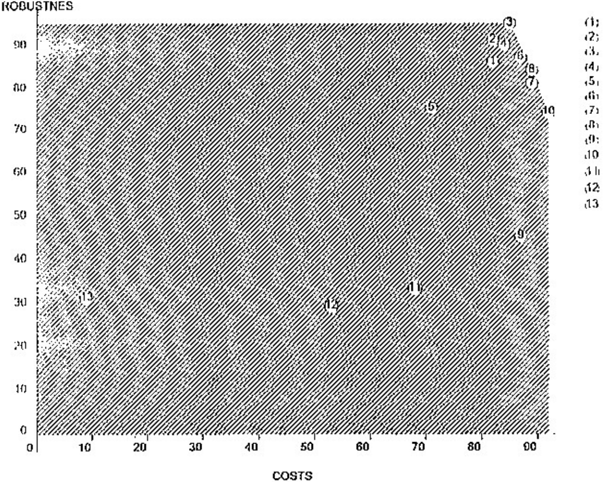


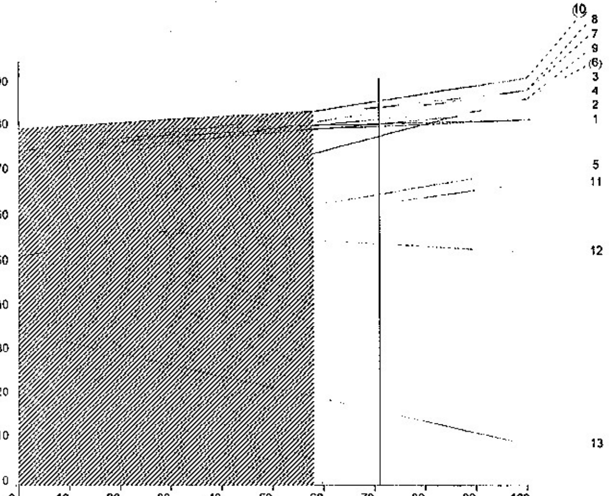
Back to NRX18 Menu   Back to POE Menu   Back to Homepage


SITES
IMPACTS
ROBUSTNES
SAFETY
ENVIRONMNT
COSTS
REPOSITORY
PRE CLOSE
POST CLOSE
COMMUNITY
TRANSPORT
REPOSITORY
TRANSPORT
GEO CERTY
WORKERS
PUBLIC
SOCIETY
LOCAL
ECONOMIC
PHYSICAL
Capital
Operation
Capital
Operation
Known Tech
Flexibility
Consents
Known Engng
Flexibility
Intervention
Invulnerability
Predictive
Investigability
Radiological
Non-radiolgcl
Radiological
Non-radiolgcl
Individual
Short
Long
Integrity
National
Population
Experience
Local Benefit
Blight
Res Stankstn
Landscape
Nature Cons
Plan Policies

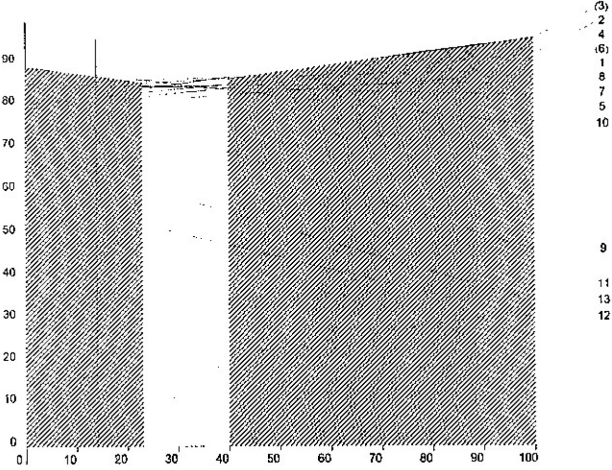


Annual individual risk
10^{-9}
10^{-8}
10^{-7}
10^{-6}
10^{-5}
100
80
60
40
20
0
Preference scale
10^{-7}
10^{-6}
10^{-5}
10^{-4}
10^{-3}
Annual individual dose (Sv)

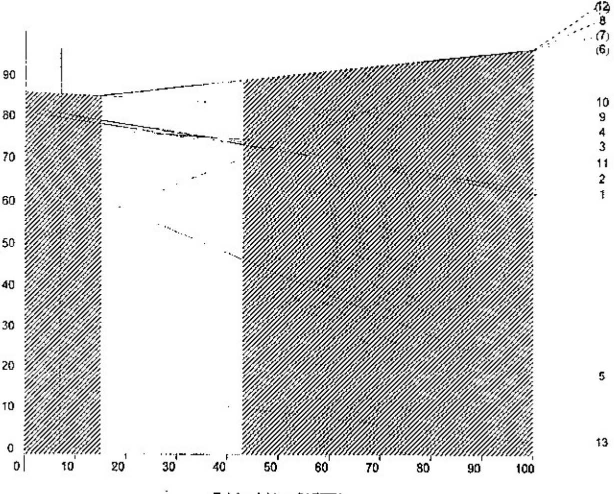

ROBUSTNES
COSTS
0
10
20
30
40
50
60
70
80
90
(1)
(2)
(3)
(4)
(5)
(6)
(7)
(8)
(9)
(10)
(11)
(12)
(13)



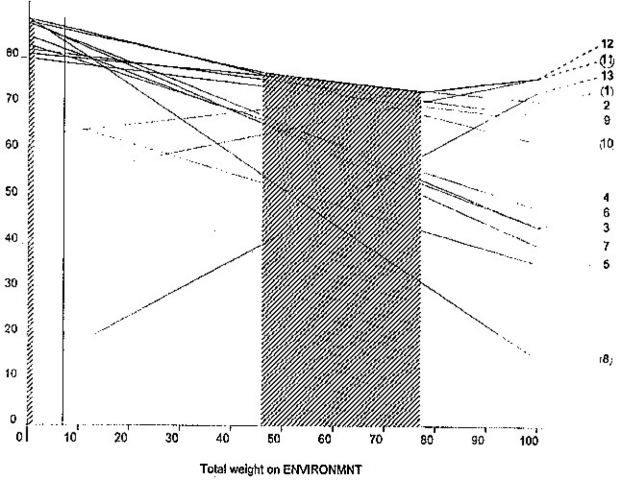
Total weight on COSTS



Total weight on ROBUSTNES



90
80
70
60
50
40
30
20
10
0
0
10
20
30
40
50
60
70
80
90
100
(12)
8
(7)
(6)
10
9
4
3
11
2
1
5
13
Total weight on SAFETY



80
70
60
50
40
30
20
10
0
0
10
20
30
40
50
60
70
80
90
100
Total weight on ENVIRONMNT
12
(11)
13
(1)
2
9
(10)
4
6
3
7
5
(8)