ISSN 1018-5593

Commission of the European Communities

radiation protection

Radiological aspects of nuclear accident scenarios

Volume 2
The RADE-AID system
Post-Chernobyl action

Report

EUR 12552/2 EN

Commission of the European Communities

radiation protection

Radiological aspects of nuclear accident scenarios

Volume 2
The RADE-AID system
Post-Chernobyl action

Edited by:

J. Sinnaeve

Commission of the European Communities
200, rue de la Loi
B-1049 Brussels

Final report

Directorate-General
Science, Research and Development

1991

EUR 12552/2 EN

Published by the
COMMISSION OF THE EUROPEAN COMMUNITIES
Directorate-General
Telecommunications, Information Industries and Innovation
L-2920 Luxembourg

LEGAL NOTICE

ISBN 92-826-2937-6 (Volumes 1 + 2)

Cataloguing data can be found at the end of this publication

Luxembourg: Office for Official Publications of the European Communities, 1991

ISBN 92-826-2939-2 Catalogue number: CD-NB-12552-EN-C

Printed in Belgium

Preface

The Chernobyl accident, which occurred on 26 April 1986, presented major challenges to the European Community with respect to the practical and regulatory aspects of radiation protection, public information, trade, particularly in food, and international politics. The Chernobyl accident was also a major challenge to the international scientific community which had to evaluate rapidly the radiological consequences of the accident and advise on the introduction of any countermeasures. Prior to the accident at Chernobyl, countermeasures to reduce the consequences of radioactive contamination had been conceived largely in the context of relatively small accidental releases and for application over relatively small areas. Less consideration had been given to the practical implications of applying such measures in case of a large source term and a spread over a very large area.

The Radiation Protection Research and Training Programme was influential in a number of important initiatives taken within the Community immediately after the accident. Information was collected by Community scientists and, from it, an assessment made within days of the possible consequences. This showed that the health impact on the population of the European Community was not expected to be significant. About four weeks after the accident, the Programme, together with the US Department of Energy, organised a meeting in Brussels during which the data on dispersion of radioactive material were discussed and evaluated. Several other meetings followed soon after on the transfer of radionuclides in the food chain and possible health effects. These meetings were carried out in close co-operation with the DG XI (Directorate General, Environment, Consumer Protection and Nuclear Safety) within the CEC, and, externally, with international organisations such as the International Atomic Energy Agency (IAEA) and the World Health Organisation (WHO). In addition, the Commission convoked a Committee of high-level independent scientists to assess the scientific evidence from current research in view of recent nuclear incidences, to consider the possible implications for the Basic Standards and emergency reference levels and to advise the Commission on future action in radiological protection including research. (EUR 11449 EN).

Soon after the accident, additional research requirements were identified by the Programme; these were mainly better methods to assess accident consequences and the further improvement of off-site accident management. Several existing contracts were reoriented and new contracts were placed; however, the financial means then available within the Programme were insufficient to fund the additional research identified as necessary. A proposal for a revision of the Programme was, therefore, elaborated in 1986. It comprised 10 specific "post-Chernobyl" research actions. This revision, with an additional budget of 10 MEcu for a period of two years, was adopted by the Council of Ministers on 21 December 1987. With the help of the Management and Coordination Advisory Committee (CGC) "Radiation Protection" a number of institutes was identified to carry out the research in a co-operative manner, and the research began in the spring of 1988.

These post-Chernobyl activities have now been completed. Detailed reports on each of these studies and an additional volume containing the executive summaries of all reports are now available.

- Evaluation of data on the transfer of radionuclides in the food chain,
- Improvement of reliable long-distance atmospheric transport models,
- Radiological aspects of nuclear accident scenarios,
  A. Real-time emergency response systems,
  B. The RADE-AID system,
- Monitoring and surveillance in accident situations,
- Underlying data for derived emergency reference levels,
- Improvement of practical countermeasures against nuclear contamination in the agricultural environment,
- Improvement of practical countermeasures against nuclear contamination in the urban environment,
- Improvement of practical countermeasures: preventive medication,
- Treatment and biological dosimetry of exposed persons,
- Feasibility of studies on health effects due to the reactor accident at Chernobyl.

The research undertaken within the "post-Chernobyl" actions has added considerably to the understanding of the basic underlying mechanisms of the transfer of radionuclides in the environment, of the treatment of accident victims and of how the environmental consequences of accidents may be mitigated. In addition, progress has been made in the setting up environmental surveillance programmes development of predictive and decision-aiding techniques, the implementation of which will lead to significant improvements in off-site accident management. Several new ideas and lines of theoretical and practical research have originated from the post-Chernobyl research and these have already been integrated into the ongoing Community Radiation Protection Research Programme. A further important feature which should not be overlooked, is the close and effective collaboration of many institutes in the research; this has markedly strengthened the ties between Community institutes and scientists. The outcome of all of this work is that the Community and all other countries are now better prepared and co-ordinated should a significant release of radioactivity ever occur again

Further research is continuing within the current Radiation Protection Research and Training Programme 1990-1991 on a number of the "post-Chernobyl" topics; these also form part of the proposal of the specific Programme on "Nuclear Fission Safety" 1992-1993, e.g. real-time emergency management systems, development of countermeasures in the agricultural environment, treatment of radiation accident victims, etc. Moreover, the Community Programme is currently making a significant contribution to an international evaluation, being undertaken by IAEA at the request of the Soviet Government, on the consequences in the USSR of the Chernobyl accident and of the measures being taken to ensure safe living conditions for the affected populations.

S. Finzi
Director DG XII.D
Nuclear Safety Research

G.B. Gerber
Head of Unit DG XII.D.3
Radiation Protection Research

E. Bennett
Director DG XI.A
Nuclear Safety, Industry and Environment, Civil Protection

B) The RADE-AID System

Participating Institutions

National Radiological Protection Board (NRPB)
Chilton, Didcot, Oxon OX11 ORQ, United Kingdom

M.E. Morrey, C.A. Robinson,

Kernforschungszentrum Karlsruhe (KfK)
7500 Karlsruhe, Federal Republic of Germany

J. Ehrhardt, C. Steinhauer,

Department of Industriele Veiligheid of the Hoofdgroep Maatschappelijke Technologie of the Nederlandse Organisatie voor Toergepast Natuurwetenschappelijk Onderzoek (MT-TNO/IV)
Apeldoorn, the Netherlands

C.S. van den Bosch, G. Wagenaar.

Acknowledgements

The authors would like to thank the following, for their contributions to this project: J H A M van der Brugh, B G M Elens, D de Weger, I Woodrow, N A Higgins, S Aumônier, S M Haywood.

CONTENTS

ANNEXES

EXECUTIVE SUMMARY

I INTRODUCTION

If an accidental release of radionuclides occurs, it may lead to an increase in the exposure of individuals to radiation and, hence, to an additional health risk in the exposed population. The significance of this additional health risk will very much depend on the magnitude and characteristics of the release and the subsequent environmental contamination. Depending upon the assessed significance of the resulting health risk, countermeasures may be implemented to reduce the exposure of the affected population.

In order to provide guidance for decisions on countermeasures, international recommendations have been developed. These are necessarily generic in nature and need to be developed in more detail in emergency plans for specific sites and situations. Such site specific emergency plans take account of local factors, such as the population distribution, the type of potential accidents and the available resources for implementing countermeasures. However, site specific emergency plans cannot provide detailed guidance for all postulated accident scenarios and variations in local conditions. Instead, the plans combine specific and quantitative advice with an allowance for flexibility of response, recognising the importance of informed judgement concerning the actual situation as an input to decisions on countermeasures.

The aim of the RADE-AID project is to develop a computer system which can be used to support the formulation of decisions on countermeasures following an accidental release of radionuclides. The system is intended to be an aid following an actual accident and a tool for assistance in planning and training. Possible uses include: aiding the determination of planned intervention levels and withdrawal criteria, the development and exercising of emergency plans, the training of those responsible for making decisions following an accident and analysis of the decision making process itself.

RADE-AID has been developed in a joint project between the Kernforschungszentrum Karlsruhe (KfK, Karlsruhe, Federal Republic of Germany), the National Radiological Protection Board (NRPB, Chilton, United Kingdom) and the department of Industriele Veiligheid of the Hoofdgroep Maatschappelijke Technologie of the Nederlandse organisatie voor Toergepast Natuurwetenschappelijk Onderzoek (MT-TNO/IV, Apeldoorn, The Netherlands). This project was funded by the Commission of the European Communities (CEC).

This summary describes the problems inherent in formulating decisions on countermeasures and the manner in which RADE-AID can assist in addressing these problems. The final section presents some stylised applications of the RADE-AID system, which illustrate its use and the form of support which it can provide in the decision-making process.

II THE PROBLEM

The purpose of introducing countermeasures after an accidental release of radionuclides is to reduce the exposure of (and hence, the health risk to) individuals. However, the consequences of taking countermeasures are not limited to the reduction of exposures. There will be other consequences, some beneficial, some harmful, and it is necessary to take account of all these consequences when formulating decisions on countermeasures.

Principles have been developed for the introduction of countermeasures which recognise this need to take account of all the beneficial and harmful consequences. The first principle states that no countermeasure should be introduced unless it produces more good than harm, ie the introduction of the countermeasure should be justified. The second principle states that the countermeasure should be introduced in a manner which maximises the net benefit. This is known as optimisation, and is complementary to the principle of justification.

In order to determine whether the introduction of a countermeasure is both justified and optimised, it is necessary to evaluate all the beneficial and harmful consequences of introducing that countermeasure. Apart from reducing the radiation health risk to the potentially exposed population, the major beneficial consequence of introducing countermeasures is likely to be the reassurance provided to individuals because action has been taken. However, there may be a wide range of harmful consequences, depending on the countermeasure involved. Some countermeasures may involve physical risk to individuals, for example, evacuation undertaken in adverse weather conditions such as fog or ice. Most countermeasures will involve a monetary cost, although the level of expenditure will range from relatively small amounts for short-term, small scale countermeasures (eg sheltering within a small area) to very large amounts for such countermeasures as widespread decontamination or food interdiction. Moreover, the nature of all the monetary costs will not bet same. For example, intervention measures will require the expenditure of money, whilst the interdiction of economically productive land will resul in the loss of potential income. Other possible harmful consequences are disruption to the normal or anticipated lifestyles of individuals and population groups, exposures to workers involved in implementing the countermeasures (particularly intensive decontamination), anxiety in the affected population resulting from the knowledge that countermeasures are required; and repercussions on international relations and trade.

The first problem is quantifying all these very different types of consequences. Whilst some are, at least in theory, straightforward to assess (eg monetary cost) others, particularly social consequences such as disruption, reassurance and anxiety, are much more difficult to quantify.

The second problem is that the beneficial and harmful consequences of taking countermeasures are unlikely to be shared equitably. In terms of the health risks, the risks resulting both from exposure to radiation and from implementation of the countermeasure vary between individuals, and particularly with age. For example, elderly people may be at greater physical risk from the introduction of countermeasures (particularly a evacuation) than younger people, whilst their risk of incurring cancer, a result of radiation exposure, is substantially lower. Another way in which the health risks may be shared unequally concerns workers, since workers deployed in the contaminated area (eg for informing the public on the countermeasures to be introduced, for facilitating evacuation or for carrying out decontamination) may receive enhanced exposures compared with those of the people they are protecting. Monetary costs are also unlikely to be shared equitably. For example, where there is disruption to trade the costs may be borne by individuals and firms located well away from the area in which the countermeasure is implemented. Finally, there is likely to be an inequable sharing of the social costs of countermeasures. For example, whilst the decision to take action may provide reassurance to one group of individuals, the knowledge that such action is necessary may result in increased anxiety for others. Again, if an area of land is interdicted, individuals' leisure and work activities may be significantly disrupted, or, if individuals are moved out of an area, the receiving communities may experience serious social upheaval. It is clear therefore that decisions on countermeasures raise questions of social equity; social value judgements must be made in order to determine how widely the harmful consequences of countermeasures should be shared.

A third problem concerns the possible over-reaction of the public to a countermeasure. For example, if a particular food is interdicted for concentrations exceeding a given level, then the public may avoid purchasing that type of food entirely. Again if people are relocated from an area, other individuals, outside of, but relatively close to, that area, may perceive themselves to be at risk and so move away, causing consequent social problems for both the area they leave and the place they move to. Finally, there may be pressure on the decision-maker to take countermeasures in order to demonstrate to the population that caring action is being taken. However, if action is taken then this may reinforce a belief that the situation is life-threatening.

It is therefore clear that any decision to introduce countermeasures must take account of a number of different factors. These factors may often compete, in the sense that ensuring the best outcome for one may result in a less favourable outcome for another. It is therefore necessary to balance all the factors, weighing one against another, in order to determine what are the best courses of action in a particular set of circumstances.

It is recognised that the conclusions of this balancing process may be dependent upon the exact circumstances at the time of the accident. The radiological, economic and, particularly, the political and social circumstances will determine both the magnitude of the beneficial and harmful consequences of introducing given countermeasures, and the degree to which they influence the final decision. For example, it is entirely possible and reasonable that, given an accident which affects different places, possibly at different times, the decisions taken on countermeasures for each of these places may differ. What is important for the decision process is that all the important factors can be shown to have been assessed, so that the best actions may be taken in each particular situation.

III The RADE-AID SYSTEM

General Decision Aiding Techniques

It has been shown in the previous section that the problem facing decision-makers following an accidental release of radionuclides is one of balancing many complex and competing factors (hereafter called 'criteria'). Decision aiding techniques have been developed for, and applied in, a wide range of situations involving competing criteria. Their usefulness is firstly based on the way in which they help the problem to be structured and broken down into its component parts and secondly, on the way in which they support the decision maker in working with the formal selection process to find an optimal solution to the problem. In this way, specific aspects of the problem can be addressed explicitly and insights gained into their significance for the final decision.

A review was carried out of the different techniques which are available, in order to determine the best approach for the RADE-AID decision logic. Of these, three techniques were short-listed for more detailed consideration: cost benefit analysis (CBA), analytical hierarchy process (AHP) and multi-attribute value/utility technique (MAVT).

Some applications of CBA provide very similar features to those of MAVT, and it was recognised that, in certain situations, CBA techniques may be appropriate for aiding decisions on countermeasures. However, it is difficult, within the CBA framework, to explicitly take into account the preferences of decision-makers for competing criteria. Furthermore, it may be difficult (or impossible) to express certain criteria in monetary terms. Finally, it is also difficult to extend the CBA methods to take account of the valuation of uncertainty. This last disadvantage of CBA must not be confused with sensitivity analysis. Sensitivity analysis is always possible, but it merely explores uncertainty in the magnitude of consequences, not uncertainty in the nature of these consequences. Since these are all aspects of the problem RADE-AID is designed to address, it was decided not to use CBA for the system.

AHP supplies an explicit structuring and analysis of the problem, but it is not ideal for enabling trade-offs to be explored and expressed. Also, if the set of criteria is revised, it is necessary to re-evaluate all the trade-offs and preferences for every criterion, regardless of whether they were considered in the original analysis. One of the advantages of AHP is that it enables internal consistency checks on these trade-offs and preferences to be made. This aspect of the method has been used in the RADE-AID system as an optional technique.

MAVT is a well-developed and proven method for evaluating options in decision situations involving multiple criteria. The technique combines relatively straightforward mathematics and clear logic structure, with flexibility and ease of interaction with the user. Explicit trade-offs can be made between the criteria, and the relative importance attributed to the outcomes of different options, evaluated against a single criterion, can be specified directly. Finally the technique can be extended to address uncertainties about the predicted outcomes of decisions to value the risk involved and to balance it against other criteria. For these reasons MAVT was selected to form the basis of the decision logic for the RADE-AID system.

Description of the RADE-AID Decision Logic

The most important feature of the RADE-AID decision logic is the emphasis on careful structuring of the problem, so that it can be broken down into a number of discrete steps. It is intended that information from each of these steps (ie not just the final step) may be used by the decision-maker as input to the decision. The steps can be summarised as follows:

- the identification of decision criteria
- the identification of decision options
- the calculation of the consequences of each decision option in terms of the criteria
- a. the valuation of the consequences and
  b. the determination of the relative importance of the criteria
- the overall valuation and ranking of the decision options in terms of the stated criteria
- the exploration of the sensitivity of the ranking to changes in the valuation of the consequences and to trade-offs between the criteria.

The first step is to define the problem, in terms of the desired objectives. Following any accident, the objective must be to act in a way which is both justified and optimised (as discussed in Section II). In other words, the objective must be to maximise the net benefits, taking into consideration the possibility of introducing no countermeasures. This overriding objective can be described in terms of subsidiary criteria, and these can be sub-divided further into a number of even more detailed criteria. This sub-division can continue until a set of criteria has been defined which is helpful in terms of evaluating the consequences of different countermeasures options.

In order to facilitate this structuring of the criteria, RADE-AID enables the user to construct a visual representation of the problem in the form of a criteria hierarchy. An example is helpful in this context. Following an accident which results in the contamination of milk by iodine-131, the maximisation of the net benefits may be split into four criteria which are considered to be important for the implementation of milk bans: the health risk avoided, the monetary cost and the adverse response of the population and the international community. Depending upon the available information and the nature of the situation, a useful further sub-division of the 'health' arm might be: 'collective dose avoided', 'individual dose avoided' and 'collective dose received by workers implementing the countermeasure'. The criteria hierarchy for this example is shown in Figure 1. In RADE-AID, this hierarchy may be constructed interactively by the user, with each 'arm' of criteria being split down to the level of detail most helpful for the problem. Moreover, if, following investigation of the problem using RADE-AID, the initial structure is found not to be ideal, it may be readily altered as necessary.

Once the criteria have been clearly set out, the user must specify the decision options available. In theory, there may be a very wide range of options, but in reality, practical and political constraints may limit this range significantly. Taking the above example, the range of decision options might be to set a milk ban for intervention levels of concentration ranging between 100 Bq/l and 10^4 Bq/l. As with the decision criteria, it may be helpful to describe these options in finer detail, for example, by specifying the disposal options which may be possible for the contaminated milk, in conjunction with each intervention level option. Generally, it is helpful to limit the number of countermeasures options considered; often it is most profitable to specify a few options which bound the possible range, and then, by using RADE-AID iteratively, to refine the options which appear most promising.

The consequences of taking each countermeasure option are then evaluated against the decision criteria. The evaluation is typically performed by the use of models or expert judgement.

After the determination of the consequences (either qualitatively or quantitatively) a relationship between consequences and the degree of appreciation of these consequences has to be established (for each criterion). In RADE-AID this valuation is measured on a scale between 0 and 1, where 0 indicates that the consequence of the countermeasure option is appreciated least, and 1 indicates that it is appreciated most. It is also possible not to assess the consequences of countermeasures and the valuation explicitly. In this case, a valuation of the countermeasures is performed by directly assigning values to specific options.

Having defined the problem and evaluated the consequences of different options in terms of the criteria, the decision-maker then specifies the overall importance of each criterion for his decision (ie he assigns weights to each criterion). These weights may reflect both the range of the consequences evaluated for each criterion and the general importance of the criterion itself. The effect of the range of consequences on the weighting of a criterion may be illustrated as follows: if the monetary costs of the milk bans varied between £10^4 and £10^8, whilst the collective doses saved only varied between 100 man Sv and 1000 man Sv, the scale on which monetary costs are valued will need to be longer than that for dose saved, and the relative weight assigned to the criterion will need to be correspondingly greater. The weights should clearly also reflect the importance of that criterion. In particular, the weighting of the criterion of adverse public response would be expected to reflect very strongly the attitude of the decision-maker; some decision-makers might assign a relatively high weight to this criterion, almost regardless of the range of actual scores evaluated against it. This may be demonstrated by comparing particular points on different criteria scales. RADE-AID provides several procedures for eliciting these weights and enables the user to select the procedure most suited both to his way of thinking and to the problem.

At this point, each option has been assigned a set of values which reflect how well each criterion is met by that option, and each criterion has been assigned a weight, which indicates its relative importance to the decision. RADE-AID combines the values with the weights to evaluate the overall ranking of the countermeasures options in terms of how well they achieve the stated criteria. This process gives each option a score between 0 and 1, 1 indicating the most preferred option. All the options are presented to the user, together with their scores, so that the ranking can be examined. Graphical displays enable the user to investigate the effect on the overall ranking of options of varying the relative weights of the criteria.

<u>Use of RADE-AID</u>

RADE-AID has been designed to allow it to be used iteratively for planning and training purposes, although it is unlikely that this facility will be of value in its use following an accident. In the preliminary stages of planning, the problem may be poorly understood and the significant factors only very poorly quantified. However, by using RADE-AID to gain insight into the problem, and also into the stability and robustness of the ranking of countermeasure options, the decision-maker can be helped to structure his thinking and identify more clearly the reasons for and implications of his decision.

One of the important features of the RADE-AID system is that it enables trade-offs between the benefits and the harmful consequences of taking different courses of action to be explicitly addressed and explored. These trade-offs are based on the judgement of the decision-maker. They depend on the decision-maker's assessment of the relative desirability of taking each action, with respect to their consequences, and on the relative importance he attaches to each type of consequence. Trade-offs are personal; there can be no objective or universal rules for making them.

It is important to recognise that whilst the use of decision aiding techniques can help to make the reasons for decisions clearer and to target the expenditure of resources into appropriate areas, they can also be indiscriminately rigorous, in that all aspects of problems which might have been overlooked or assessed intuitively may be explicitly addressed and evaluated. It is therefore important that the level of resource applied to the decision should match the importance and complexity of the problem to be solved. The RADE-AID system is being specifically developed to enable the appropriate level of resources to be utilised in different applications. Default data and supporting guidance are being collected to assist users in applications where detailed research is not warranted. Where better information is available or desirable, or where the decision is intended solely to reflect the judgement of the user, the system will accept alternative input generated by the user.

In the preceding paragraphs, the general operation of the RADE-AID system has been described. RADE-AID is an evolving system, and the prototype version which has been developed under the present contract does not include every feature which would be desirable in such a system. For the prototype system emphasis has been placed on development of the decision logic and user-friendly interaction with the decision-maker, for both the elicitation of criteria, values and weights and the performance of sensitivity analyses. Less emphasis has been placed on the calculation and display of relevant information concerning the radiological situation and other factors. In the prototype, the data necessary for the decision process have to be provided from outside the system. This prototype system has been designed to run on IBM-compatible Personal Computers.

It should be emphasised that RADE-AID is not intended to replace the role and judgement of the decision-maker. It is intended as a decision aiding tool, not a decision-making machine. Given a decision problem with competing criteria, a decision-maker must necessarily assess the consequences of various alternatives and value them according to these criteria. This process may be achieved intuitively or explicitly. The advantage of performing the analysis explicitly, using formal techniques, is that the process is clearly structured and it is less likely that important factors are overlooked. Moreover, by indicating which aspects of the problem are crucial to the decision, and which are not, resources can be channelled, to obtain the information necessary for formulating the decision.

IV ILLUSTRATIVE APPLICATIONS

In order to explore the appropriateness of the decision logic for the management of radiological emergencies, two illustrative applications were considered. These explored the use of the decision logic for decisions on countermeasures against external exposure and on food interdiction. The applications were deliberately stylised both for simplicity and to illustrate the possibilities of the system. The purpose of these illustrative applications was solely to demonstrate whether the prototype system forms the basis of an appropriate and flexible decision-aiding tool. However the structures developed for the problems and the associated data are considered to be appropriate for providing assistance with planning.

The two applications were chosen to explore the introduction of very different types of countermeasure, the first involving the potential relocation of people and the potentially resource-intensive operation of decontamination, and the second involving the combinations of actions which could be taken to reduce the exposure of the population from contaminated foods. In addition, different procedures were used for valuing the consequences of countermeasure options in terms of the criteria, and for eliciting the relative weights assigned to the criteria. In this way, the use of the system was explored as fully as possible. For the purposes of these illustrations it was assumed that the countermeasures for external exposure and food interdiction are completely independent.

The two types of problem (control of external exposure and control of foods) have been structured using the same fundamental criteria. These are the health risks avoided, the monetary costs, and the adverse public and international reaction. These criteria are those illustrated in Figure 1. Depending on the application and valuation approach (ie direct or indirect) adopted these criteria hierarchies were further split so that the more general criteria were more precisely defined.

Control of External Exposure

One possible long term exposure pathway, following an accidental release of radioactive material, is external exposure from radionuclides deposited on the ground. If this occurs, there are two types of countermeasure which can provide protection for individuals in the contaminated area; the individuals may be moved out of the area until the levels of radioactivity have reduced, or the area may be decontaminated. If both types of countermeasure are carried out, then the decontamination of land and property will reduce the time for which individuals must be kept out of the area.

The criterion for introducing relocation is generally specified in terms of a dose rate; for decontamination, a target level of decontamination is commonly defined. The problem for the decision-maker is therefore to determine which countermeasures, if any, should be carried out, and to specify the appropriate criteria for them. (In practice, the problem is more complex, because other aspects of the decision, such as how quickly people from different areas should be moved out, the appropriate dose rate to allow return from relocation and whether some areas should be preferentially decontaminated, also need to be addressed. However these aspects were omitted from the illustrative applications.)

For the purposes of exploring the use of the RADE-AID decision logic, two highly stylised accident situations have been postulated. They are each identical in magnitude and release characteristics, but one is assumed to occur in an area of relatively low population density (site A), whilst the other is assumed to occur in a more densely populated area (site B). The assumed releases are very large, representing the rapid release of about 1% of the volatile core inventory of a large (gigawatt) reactor.

The criteria defined in the hierarchy in Figure 1 were represented by ten proxy attributes which it was considered might be more easily quantifiable than the primary criteria. These included such factors as the numbers of people initially relocated and the perceived acceptability of the intervention level used. These attributes were used as performance indicators for the various options, with regard to the criteria concerned. The choice of these attributes reflected the judgements and preferences of the authors; it was recognised that they would not necessarily encompass all the factors of concern to decision-makers. However, it was judged that they formed a sufficiently comprehensive set for the purposes of illustrating the application of the system.

The possible countermeasures options at each site were defined to be a set of five different intervention levels for relocation, ranging from 5 mSv y^{-1} to 100 mSv y^{-1}. Since much of the land around site A was assumed to be agricultural or parkland, it was assumed, for simplicity, that decontamination of the land would not be carried out (or at least, only in relatively small areas). However, for site B, which was assumed to be mainly urban or industrial the option of decontamination was considered.

Use of RADE-AID to explore these scenarios proved very useful in providing insights into the problems posed and also in indicating where more research was required. Two specific illustrations of these benefits are discussed below. However, it should be remembered that any conclusions drawn result from the personal preferences of the authors and are not intended to necessarily reflect the conclusions which others would draw.

It became apparent that although the consequences of taking the same countermeasures at the two sites were often very different (eg fewer people were affected for site A), this would not necessarily result in the adoption of different intervention levels at the two sites. Clearly, the choice of intervention level depends upon the preferences and weights expressed for the various consequences, but since a reduction in detrimental consequence (eg number of people relocated) was usually accompanied by a reduction in a beneficial consequence (eg collective dose saved), consistent assumptions regarding the criteria often yielded similar conclusions regarding the best intervention level for the two sites.

RADE-AID showed that unless very significant weight was attached to the criterion of monetary costs, then the uncertainty on the calculated costs did not influence the overall decision, and so significant refinement of these calculations would probably not be warranted.

Control of Food

Internal radiation exposure to members of the public through ingestion of contaminated foods may be limited by the imposition of food bans. In the present context, food bans include all methods by which consumption of contaminated food may be prevented; whether by disposing of contaminated food or by reducing its contamination using processing or storage before it is available for consumption. Following Chernobyl, food was banned if the concentration of radionuclides in it exceeded given intervention levels. This approach was used in the stylised applications of RADE-AID for food bans.

If a decision is taken to ban food with activity concentrations greater than a specified intervention level, then it is necessary to determine how food exceeding these levels should be dealt with, and also, how future contamination of foods above the intervention levels can best be avoided (eg natural or forced decontamination of land, or feeding alternative feeds to livestock). Such decisions may be quite complex. For example there may be several radionuclides to control (each with different physical and chemical properties), and the ease with which control measures may be applied may vary with soil type, weather conditions and the agricultural practices of the area. Moreover, there will exist external constraints in terms of the resources (eg equipment and storage facilities) which can be utilised. Some possible courses of action may result in additional doses to workers or even to the general population.

For the illustrative application of RADE-AID it was decided to consider only the imposition of grain bans. The harvesting of grain occurs discretely (and has been assumed here to occur only once a year) and this makes it easier to model the consequences of taking different countermeasures. However, it is judged that the consideration of grain bans provides a sufficient demonstration of the potential of RADE-AID as a decision-aiding system for the control of other foods.

For the example applications four releases were considered which cover a broad range of characteristics with respect to the temporal and spatial extent of food bans. Three releases of different magnitudes were assumed to occur in summer, whilst the fourth was assumed to take place in winter. The winter release and two of the summer releases consisted of a mixture of iodine-131, caesium-134 and caesium-137. The remaining summer release contained only iodine-131.

For the countermeasures options, three intervention levels of activity concentration for each radionuclide were chosen, spanning two orders of magnitude. In addition, a set of options for dealing with the banned grain, and the land that produced it were specified. These included storage, processing and disposal of the banned grain and various types of decontamination measures applied to the land.

The criteria hierarchy shown in Figure 1 was extended for the monetary arm, but not for the socio-political arm. This was to enable the use of the direct valuation of options against the two socio-political criteria to be explored. Supporting information concerning the extent of bans, the amount requiring disposal, etc, was calculated and presented to the user to assist in the direct valuation.

These applications demonstrated a number of features of the system. The ability to screen out, from the decision logic, countermeasures which could never achieve the stated criteria (eg situations where it would not be practical to store the milk until contamination levels had reduced below the intervention level) was useful for reducing the number of options which were presented to the user, and hence the perceived complexity of the problem. Exploration of the ranking using the sensitivity analysis facilities was useful in providing deeper insights into the problem and for identifying those options which warranted more detailed investigation. A comparison of the winter and summer accidents clearly showed that the optimum countermeasures vary with time of year at which the accident occurs.

Discussion

The illustrative applications demonstrated that RADE-AID can form a useful tool in the determination of decisions on countermeasures. A number of aspects of its usefulness were highlighted, and these are discussed below.

The structuring of the problems in terms of the criteria hierarchies and the identification of factors relevant to the decision helped in the thorough exploration of the problem and an explicit consideration of which were the key criteria. This meant that when the consequences of taking various actions were presented, their significance was more readily appreciated and quantified.

The explicit consideration of all types of consequences and the presentation of information relating to them provided useful insights into the decision problem. For example, consequences which might generally be considered important might be shown to have no influence for a particular accident scenario, or consequences could be identified as being a potentially very significant factor in the decision.

The explicit assigning of weights and values also deepened understanding of the decision problem. It encouraged the thorough consideration of each of the criteria and their relative importance. It also required the user to properly assimilate the information provided by the consequence predictions, so that meaningful values and weights could be assigned. Thus, this step, again, encouraged deeper insights into the decision problem, and therefore, into the best solutions.

The overall ranking of the countermeasures options, by the system, in terms of the expressed preferences of the user, was helpful in two respects. First, it often clearly indicated countermeasures options which could be excluded from further consideration (ie those at the bottom of the ranking order). Second, it triggered re-evaluation of those options which were ranked towards the top of the ordering. This was particularly important in cases where the initial ranking appeared to be counter-intuitive. In this case, re-examination of the problem and the weights and values assigned, would reveal the reasons for this ordering. It was then possible to decide whether the inputs required changing, or whether, in fact, the overall ranking did, indeed, reflect the relative merits of the options.

The facilities for exploring the sensitivity of the ranking to the assigned weights were found to be particularly helpful. Using these displays, it could be seen clearly which inputs were dominating the ranking, and those to which the overall ranking was most sensitive. Where the ranking was sensitive to a particular value, the accuracy of the prediction leading to the assignment of that value could be assessed and conclusions reached concerning the robustness of the evaluation. Similarly, where the ranking was sensitive to the magnitude of a particular weight, the degree of belief in that weight could be assessed and conclusions drawn. Equally, the sensitivity analyses could be used to show the range of possible rankings which might reasonably be achieved by varying the values and weights within what were judged to be reasonable bounds. In this way, options could be identifed which would never be optimum, and also the range of options which could be justified reasonably well could be seen.

V CONCLUSIONS

The choice of the appropriate type and level of intervention to mitigate the radiation exposure of the population after radioactive contamination of the environment, requires a balance to be achieved between a variety of competing criteria. The magnitude of these criteria may vary with the accident characteristics, and their relative importance may be sensitive to political and social value judgements. The radiological decision-aiding system, RADE-AID, uses decision analysis techniques to compare and rank different intervention strategies by considering both directly quantifiable factors and factors of a socio-political nature. The user can interact directly with the system, so RADE-AID can help the decision-maker to explore the consequences of and reasons for his decisions.

A prototype version of RADE-AID has been developed. This computer program comprises the full decision logic, together with facilities for assigning weights, constructing criteria hierarchies and value functions, and performing sensitivity analyses on the influence of changing the weights. It can be made available to interested institutions on a research basis. It is hoped that, through this interaction with other researchers, enhanced progress on this project can be achieved. In this phase of the project, emphasis has been placed on development of an appropriate decision logic and procedures for eliciting value judgements and weights from the user. Subsequent development will include enhanced facilities for presentation of supporting information.

In order to explore the usefulness of the RADE-AID decision logic, some stylised applications have been considered. These involve decisions on the implementation of countermeasures to reduce external exposure and the imposition of food bans to reduce internal exposure. The results demonstrated that use of RADE-AID can provide insights into the decision problem, and so assist the user in determining the appropriate course of action. They also highlighted areas where improvements in the system would be beneficial. These were generally aspects of the system which had been previously identified for development in the next phase of the project.

Future work will concentrate on the presentation of supporting data and extensions to the decision logic and sensitivity analysis functions. However, the most important aspect of future work will be to discuss the application of RADE-AID with decision-makers. If RADE-AID is to be of assistance to decision-makers then it is important that its further development should be carried out in conjunction with them. In this way, guidance can be developed on the appropriate structuring of countermeasures problems, and the valuation of consequences and relative weights to criteria, so that the system can be tailored to the requirements of those with responsibility for deciding on countermeasures after an accident.

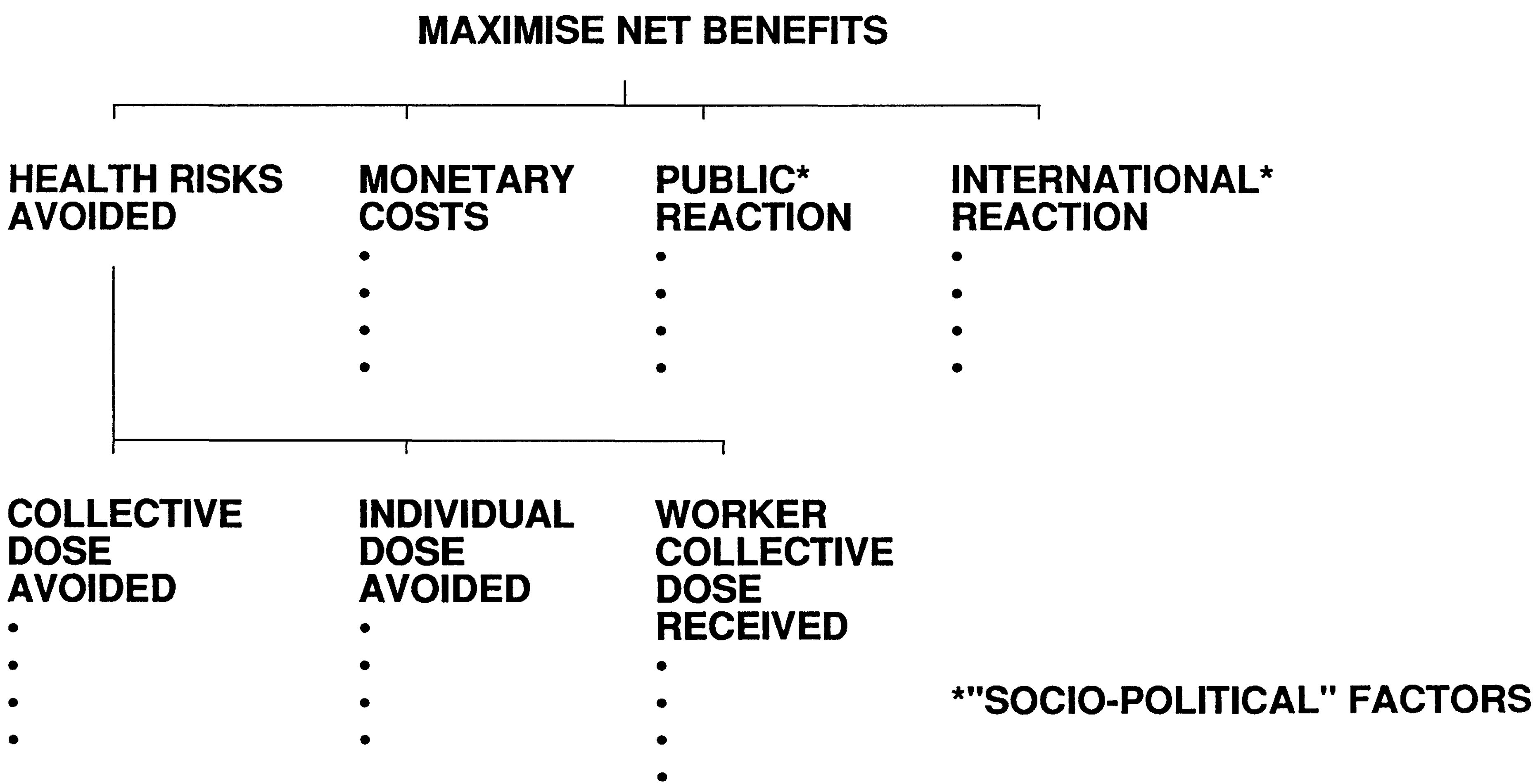


Figure 1: ILLUSTRATIVE CRITERIA HIERARCHY

1 INTRODUCTION

If an accidental release of radionuclides occurs, it may lead to an increase in the exposure of individuals to radiation and, hence, to an additional health risk in the exposed population. The significance of this additional health risk will very much depend on the magnitude and characteristics of the release and the subsequent environmental contamination. Depending upon the assessed significance of the resulting health risk, countermeasures may be implemented to reduce the exposure of the affected population.

In order to provide guidance for decisions on countermeasures, international recommendations have been developed. These are necessarily generic in nature and need to be developed in more detail in emergency plans for specific sites and situations. Such site specific emergency plans take account of local factors, such as the population distribution, the type of potential accidents and the available resources for implementing countermeasures. However, site specific emergency plans cannot provide detailed guidance for all postulated accident scenarios and variations in local conditions. Instead, the plans combine specific and quantitative advice with an allowance for flexibility, recognising the importance of informed judgement concerning the actual situation as an input to decisions on countermeasures.

The aim of the RADE-AID project is to develop a computer system which can be used to support the formulation of decisions on countermeasures following an accidental release of radionuclides. The system is intended to be an aid following an actual accident and a tool for assistance in emergency planning and training. Possible uses include: aiding the determination of planned intervention levels and withdrawal criteria, the development and exercising of emergency plans, the training of those responsible for making decisions following an accident and analysis of the decision making process itself.

RADE-AID has been developed in a joint project between the Kernforschungszentrum Karlsruhe (KfK, Karlsruhe, Federal Republic of Germany), the National Radiological Protection Board (NRPB, Chilton, United Kingdom) and the department of Industriele Veiligheid of the Nederlandse organisatie voor Toegepast Natuur-wetenschappelijk Onderzoek (MT-TNO/IV, Apeldoorn, The Netherlands). This project was funded by the Commission of the European Communities (CEC).

This report begins by describing the problems inherent in formulating decisions on countermeasures. Chapters III and IV then discuss the techniques of decision analysis, how they are implemented in RADE-AID and how they can assist decision-makers in addressing the problems associated with decisions on countermeasures. Chapter V presents some stylised applications of the RADE- AID system, which illustrate its use and the form of support which it can provide in the decision-making process.

II PROBLEMS IN COUNTERMEASURES DECISIONS

The purpose of introducing countermeasures after an accidental release of radionuclides is to reduce the exposure of (and hence, the health risk to) individuals. However, the consequences of taking countermeasures are not limited to the reduction of exposures. There will be other consequences, some beneficial, some harmful, and it is necessary to take account of all these consequences when formulating decisions on countermeasures.

Principles have been developed for the introduction of countermeasures which recognise this need to take account of all the beneficial and harmful consequences. The first principle states that no countermeasure should be introduced unless it produces more good than harm, ie the introduction of the countermeasure should be justified. The second principle states that the countermeasure should be introduced in a manner which maximises the net benefit. This is known as optimisation, and is complementary to the principle of justification.

In order to determine whether the introduction of a countermeasure is both justified and optimised, it is necessary to evaluate all the beneficial and harmful consequences of introducing that countermeasure. Apart from reducing the radiation health risk to the potentially exposed population, the major beneficial consequence of introducing countermeasures is likely to be the reassurance provided to individuals because action has been taken. However, there may be a wide range of harmful consequences, depending on the countermeasure involved. Some countermeasures may involve physical risk to individuals, for example, evacuation undertaken in adverse weather conditions such as fog or ice. Most countermeasures will involve a monetary cost, although the level of expenditure will range from relatively small amounts for short-term, small scale countermeasures (eg sheltering within a small area) to very large amounts for such countermeasures as widespread decontamination or food interdiction. Moreover, the nature of all the monetary costs will not be same. For example, intervention measures will require the expenditure of money, whilst the interdiction of economically productive land will result in the loss of potential income. Other possible harmful consequences are disruption to the normal or anticipated lifestyles of individuals and population groups, exposures to workers involved in implementing the countermeasures (particularly intensive decontamination), anxiety in the affected population resulting from the knowledge that countermeasures are required; and repercussions on international relations and trade.

The first problem is quantifying all these very different types of consequences. Whilst some are, at least in theory, straightforward to assess (eg monetary cost) others, particularly social consequences such as disruption, reassurance and anxiety, are much more difficult to quantify.

The second problem is that the beneficial and harmful consequences of taking countermeasures are unlikely to be shared equitably. In terms of the health risks, the risks resulting both from exposure to radiation and from implementation of the countermeasure vary between individuals, and particularly with age. For example, elderly people may be at greater physical risk from the introduction of countermeasures (particularly evacuation) than younger people, whilst their risk of incurring cancer, as a result of radiation exposure, is substantially lower. Another way in which the health risks may be shared unequally concerns workers, since workers deployed in the contaminated area (eg for informing the public on the countermeasures to be introduced, for facilitating evacuation or for carrying out decontamination) may receive enhanced exposures compared with those of the people they are protecting. Monetary costs are also unlikely to be shared equitably. For example, where there is disruption to trade the costs may be borne by individuals and firms located well away from the area in which the countermeasure is implemented. Finally, there is likely to be an inequable sharing of the social costs of countermeasures. For example, whilst the decision to take action may provide reassurance to one group of individuals, the knowledge that such action is necessary may result in increased anxiety for others. Again, if an area of land is interdicted, individuals' leisure and work activities may be significantly disrupted, or, if individuals are moved out of an area, the receiving communities may experience serious social upheaval. It is clear therefore that decisions on countermeasures raise questions of social equity; social value judgements must be made in order to determine how widely the harmful consequences of countermeasures should be shared.

A third problem concerns the possible over-reaction of the public to a countermeasure. For example, if a particular food is interdicted for concentrations exceeding a given level, then the public may avoid purchasing that type of food entirely. Again if people are relocated from an area, other individuals, outside of, but relatively close to, that area, may perceive themselves to be at risk and so move away, causing consequent social problems for both the area they leave and the place they move to. Finally, there may be pressure on the decision-maker to take countermeasures in order to demonstrate to the population that caring action is being taken. However, if action is taken then this may reinforce a belief that the situation is life-threatening.

It is therefore clear that any decision to introduce countermeasures must take account of a number of different factors. These factors may often compete, in the sense that ensuring the best outcome for one may result in a less favourable outcome for another. It is therefore necessary to balance all the factors, weighing one against another, in order to determine what are the best courses of action in a particular set of circumstances.

It is recognised that the conclusions of this balancing process may be dependent upon the exact circumstances at the time of the accident. The radiological, economic and, particularly, the political and social circumstances will determine both the magnitude of the beneficial and harmful consequences of introducing given countermeasures, and the degree to which they influence the final decision. For example, it is entirely possible and reasonable that, given an accident which affects different places, possibly at different times, the decisions taken on countermeasures for each of these places may differ. What is important for the decision process is that all the important factors can be shown to have been assessed, so that the best actions may be taken in each particular situation.

III DECISION LOGIC

III.1 Introduction: Decision Analysis

The goal of decision analysis is to structure and simplify the task of making hard decisions as well and as easily as the nature of decision permits. These techniques all depend heavily on human judgements of many kinds[1]. Decision analysis is especially concerned with multiple conflicting objectives, meaning that given a set of decision options, doing well with regard to one factor requires doing poorly with regard to another. Such trade-offs between factors are judgements. They depend on the decision-maker's assessment of the relative desirability of the available options with regard to each factor, and on his idea about the relative importance of these factors. Trade-offs are personal: there can be no objective or universal rules for making them[1]. However, a larger number of decision-makers can have statistically the same average opinions[2]. The result of decision analysis is a ranking of all available options according to their overall evaluated performance. From this ranking the option judged as the "best" option is clearly identified.

The costs of systematic, careful thought using formally appropriate tools are high. This is worthwhile only when the stakes are high and the inference or decision is intellectually difficult or insecure[1].

The structure of this chapter is as follows. First some widely used decision methods are compared. This will show that the so called Multi-Attribute Value/Utility Technique is the most appropriate one for RADE-AID. Next the structuring of decision problems is described, followed by a description of the techniques for eliciting decision-makers' preferences and priorities, the method used to combine this information with predictions of the consequences of taking different countermeasures, in order to identify the "best" alternative, and the procedures available for performing sensitivity analysis on the resultant ranking of countermeasures options. Then some commercially available software packages are assessed and some comments made on the use of computerised tools in general. Finally the chapter concludes with some more philosophical statements.

Terminology

Some introduction to the terminology used in this chapter is appropriate here. A decision problem exists when there are several alternatives or (decision) options. In the radiological context here the alternatives are the various countermeasures. The factors considered important in the selection of alternatives are attributes. Other terms often used are criteria or objectives. Examples are the monetary costs of countermeasures or the dose saved by a countermeasure. The consequences of one alternative with respect to one attribute is an effect score. For instance, the monetary costs (attribute) of taken no action (alternative) are 0 ECU (effect score). An effect score is always related to a particular dimension (for instance, money, dose or a percentage). In the decision process an effect score is valuated by a value function. This function could be seen to express the relative desirability of an effect score on a uniform scale (typically 0 - 100). For instance, the monetary costs of 0 ECU mentioned above might be valuated 100 (they are most preferred), whereas the monetary costs of an action, such as evacuation might be valuated 0 (least preferred). Finally weight factors express the relative importance of different attributes. An example is saying that the dose saved by a countermeasure is three times more important than the costs involved with it. This could be translated to assigning a weight factor of 0.75 to the dose saved and a weight factor of 0.25 to the costs. A short overview of the terminology is also contained in the glossary at the end of this chapter.

III.2 Appropriate Methods

The formulation of a countermeasure strategy, following a radiological emergency, will be based on a number of quantitative and qualitative considerations. Therefore, ordering the alternative actions is a multi-dimensional decision problem for which there exist several well known decision aiding techniques, including:

- Cost Benefit Analysis,
- Analytic Hierarchy Process,
- Multi-Attribute Value/Utility Technique.

Cost Benefit Analysis is the oldest and generally most well known method. The Analytic Hierarchy Process and the Multi-Attribute Value/Utility Technique are the most widely used in decision practice[(3)]. After a first review, these techniques remained as serious candidates for handling problems likely to be encountered in the framework of the RADE-AID project.

In previous TNO reports[(4,5)] a large number of decision techniques have been investigated and evaluated regarding their usefulness in decision-making about hazardous activities (see also reference 6).

Cost Benefit Analysis examines the economic efficiency of policy options, without regard to value-laden issues such as the distribution of wealth, or the quantification of attributes which are difficult to quantify (which could be the most decisive factors)[7]. The basic approach is that all costs and benefits are translated into financial terms. In most actual analyses many factors have to be priced for which no market exists. Moreover, the market price could change dramatically following a nuclear accident.

Furthermore the model is supposed to be an objective model of the world and to ignore the decision-maker's preferences, but it is he who has to determine the relative importance of the relevant attributes[8].

The Analytic Hierarchy Process organises the basic rationality by breaking down a problem into its smaller constituent parts and then calls for only simple pair wise comparison judgements to develop priorities[9]. The greatest weaknesses of Analytic Hierarchy Process are the ambiguous questioning procedure and the strong assumption of a ratio scale for measurements of effect scores and weight factors. The trade-offs being made between the attributes are not clear. Furthermore the complete procedure must be repeated when an additional alternative is added to the set of options[6]. One great advantage of the method is the way in which the consistency of judgements is checked. This part of the method is used in RADE-AID as a auxiliary routine for estimating weight factors.

Multi-Attribute Value/Utility Techniques first require the decision-maker to rate the effect score of the alternatives on each value/utility dimension or attribute separately. Next he assigns relative weights to the value/utility dimensions that express the trade-offs among attributes. Ratings and weights must then be aggregated by means of some formal model that generates an overall evaluation of each option.

Multi-attribute decision analysis was selected as the method of analysis because it is a well-developed and proven method for evaluating options in decision situations involving multiple objectives[10]. Moreover, it is a technique commended by the International Commission on Radiological Protection for use in radiological protection[11]. The main advantages of this method are[4,5]:

- the clear structure of the decision logic,
- the relative simplicity of the mathematics,
- the explicit trade-offs between attributes, and
- the explicit specification of relative preference for outcomes of different options, scored against the same attribute.

In fact it is crucial that in deciding public matters the final trade-offs between the dimensions are made explicit.

Multi-attribute decision analysis is capable of including all aspects of a problem, for example, valuation of uncertainty (=utility) in risky decisions, subjective preferences etc.

As a tool for decision aiding Cost Benefit Analysis could be thought of as a special case of decision analysis, i.e. when equity is not important, valuation of uncertainty can be largely ignored, and utilities are linear and additive, and imponderables can be priced[8].

III.3 Structuring the Problem

Decision analysis attacks complex problems by reducing them into smaller, manageable components. Structuring the problem is by far the most important step in decision analysis, which can only be done by art and not by algorithm[1].

Structuring the problem is specifying what attributes are relevant, what the alternative options are, defining the relation between alternatives and effect scores (consequences), and determining of the uncertainties relevant to the decision. The decision process can be subdivided into the following steps:

- identification of the objectives and the derived attributes on which they can be measured,
- identification of alternative options,
- evaluation of the alternatives on each of the attributes, leading to sets of effect scores (outcomes),

---

EVALUATION MATRIX

- a. valuation of the obtained effect scores,
- b. determination of the relative importance of the attributes,
- overall evaluation and ranking of the alternatives,
- exploration of the sensitivity of the ranking.

III.3.1 Hierarchy

Structuring the problem in terms of the relevant objections and attributes can be facilitated by the construction of an hierarchy. Creating such an hierarchy is advantageous, because it enables the decision-maker to disaggregate highly complex criteria into their components[1,12,13]. Objectives are often hierarchical in nature. The overall objective can be broken down into sub-objectives. These sub-objectives can also be further subdivided. When objectives are considered in this manner, those that occur as loose-sounding may be gradually broken down until at the base of the hierarchy it can be represented by specific items ("top down"). Or the other way round ("bottom up"), grouping the basic attributes ("endpoints"), makes it more easy to determine the relative importance of the attributes. An example of a hierarchy is shown in Figure III.1.

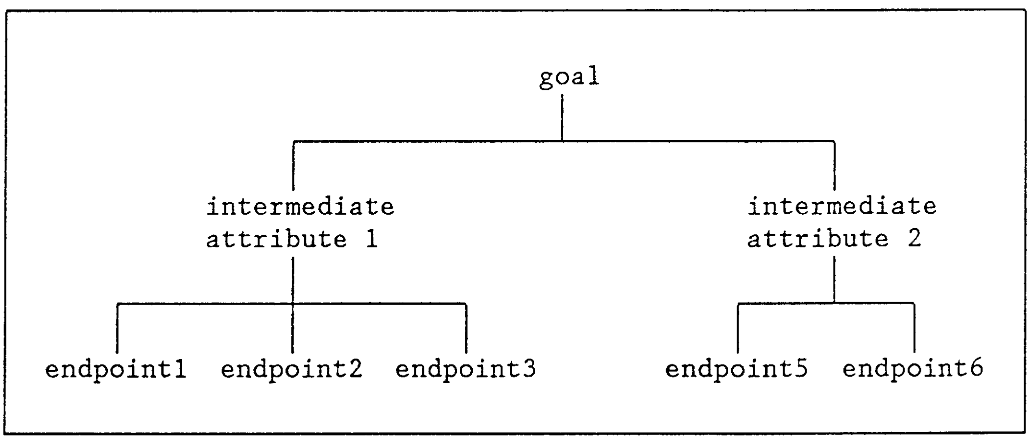


Figure III.1: An example of a hierarchy of attributes.

The attributes in the hierarchy are in principle incomparable, like health effects and number of people self-relocating; or are explicitly valued differently, like cost for medical treatment and capital losses. If the latter are not valued differently, they can easily be summed into total cost for medical treatment and capital losses. In other words the dimension of the entities in the hierarchy is value.

Constructing a hierarchy of attributes makes it easier to estimate the relative importance of the attributes, because the trade-offs between different attributes are only made between "children" of the same "parent" in the hierarchy. Referring to the hierarchy drawn in Figure III.3, the comparisons of the relative importance being made are:

- intermediate attribute 1 ↔ intermediate attribute 2;
- endpoint 1 ↔ endpoint 2 ↔ endpoint 3;
- endpoint 5 ↔ endpoint 6

In the RADE-AID system, hierarchies may be constructed interactively by the user, with each arm of criteria being developed to the level of detail most helpful for the problem). Moreover, if, following investigation of the problem using RADE-AID, the initial structure is found not to be ideal, it may be altered as necessary.

III.3.2 Evaluation Matrix

Having identified the attributes and the alternatives, the "performance" (consequences or outcomes) of every alternative on each of the attributes (effect scores) is determined by models or by observation.

The evaluation matrix, containing the sets of effect scores for every alternative, is the main interface between the radiological objective and subjective decision parts. The elements of the evaluation matrix form the input to the decision logic.

In order to obtain the effect scores, the decision logic may make use of models. Alternatively, effect scores may be obtained using expert judgement. The results of the model calculations, or judgements, are stored in the evaluation matrix. On the rows are the attributes, in the columns are the alternatives (see Figure III.2).

	Attribute 1	Attribute 2	...	Attribute m
Alternative 1	Effectscore	Effectscore	...	Effectscore
Alternative 2	Effectscore	Effectscore	...	Effectscore
. . .	. . .	. . .	. . .	. . .
Alternative n	Effectscore	Effectscore	...	Effectscore

Figure III.2: Evaluation matrix.

III.3.3 First Eliminations

In principle there could be options which can be removed from the evaluation matrix by simple (objective) logical rules, namely by one-dimensional elimination methods[6], like skipping those (unfeasible) alternatives that exceed physical constraints, and by "dominance", i.e. skipping those alternatives which have worse or equal scores on every relevant attribute. This is illustrated in Figure III.3.

In the objective pre-selection, the alternatives are evaluated on their meaningfulness (will it reach the required aim), physical feasibility and technical applicability. In practice this part of decision making is often carried out by the (radiological) models implicitly. The impracticable alternatives will never "enter" the evaluation matrix. So, some decisions have already been taken by the selection of the applicable alternatives, but these results can be seen as the product of pure scientific calculations.

Subsequently, the (non-acceptable) alternatives exceeding subjective (value) constraints will also be removed. This is done when at least one effect score of the alternative is outside the (acceptable) range of the effect score. This reduction of the number of alternatives is an explicit action of the (subjective) decision technique.

Alternative a: $[E1_a, E2_a, \ldots, Ei_a, \ldots, En_a]$
Alternative b: $[E1_b, E2_b, \ldots, Ei_b, \ldots, En_b]$

Exceeding constraint:

If $Ei_a > Ei_{a,\text{max possible}}$ → skip Alternative a

Dominance:

If $(1_a \geq E1_b)$ and $(E2_a \geq E2_b)$
and $(Ei_a \geq Ei_b)$
and $(En_a \geq En_b)$ → skip Alternative b

Exceeding subjective constraint:

If $Ei_a > Ei_{a,\text{max acceptable}}$ → skip Alternative a

Note: (Ei_j = Effect score on attribute: for alternative j)

Figure III.3: One-dimensional decision rules

So, there are several boundary conditions which narrow the space of possible alternative actions. The important question which must be answered is: "Will there still be freedom of action?". It should be realised that a decision problem appears only if more than one possible alternative action remains. This means with regard to the (remaining) alternatives, the effect scores on all attributes are all acceptable, but the alternatives have high and low effect scores on different attributes.

When none or only one alternative is left, there is no choice, and there does not exist a decision problem. If still more than one option remains (Pareto-optimum[6]) there does exist a decision problem, which is in fact an impasse, which can <u>only</u> be decided on <u>subjective</u> arguments.

III.4 The Multi-Attribute Value Technique

When the decision problem is structured the relevant attributes, the (remaining) alternative options and the corresponding effect scores (consequences) are identified. Now the decision-maker must reveal his preferences and priorities systematically in order to range the alternative options. First the valuation of the effect scores is described, secondly the relative importance of attributes and finally the aggregation method.

III.4.1 Valuation of Effect Scores

A value function is the relation between the effect score on some attribute ("endpoint") and the degree of appreciation of this score; the appreciation is (arbitrarily) measured on a scale between 0 and 1 or 0 and 100. The foundation of the value function is the basic principle that people can communicate not only about preference but also about the strength of preference[1]. The value function expresses the preference among objects of evaluation. These objects correspond to all possible effect scores for an attribute.

The estimation of the value corresponding to an effect score is not done directly by coupling a degree of appreciation to it, but by using the value function that was created in advance by valuing hypothetical effect scores between the maximum and minimum of the effect score scale. Proper value functions are monotonous non-decreasing functions or monotonous non-increasing functions. If the value function is not entirely linear it means that equal differences in effect scores, not at the same level, are valued differently. Examples of value functions are shown in Figure III.4.

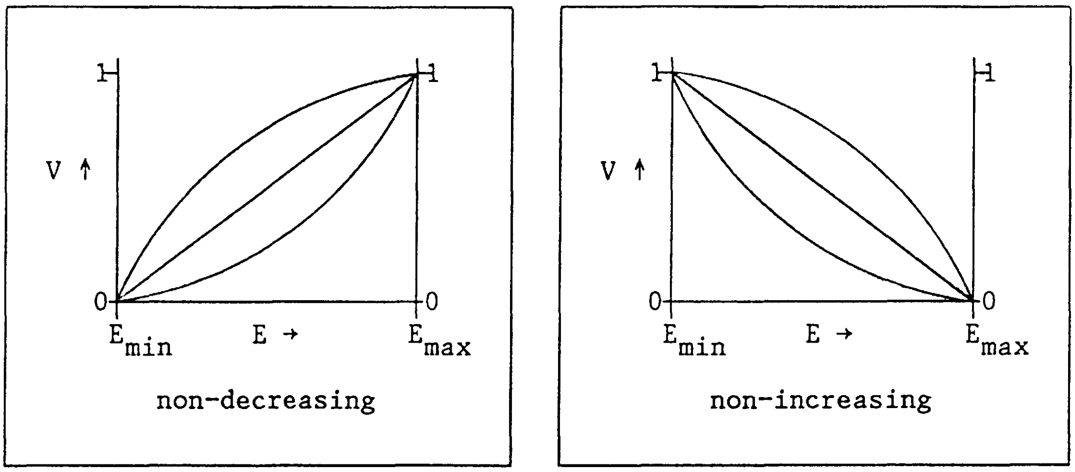


Figure III.4: Examples of value functions.

In constructing a specific value function, a reasonable first estimate is to consider the function linear in the relevant domain of the effect score, i.e. between the worst and best acceptable level[13,14]. However, this initial shape can be adapted to meet the judgements of the decision-makers. If the decision-maker has opinions about the shape of the function, or about the relative valuation of differences in effect score at either end of the effect score scale, it is possible to use this information to modify the shape of the function.

One method for constructing value functions is the so called midpoint value method or bisection method[1]. After the minimum (acceptable) effect score and the maximum (acceptable) effect score of an attribute have been determined, the method asks the decision-maker to find the effect score that is half way between the valuation of the two extremes. To determine the midpoint value in the range one begin with the midpoint (E_p) on the effect score scale and ask whether the decision-maker feels that the difference between the E_p and E_{min}, and E_p and E_{max} are valued differently (i.e. are associated with different relative strengths of preference). After few trials and errors the point of indifference can be determined: $V(E_p) - V(E_{min}) \approx V(E_p) - V(E_{max})$, meaning that $V(E_p) = 0.5$. Further subdivision of the scale leads to more E_p's and refinement of the value function:

$V(E_p') = 0.25$, $(VE_p'') = 0.75$, etc. A value function resulting from the process is shown in Figure III.5.

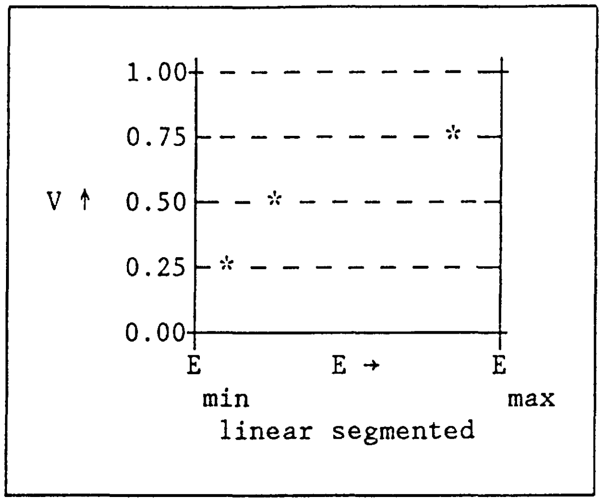


Figure III.5: Example of a value function, obtained by the midpoint value method.

The value functions could be seen as the interfaces between the effect scores and the hierarchy (Figure III.6).

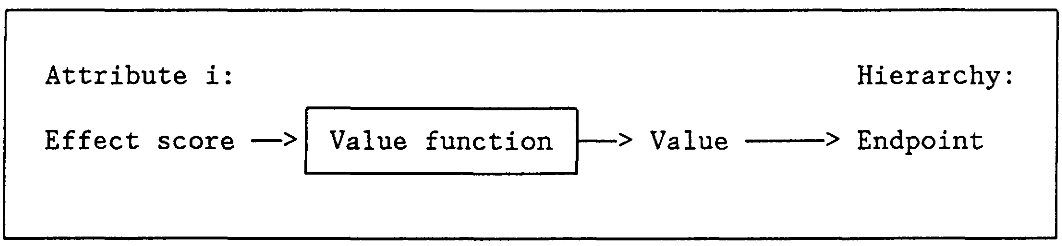


Figure III.6: Functional relationship effect scores and endpoints.

Direct valuation of an attribute

Sometimes it may turn out to be difficult or hardly possible to split up a high level abstract attribute into more detailed concrete and measurable attributes. This could be because some or all of the information cannot be expressed as a set of quantitatively or qualitatively measurable independent quantities. However, some kind of holistic valuation of alternatives still has to be made.

With the direct valuation technique, (i.e. meaning not using a general applicable value function), one does not explicitly construct any attribute scale on which the effect score is measured, but directly assigns attribute values to alternatives. The distinguishable value levels could be poor, fair, indifferent, good, excellent. Scale construction can be substantially refined by the expansion of such one-word descriptions(1). In general, one would attempt to construct circumscriptions (i.e. descriptions of distinguishable value levels) that were equally spaced in value and assign values that preserve that equal spacing.

Direct valuation of the effect scores has the advantage of avoiding the making of two qualitative judgements: first expert judgement and second the decision-maker's preferences. But it should be kept in mind that the expert and the decision-maker are not necessarily the same person.

Furthermore, a great disadvantage of such a procedure would be that the distinguishable categories of possible scores the attribute can take are not defined at all, so nobody would know what type of situation corresponded to a certain assigned value number between 0 and 100. This will be especially the case when the alternative options and the corresponding effect scores are not known in advance.

A transparent way to tackle this kind of problem seems to be to separate the qualitative "measurement" of the aggregated "effect score" on the abstract attribute from its subjective valuation. This means first constructing a scale based on qualitative but clear and unambiguous circumscriptions of the possible levels the attribute can take on, and second letting the decision-maker assign his own values to these categories. The following (Figure III.7) is an example of such circumscriptions, concerning (relevant) effects or consequences of locating a site for the disposal of nuclear waste in a area(10).

Impact level	Socioeconomic impacts in the affected area
0	No social or local economic disruptions occur; no commercial, residential or agricultural displacement occurs; no adverse impacts on water resources occur.
1	An in-migrating population of about 5,000 persons is dispersed over an area with a population of around 50,000; in-migrant lifestyles match those of current residents and no major social disruption results; disruption of existing business patterns is avoided by standard economic planning measures; no adverse impacts on water resources occur, but minimal commercial, residential or agricultural displacement results.
2	An in-migrating population of about 5,000 persons is concentrated in a few communities within an area with a population of around 50,000; major upgrading of the infra-

Impact level	Socioeconomic impacts in the effected area
	structure is required; 25% of the residents have lifestyles and values that are unlikely to match those of in-migrants; major social disruptions do not result; disruption of existing business patterns is avoided by standard economic planning measures; minor diversion of water resources from other activities occur; half of the land is privately owned, and commercial, residential or agricultural displacement results.
3	An in-migrating population of about 10,000 persons is concentrated in a few communities within an area with a population of around 100,000; major upgrading of the public infrastructure and considerable new housing are required; affected communities have homogeneous lifestyles and values that do not match those of the in-migrants; significant disruption to existing business patterns and substantial economic decline result after the completion of water-emplacement operations; minor diversion of water resources from other activities occurs; all land is privately owned and commercial, residential or agricultural displacement results.
4	An in-migrating population of about 10,000 persons is concentrated in few communities within an area with a population of around 100,000; major upgrading of the public infrastructure and considerable new housing are required; affected communities have homogeneous lifestyles and values that do not match those of the in-migrants; significant disruption to existing business patterns and substantial economic decline result after the completion of water-emplacement operations; major diversion of area water sources occurs, resulting in impacts on development in the affected area; all land is privately owned and commercial, residential or agricultural displacement results.

Figure III.7: Example of circumscriptions of impact levels of an attribute.

A less qualitative method would be to define indicators which really can be measured, that reflect the aspects of the abstract attribute. The real situation can perhaps not be directly measured but could be identified by the outcome of those indicators, which are not relevant attributes as such. Another possibility is that the indicators would be seen as real effect scores, that could be related to separate value-functions directly. Defining a set of real effect scores by which the attributes could be quantitatively measured is to be preferred above any type of direct valuation. The value function resulting from the process is shown in Figure III.8.

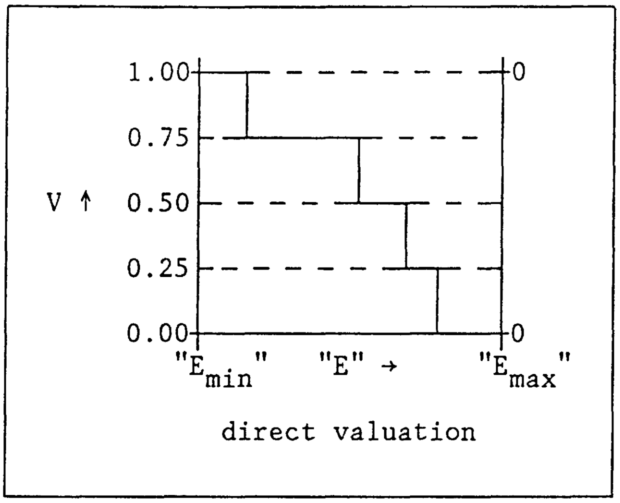


Figure III.8: Example of a value function, obtained by direct valuation of circumscriptions of impact levels.

<ins>The distinction between value and utility in riskless events</ins>

Before the coming of the multi-attribute value techniques Neuman and Morgenstern developed the theory about the utility of gambles, whose basic principles are described in Annex A.

The superficial resemblance between "value" and utility is unmistakable. Both are measured on a arbitrarily chosen interval scale. Also like the determination of value, utility is not generated within the system, but is input by the decision-maker. In Section III.6 the method used in the package Prefcalc is described very briefly; this procedure does generate value/ utility functions.

Complex procedures exist to find the utilities of <ins>non risky</ins> objects based on <ins>hypothetical</ins> gambles(15). The question arises whether the resulting utility functions will differ from value functions based on methods to elicit relative strength of preferences not based on gambles. In the opinion of Von Winterfeldt and Edwards(1) the distinction between value and utility (of non risky events) is spurious. One of the practical arguments is that the error and variance within value and measurements procedures overshadow to a great extent the subtle distinctions that one may extract from theoretical differences. In dealing with <ins>risky</ins> events or uncertain outcomes (real gambles) the utility may be seen as a transformation of value intended to take into account the decision-maker's attitude towards risk and uncertainty.

III.4.2 Relative Importance of Attributes

Weights factors W_i are the numerical representation of the trade-offs between the valuation of different attributes. The weight factors are usually normalised to numbers between zero and one. They can be estimated by the decision-maker directly, or when the decision-maker is not certain, he may use some auxiliary techniques for constructing attribute weights. In these methods the concept "attribute importance" and/or the scale of the attribute play a role. The following methods will be described:

- Numerical estimation methods:
  * Direct rating,
  * Ratio estimation,
  * Ranking,
  * Swing weights;
- Indifference:
  * Cross-attribute indifference.

Weighting based on intrinsic importance

The numerical estimation methods usually incorporate the concept of (intrinsic) attribute importance in order to quantify the relative weight that an attribute carries in the overall determination of value.

Direct rating[1], meaning to assign directly numbers to the weight factors, is rarely used as weighting procedure. A version of it is the distribution of 100 points over the attributes so that the number of points assigned to each reflects its relative importance.

In the ratio estimation procedure an estimation is made how much more important an attribute is than the least important one[1]. A variant is to refer the importance of attributes to the most important one. The latter has the advantage that experts usually agree better on what is most important than what is least important. It has the disadvantage of making it more difficult to preserve the ratio properties of the weight estimates[14].

A simple method of ranking is rank weighting, in which the attributes are first ranked in order of importance[1]. The lowest ranking is given a score of 10. The next lowest attribute is then considered and it is asked how much more important it is than the lowest. This is then assigned a number to reflect its importance and one works one's way up the list of attributes. In doing so, it is important to preserve ratios in the sense that if an attribute is allotted a score of 30, it should be considered three times as important as an attribute with a score of ten, but only half as important as an attribute with a score of 60, and so on. In assigning numbers, one should not be reticent about changing previous assessments, rearranging, etc[2]. A variant of this procedure is to rate the importance of each parameter on a scale 0-100 by assigning 100 to the most important attribute and rating the others relative to that parameter. The determined ranks can be transformed into (normalised) weights by several mathematical rules. Among them are the rank reciprocal rule, the rank sum rule, and the rank exponent rule. These methods are described in Annex B.

Weighting using effect score scales

All these weighting techniques mentioned so far explicitly involve the notion of intrinsic attribute importance. This emphasis on importance has been criticised. Some consider weights to be simple rescaling parameters that are necessary to match the units of one single attribute value-function with the units of another. Since units are dependent on the range of the scale over which the value function is defined, the weight should change when the range of the scale changes.

The problem is that direct judgements of importance may be insensitive to the ranges of the scales under consideration indeed, and thus importance may distort the rescaling of single-attribute value functions. Are in general the importance judgements appropriately adjusted in relation to the weights? The question has no satisfactory answer yet. The use of the concept of intrinsic importance is intuitively compelling, but we must address the fact that the ranges may also influence the weights.

There are some helpful ideas:

- use the natural ranges of the attributes or, less preferably, the plausible ranges, so that the range will not be dependent on the problem at hand,
- otherwise, be very explicit about the range being used.
- use other methods that take account of the range of the scales.

Swing weighting[1] is a procedural hybrid derived from an indifference method in which cross-attribute strengths of preference are systematically compared. Swing weighting does not make use of concept of intrinsic importance, but takes into account the scale of the attribute. In this technique it is asked how much an attribute contributes to the overall value of the alternatives relative to other attributes. Typically, the alternatives are compared that "swing" between the worst and the best levels in each attribute. It is determined which of the swings contribute more in overall value and then the extent to which the value "swings" differ is assessed.

In the most common swing technique two hypothetical alternatives are constructed: the ideal alternative (best level on all attributes) the anti-ideal alternative (worst level on all attributes):

$$\text{Ideal:} \quad (E_1+, E_2+, \ldots, E_n+)$$
$$\text{Anti-ideal:} \quad (E_1^-, E_2^-, \ldots, E_n^-)$$

The decision-maker is confronted with the question to assume that he is stuck with the worst alternative, but that one attribute can be changed from its worst level E_i^- to its best level E_i^+. Which one would be changed? And after that which one should be changed second, third, and so on. Obviously, the order in which the decision-maker wants to change attribute levels from worst to best depends on the relative value difference between E_i^- to E_i^+. The attribute that seems to make the most difference in value should be improved first, the one that has the second greatest impact on value should be improved second, and so on. This process establishes in a fairly natural way the rank order of the weights (see Annex C).

To obtain the ratio-scale weights from these rank orders, the weight factor corresponding to the first selected attribute will be assigned an arbitrary value difference of 100 points. A value difference of 0 points is assigned to that attribute for which it makes hardly no value difference if one moved it from the worst to the best. Then, either all the other value differences are expressed as percentages of 100, or one of the other numerical rank methods described earlier could be used instead.

The cross-attribute indifference method(1) also explicitly takes into account the scale of the attribute. In the cross-attribute indifference procedure one determines the weight by matching the strength of preference in one attribute to the strength of preference in another. The methods compare cross-attribute strengths of preference systematically; by varying alternatives in two attributes and using simple equations that can be solved for the attribute weights. In the sequential trade-off technique, one trades off each attribute against a special attribute (like money) in order to find, for each alternative, a hypothetical alternative that is indifferent to it and has constant values in all but the special attribute. A single value-function over this special attribute is then sufficient for comparing the alternatives.

The weighing procedure is similar to the swing weight procedure, but it does not involve direct numerical estimation. Consider the relative strength of preference between $A(E_i^+, E_j^-)$ and $O(E_i^-, E_j^-)$ and compare this with the relative strength of preference between $B(E_i^-, E_j^+)$ and $O(E_i^-, E_j^-)$: is it greater, equal or smaller? The question refers directly to the comparison of the weight factors W_i and W_j. To determine how much larger W_i is than W_j, the effect score E_i^+ is reduced to some intermediate level E_i' several times until the indifference judgements have been made. This implies that:

$$W_i \cdot V(E_i') \approx W_j, \text{ and thus:}$$

$$\frac{W_j}{W_i} = V(E_i') \text{ (see Annex D)}$$

Repetition for all n * (n - 1) / 2 pairs of attributes gives the desired information, necessary to determine (n - 1) weights. The redundancy can be used to find inconsistent judgements, by use of the pair-wise comparison. The value function for at least one effect score must be known in advance.

Weighting for intermediate attributes

In the aggregation procedure the weight factors multiply single attribute value functions, and do not operate on the effect scores. When the weight factors operate on the intermediate attributes, which are in fact aggregates of underlying values, the scale problem is not apparent, since the ranges of all the values vary from 0 to 1. So, only the aspect of importance plays a role in assigning weights to the attributes. A possibility would be the use of swing weights acting on all underlying attributes simultaneously. Applying the method this way will probably confuse the decision-maker, particularly if the swing weight method has also been used at the lower level. The conclusion is that ranking methods are recommended for intermediate attributes (attributes higher in the hierarchy than the endpoints).

Discussion

A problematic situation arises if, for instance, the options evaluated do not cover the plausible range of the dimensions of value[13]. This applies to contexts in which the effect scores on the various attributes are unknown at the time weight judgements must be made, as is the case for instance in emergency management. The reason why this presents a problem is that the range of value of a value attribute is in a sense a kind of importance weight. An attribute whose values range from 0 to 50 is effectively only half as important in controlling evaluation as one having the same weight factor whose values range from 0 to 100. While this problem can be solved only by judgmental methods, it can be put into a simple perspective, by a transformation of value and weight factors. The effect of the transformation is to put all of the scaling information into adapted weight factors at least as it applies to the set of alternatives at hand. If the actual range of the attribute is small, changes in the corresponding effect score will have minor influence on the overall valuation of the alternatives, despite a high intrinsic importance of that attribute (see Annex E).

In "Ratio estimation", "Swing weights" and "Cross-attribute indifference method" cross-checks can be made by comparing all attributes with one another; all ratios of attribute weights should be consistent[2]. The pair-wise comparison method used in the Analytic Hierarchy Process is perfectly suited to the creation of the optimum set of weights with respect to consistency. The method tries to calculate the best "fitting" weight factors given the ratio judgements. The degree of inconsistency can be estimated and compared with the level of acceptable inconsistency[9].

III.4.3 Aggregation Model

The aggregation of the various kinds of judgements is the essential step. Aggregation is in fact the transformation of the effect scores $E = (E_1 \ldots E_n)$ onto a uniform dimension and their conversion onto the same scale. The final result of the decision analysis, i.e. the ranking of the alternatives is determined by the (overall) score V on that (value) scale.

The option having the highest overall value score is the one judged as the "best" option.

The multiple attribute aggregation (value) function used in RADE-AID is the linear additive model:

$$V(\vec{E}) = \sum_{i=1}^{n} W_i \cdot V(E_i) \text{ with } \sum_{i=1}^{n} W_i = 1$$

When using the linear additive value model the sum of the weight factors (of one parent in the hierarchy) is one or a hundred; this does not hold necessarily in other aggregation models. The additive form further assumes that the single attribute value functions V_i can be constructed disregarding other attributes (additive difference independence). It requires that the relative strength of preference between two objects x and y, that have identical fixed levels in some other attributes, do not change when these other attributes are fixed at some other level. These means that the value functions can be constructed independently.

It should be kept in mind that there are two different main types of interactions possible[12,14]:

- value dependency with $V(E_i) = f(E_1,E_2,...,E_n)$, where the value of an effect score depends also on the other effect scores;
- environmental dependency with $E_i = f(E_1,E_2,...,E_n)$, where an effect score carries information already expressed by other effect scores.

Both interactions influence the final valuation of the alternatives. If the value dependency is negligible compared to the uncertainty of the judgements and measurements, the simple additive value-function will still be appropriate.

Environmental dependency (double counting) can probably be avoided by a proper redefinition of the set of relevant attributes. Other value aggregation models exist, that are able to deal with interaction between attributes, like the multiplicative model:

$$1 + W + V(\vec{E}) = \prod_{i=1}^{n} (1 + W + W_i \cdot V(E)_i)$$

This is still a rather simple aggregation model, including only one (extra) factor, which defines all interaction[1,6]. The best policy is to avoid those complex models as long as reasonably possible, since the elicitation methods corresponding to more complex models require much more effort.

When using the linear additive model, the aggregation of hierarchically constructed attributes goes step-wise. First the values of the lowest intermediates are calculated, then the next higher intermediates, until finally reaching the top intermediate: "goal" (see Annex F). The construction of a hierarchy of attributes is a very helpful instrument, and furthermore it does not affect the linear additive aggregation model. The final outcome is not dependent on the way the hierarchy is structured.

III.5 Sensitivity Analysis

The detailed characteristics of the final choice and of its close competitors can be studied more carefully using sensitivity analysis. It may leave the original analysis and conclusions unchanged or it may lead to further thought.

Sensitivity analysis plays an important role in gaining insight into the decision problem and is a useful tool in testing the stability and solidity of the results. The outcomes of the decision logic should never be accepted without scepticism and a further analysis of the results should always be applied.

It is most useful to perform a sensitivity analysis with respect to (small) variations in the weight factors δW_i on the overall evaluation $V(E_1, E_2, \ldots E_N)$ for all alternatives. The linear additive value aggregation model is well suited to perform simply this sensitivity analysis:

$$\delta V(\vec{E}) = \sum_{i=1}^{n} V(E\ ) \cdot \delta W_i$$

Conditions:

$$1: \qquad 0 = \sum_{i=1}^{n} \delta W_i \leftrightarrow \sum_{i=1}^{n} (W_i + \delta W_i) = 1$$

2: The variation of a certain weight factor δW_i is proportionally distributed to the other weight factors:

$$\delta W_j = \delta W_i \cdot \frac{W_j}{(1-W_i)}$$

Figure III.9 illustrates how the results of such a sensitivity analysis are displayed in RADE-AID.

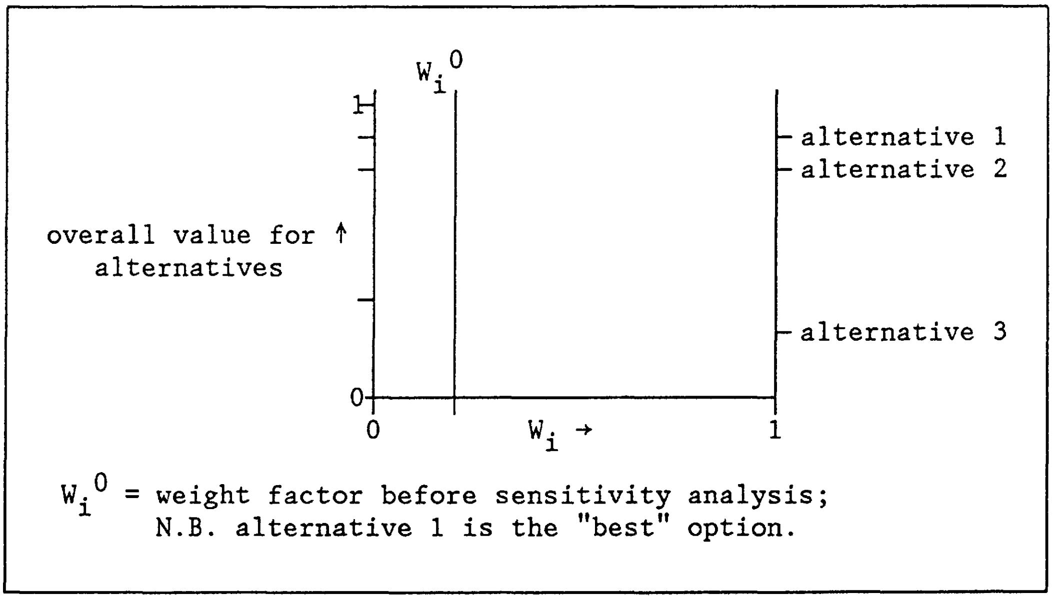


Figure III.9: Graphical representation of the results of sensitivity analysis (stylised)

It is also possible to explore the significance of uncertainties in the estimated effect scores and judgements, in terms of the ranking of the alternatives. Such analysis may indicate where obtaining additional information in order to lower uncertainties may be most useful. The search for additional information should be undertaken only after the key aspects of decision have been isolated[12], and the corresponding costs are considered to be reasonable.

III.6 Evaluation of Available Software Packages

Four commercial available software packages were studied:

- VISA,
- Prefcalc,

- Expert Choice,
- HIVIEW.

Except Expert Choice, the packages are all based on the Multi-Attribute Value/Utility Technique.

VISA is a computer program for multiple criteria decision aiding, based on a simple weighted multi-attribute value function, incorporating a hierarchical structure of criteria and visual interactive sensitivity analysis[16].

Prefcalc is an implementation of the UTA (utilité additive) method. The purpose of this method is to assess additive value/utility functions which aggregate multiple attributes in a composite evaluation. It does this by using the information given by a subjective ranking on a set of alternatives (weak order comparison judgements) and performing a multi-attribute evaluation of these alternatives. It is an ordinal regression method using linear programming to estimate the parameters of the value/utility function[17].

Expert Choice is an implementation of the Analytic Hierarchy process. The method is based on the judgements of pair wise comparisons of the importance of the attributes and the judgements of pair wise comparisons of alternatives with respect to particular attributes[9].

HIVIEW gives facilities to structure the hierarchy of objectives or attributes, but appeared to be unable to perform the formal mathematics which relates the outcomes of the possible alternatives (effect scores) to more general value functions in order to calculate values. The package can deal with direct valuation of the effect score on the attributes. It does not contain auxiliary routines to assist the decision-maker to estimate weight factors and valuations[13].

All packages perform very useful facilities but none covers all the aspects of the decision-making process considered important for RADE-AID. However, all the packages together perform functions covering a large part of the needed facilities. The incorporation of parts of the packages directly into a system, in which it must be able to process large amount of necessary data from the (radiological) models, was not possible for technical reasons such as the unavailability of source code. Therefore, ideas from these packages were used to provide additional facilities within RADE-AID.

Results of psychological research on human mental limitations often show that even under the best circumstances human intellectual performance is not very good. One solution might be: replace the errant human being and use the computer instead. But the purpose of decision analysts is to meet the requirements for good human performance, rather than to automate the intellectual task. The reason for this is that many intellectual tasks cannot be done well without a great deal of human participation[1].

Some believe that the use of models somehow diminishes the role of the decision-maker, who ends up relinquishing control to an algorithm which he may not fully understand and therefore is unable to trust. However, decision aids are not to be believed, they are to be used[1]. It is the decision-maker who must recognise and structure the problem, as well as provide many subjective inputs necessary for analysis.

The key points are that a decision-maker finds it difficult to think simultaneously about all the dimensions relevant to a complex decision, and that subjects making holistic judgements often do not know what cues are actually important in controlling their judgements. A somewhat formal evaluation procedure could help to ensure that all relevant dimensions of evaluation are used, and used consistently in a pre-determined manner[2].

Decision analysis was initially presented as a general methodology without any reference to the use of computer based systems. Computer-based versions of decision analysis primarily help in quantifying the decision-makers' own subjective preferences[18]. Decision-makers should resist the idea that machines or computational procedures can replace them. The decision-maker is the person who takes the blame if the decision leads to a distressing outcome. So he must feel and should insist on feeling that responsibility is deserved[1].

IV IMPLEMENTATION OF THE SYSTEM

An ideal goal of the design of any decision aiding tool is to combine generality of purpose with enough user-friendliness so that the decision analyst does not need to be present when the tool is used. Beside the formal logic a computerised decision aid must then supply additional auxiliary functions. In addition, RADE-AID contains a great number of different ways of looking at both the objective data and subjective results.

The starting point for the design and implementation of a computer system is the specification of the functional objectives the system should meet. For RADE-AID these were specified as follows. RADE-AID should:

- display coherent information about the actual situation;
- calculate realistic predictions about the (future) environmental contamination and radiation exposure of the population;
- demonstrate the influence of countermeasures on consequences of the accident;
- propose an optimal (combination of) countermeasure(s) as the result of a sophisticated decision logic;
- provide a tailored presentation of results including indications of uncertainty;
- serve as an instrument for training and in developing and exercising emergency plans.

During the current research it became obvious that reaching all objectives in the same extensive depth was not possible within the scope of the project. This conclusion has led the research to give priority to some objectives above others. Especially the first and fifth objective were made subordinate to others. This does not imply that those objectives were not achieved; only that they were given less attention compared to others. For example, the presentation of information about the accident is available in the current system, in order to show how this facility can be useful to decision-makers, but it has been implemented for a specific set of data only. The second objective has also not been given priority. Realistic predictions are of course made, but they are calculated outside RADE-AID by existing models. The results of calculations are supplied to RADE-AID.

RADE-AID is designed to be a Decision Support System (DSS). A decision support system may be defined as an interactive system to assist a decision-maker in using databases and models (including decision techniques) on a computer to solve complex problems. This definition is reflected in the architecture of a DSS. Figure IV.1 illustrates the archetype of a DSS.

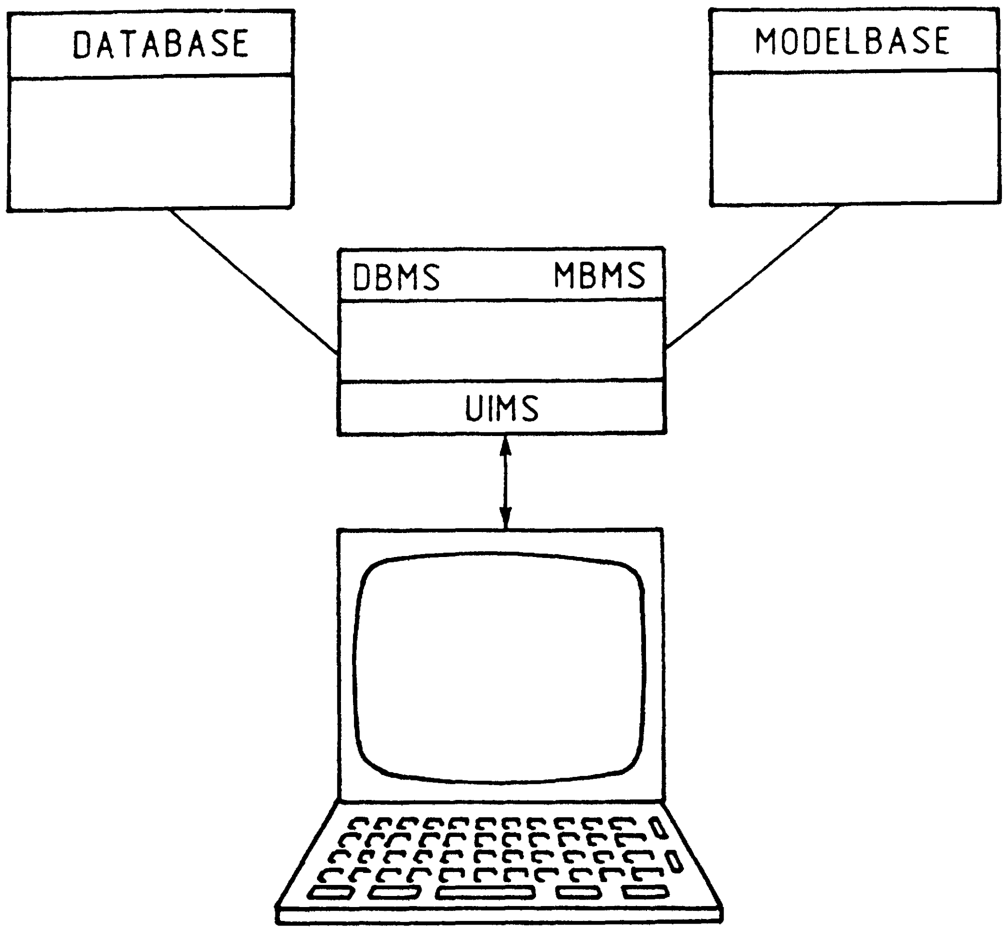


Figure IV.1: Archetype of a decision support system.

The database of a DSS is expected:

- to combine various data;
- to elucidate logical data structures;
- to allow users their own view on the data;
- to record (free) text.

The model base is expected:

- to record and to document a large range of models;
- to process new models fast and easily;
- to feed the models with data, for instance from the database.

The software system to interact with the user (decision-maker) has to offer the following facilities:

- presentation of data in various forms, using colour and/or graphical presentation;

- communication between the computer and the user by the use of menus, windows, etc;
- handling of models;
- changing the mode of interaction (for instance novice versus expert users).

RADE-AID is a DSS with two important aims. First it is an interactive computer program capable of displaying both the current radiological situation and the likely consequences. Second it provides assistance to a decision-maker in determining the optimum course of action and in evaluating the relative merits of several different courses of action.

Combining both the architecture of a DSS in general and the specific characteristics and constraints of RADE-AID leads to a functional design of the system. The functional specification of RADE-AID is shown in Figure IV.2. This scheme is based on ISAC: Information Systems work and Analysis of Changes[19].

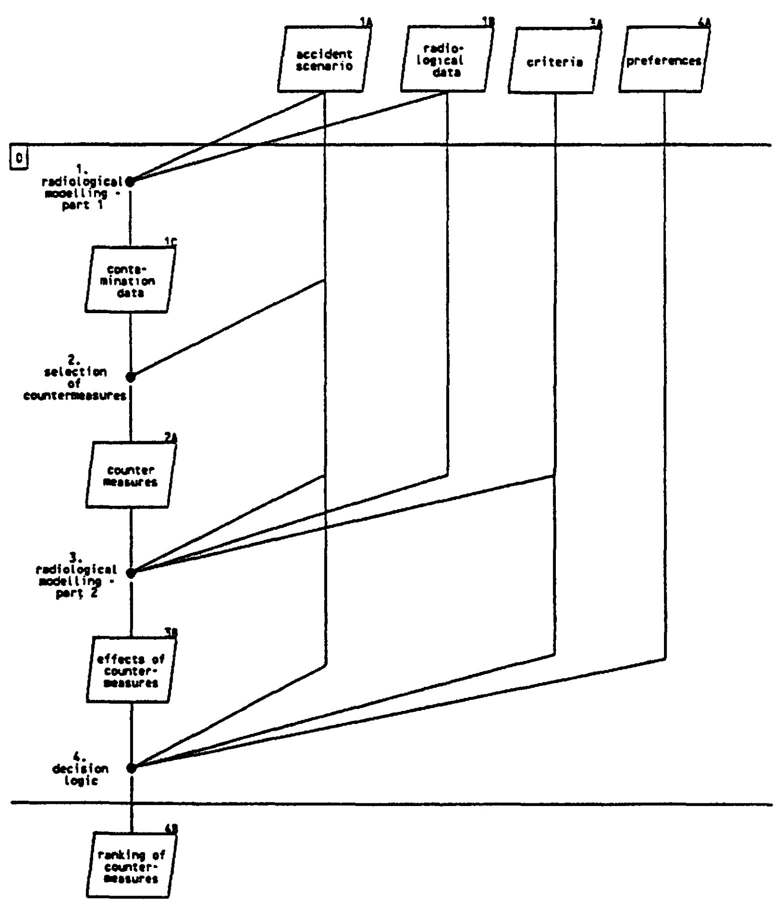


Figure IV.2: Functional scheme of RADE-AID (top level).

The elements of Figure IV.2 are in turn discussed below. Elements of the functional design which have not yet been implemented are indicated.

The starting point for RADE-AID is an accident scenario (1A; codes refer to Figure IV.2). This scenario contains data on several aspects of the accident. Examples are:

- all countermeasures to be considered,
- data on the source term,
- activity concentration,
- and so on.

By the use of radiological models (1) and data (1B) the radiation exposure to the public is determined. Doses and concentrations in various foodstuffs are calculated (1C).

Given the contamination (1C), feasible countermeasures are selected (2,2A). These countermeasures are then judged on their effects with respect to several criteria (3A). Radiological models (3) and data (1B) are again used to quantify the effects of countermeasures (3B), given the criteria.

The flexibility of the decision logic (4) allows for the changing of the default values in the general accident scenario (criteria, effects, countermeasures) as well as incorporating the decision-maker's (subjective) valuation of the situation.

As a final result RADE-AID determines an "optimum" choice (4B), which is presented to the decision-maker. This choice reflects the preferences from the decision-maker as well as the current policy concerning radiological accidents (4A). There is also an opportunity for sensitivity analysis of the results. In the prototype system steps 1-3 are carried out outside the system and presented to the system in the form of a database of information. From step 4 onwards, nearly all the functionality envisaged for RADE-AID has been implemented. The functions presently implemented in RADE-AID are illustrated in Figure IV.3.

From Figures IV.2 and IV.3 it is clear that, at present, the estimated structure of the problem must be determined in advance, in order to provide the system with the appropriate information about the consequences of countermeasures. This means that the hierarchy is established beforehand and that the relevant attributes (from a scientific point of view) have already been identified. Also the feasible countermeasures have been determined in hypothetical radioactive

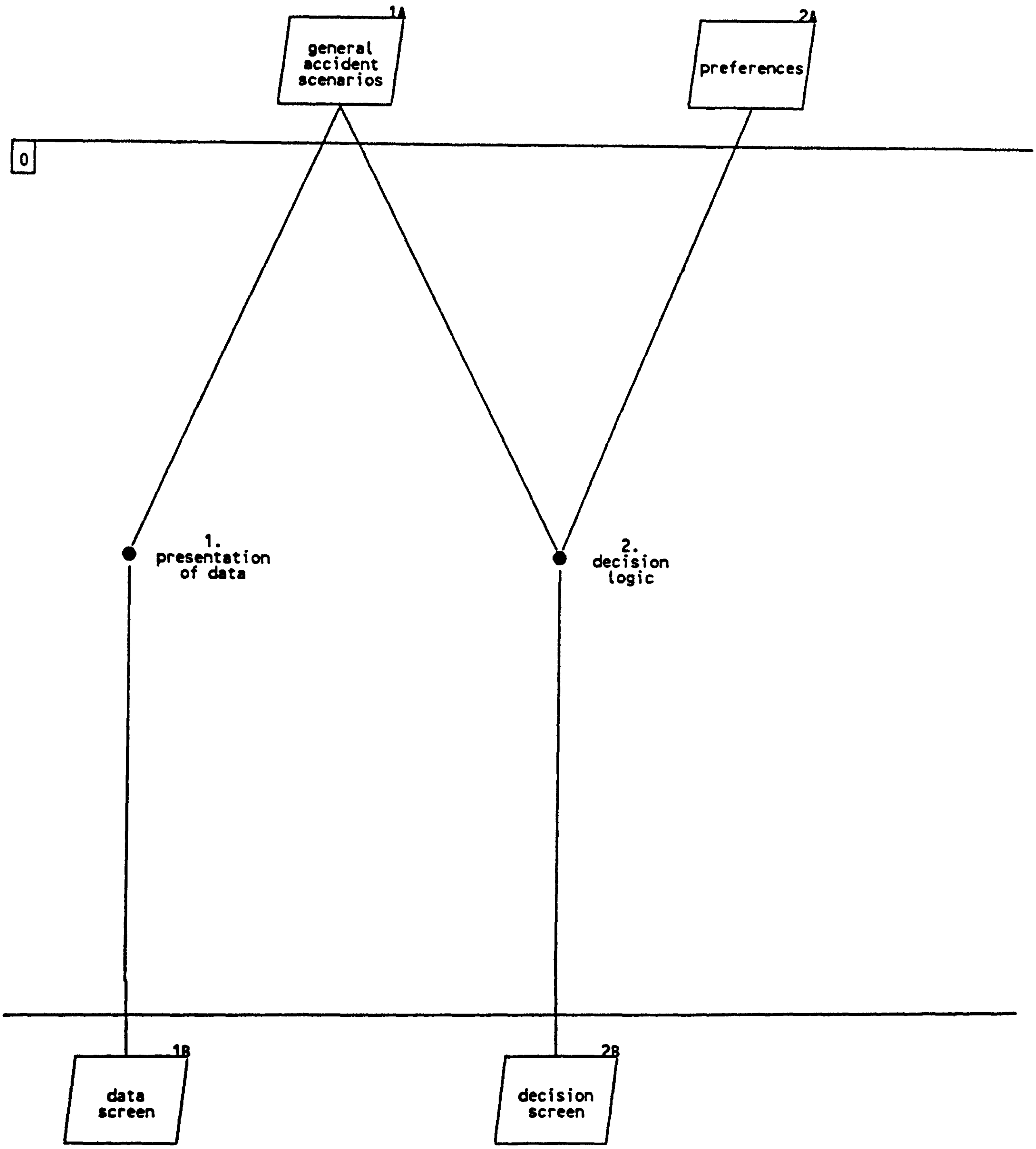


Figure IV.3: Functions presently implemented in RADE-AID.

contamination scenarios. In practice this may be achieved by iterative use of RADE-AID, discussions with decision-makers and evaluation of radiological models. Once the problem has been satisfactorily structured and the consequences of feasible countermeasures evaluated, RADE-AID can be used to elicit weight factors and modified value functions from decision-makers.

Figure IV.3 shows that the prototype RADE-AID system provides two major options:

- presentation and
- decision logic.

Both options are globally discussed below: the detailed information is contained in Annex G. The last paragraph of this chapter is devoted to the technical details of the implementation.

IV.1 Presentation

As it is shown in Figure IV.3, presentation is concerned with the presentation of the accident scenario to the user (decision-maker). Within the constraints of the present contract it has not been possible to provide a general facility for displaying any relevant data (this is primarily because the data are not generated directly within the RADE-AID system). However, since the presentation of data is considered to be an important part of RADE-AID, an illustrative presentation facility has been developed which displays information on food contamination. This illustration is described here.

The following data are available:

- general data on the area involved;
- data on the area, dependent on countermeasures;
- data on costs;
- general data on health effects;
- data on health effects, dependent on countermeasures.

Most of these options are again subdivided; an exhaustive list is contained in Annex G. The data is presented in two ways: tabular and graphical. Examples are shown in Figures IV.4 and IV.5. An explanation of the contents of the figures is provided in the next chapter; the results used in the figures are from the (stylised) applications described there.

Yield with ban duration greater/equal T_i

Time T_i	IL 1	IL 2	IL 3
0 D	2.19 E +06	2.92 E +06	2.87 E +07
15 D	2.19 E +06	2.92 E +06	2.87 E +07
30 D	2.19 E +06	2.92 E +06	2.71 E +07
90 D	1.46 E +06	2.92 E +06	2.71 E +07
180 D	1.46 E +06	2.92 E +06	2.71 E +07
1 A	1.46 E +06	2.92 E +06	2.45 E +07
2 A	1.46 E +06	2.92 E +06	2.26 E +07
5 A	0.00 E -00	2.92 E +06	1.98 E +07
10 A	0.00 E -00	2.19 E +06	7.25 E +06
20 A	0.00 E -00	2.19 E +06	5.09 E +06
50 A	0.00 E -00	2.19 E +06	3.64 E +06

Press <enter> to continue...

Figure IV.4: RADE-AID - presentation of data from the accident scenario in tabular form

The graphical presentation can take various shapes. Examples are:

- histograms (Figure IV.5);
- pie charts (not yet implemented in RADE-AID);
- graphics;
- isocontours (not yet implemented in RADE-AID).

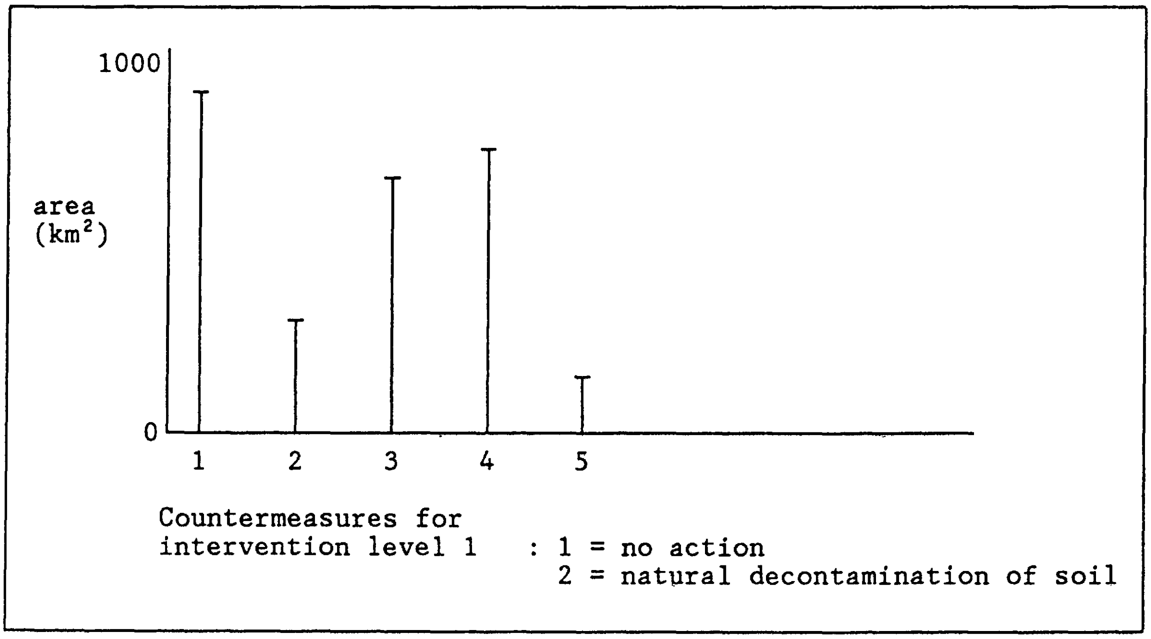


Figure IV.5: RADE-AID - presentation of data from the accident scenario in graphical form (stylised)

IV.2 Decision Logic

The complete decision logic currently supports the following main functions:

- a formalised method to support breakdown of the objectives, the construction of value functions and the determination of (consistent) weight factors;
- a method of aggregation to determine the overall valuation based on the valuation of the effect scores on each attribute;
- several ways of graphical and numerical representation of the (final) results, since it is of crucial importance that the user of the system is able to look at the (subjective) data in as many ways as possible:
  * the ranking and overall valuation of alternatives,
  * the valuation of the separate effect scores as percentage of the overall valuation of the alternative,
  * the effect scores of the alternatives on a separate attribute,
  * the value of the effect scores of the alternatives on a separate attribute,
  * the comparison of the values of effect scores of two different alternatives, including comparison with the ideal alternative (losses) and the anti-ideal alternative (gains) for every attribute,
  * the two dimensional display of the alternatives on two antagonistic attributes (a cost versus a benefit)
  * the hierarchy of relevant attributes,
  * global and local weight factors and value functions,
  * the data defining the problem: attributes, effect scores of the alternatives;
- the performance of sensitivity analyses on the outcome of the decision logic, i.e. the ranking of the alternatives, with respect to changes in the weight factors;
- the ability to generate <u>overall</u> value functions and weight factors based on the judgement of different individual decision-makers and experts.

These functions are translated to the decision logic part of the program as five major options:

- file manipulation;

- definition of alternatives;
- definition of attributes (including weight factors);
- definition of effect scores (including value functions);
- presentation of results.

The options are in turn discussed below. The choice between options is made through the use of menus; this prevents the occurrence of (human) errors. Menus are operated by cursor movements. An example of the use of menus is given in Figure IV.6.

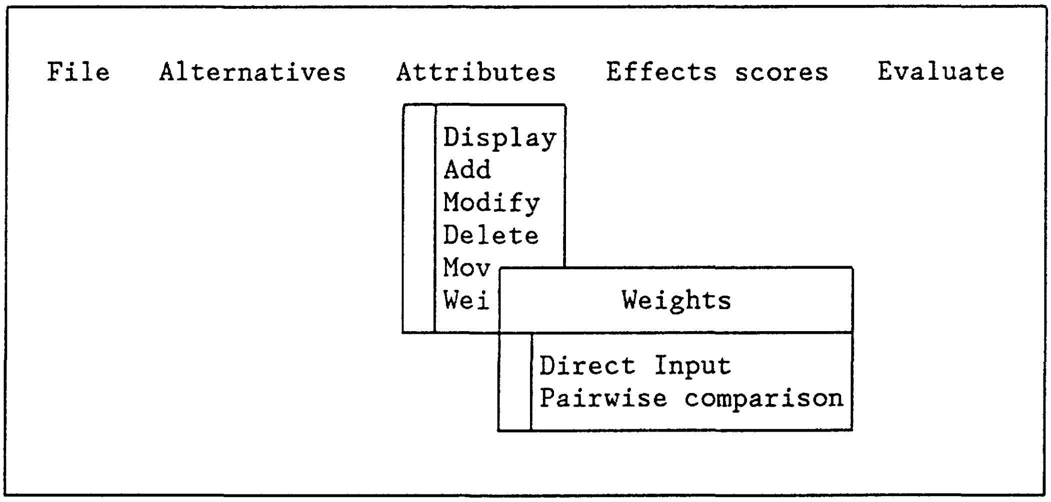


Figure IV.6: RADE-AID - use of menus.

IV.2.1 File Manipulation

File manipulation supplies the user with storage and retrieval of files (defined by the use of other options). A file contains all necessary data on a case, such as the alternatives, the attributes, the effect scores, the weight factors and the value functions. This option supports the use of the system by several different decision-makers, each having his or her own subjective point of view. An exhaustive list of options is:

- loading of a file;
- definition of a new file;
- saving of a file;
- changing of a directory;
- returning temporarily to the operating system;
- leaving RADE-AID.

For a description of these options, refer to Annex G.

IV.2.2 Alternatives

Alternatives may be:

- displayed;
- added;
- modified;
- deleted.

These options are self-explanatory.

IV.2.3 Attributes

This option not only allows the manipulation of attributes (including their definition), but also the definition of weight factors through the use of various procedures. An exhaustive list of options is:

- display of attributes;
- addition of attributes;
- modification of attributes;
- deletion of attributes;
- movement of attributes;
- definition of weight factors.

The central point of all options above is the representation of the attributes. They are represented graphically through the use of a hierarchy. An example of such a hierarchy is shown in Figure IV.7.

```
File   Alternatives   Attributes   Effects scores   Evaluate

                     Attribute tree

grain bans
 ├────────health
 │          ├────individual dose
 │          └────collective dose
 │
 └────────non-health
            ├────────costs
            │          ├────disposal
            │          └────other costs
            └────────social-political
                       ├───────public response
                       └───────international relations
```

Figure IV.7: RADE-AID - example hierarchy of attributes.

For a detailed description of the options, except the definition of weight factors, refer to Annex G.

A number of ways of defining weight factors are foreseen:

- direct definition;
- definition by pairwise comparison;
- definition by the distribution of 100 points;
- definition by the rank exponent procedure;
- definition by cross-attribute indifference.

Currently only the first one (direct definition) is fully integrated in RADE-AID. The second one, pairwise comparison, is implemented, but can only be used outside the system.

Direct definition forces the user to define two (or more) weight factors whenever an attribute in the hierarchy is subdivided into other attributes. The weight factors should sum up to 1. RADE-AID normalises them if they do not sum up to 1. This option is direct, but the user should decide carefully how to choose the weight factors.

Definition of weight factors by pairwise comparison is an indirect way of definition. This option also considers attributes with a common parent in the hierarchy. Instead of directly asking for weight factors, this option asks the user to compare each pair of attributes. The user has to indicate how he values one attribute relative to another. For example, the speed of a car is twice as important as its colour. The implication of this example would be to assign speed a factor 2/3 and colour 1/3 (assuming no other attributes exist). The method is redundant; it checks the internal consistency of the valuations used. This consistency is displayed together with the weight factors thus allowing the user an indication of the validity of his valuation. The result of this process is shown in Figure IV.8 (note: direct definition could lead to a similar result).

```
File    Alternatives    Attributes    Effects scores    Evaluate

                          Attribute tree

grain bans   (1.00)
  ├─────────health   (0.70)
  │          ├────individual dose    (0.99)
  │          └────collective dose    (0.01)
  └─────────non-health   (0.30)
             ├────────costs   (0.50)
             │         ├───disposal   (0.90)
             │         └───other costs   (0.10)
             └────────social-political   (0.50)
                       ├───────public response   (0.20)
                       └───────international relations   (0.80)
```

Figure IV.8: RADE-AID - example definition of weight factors.

IV.2.4 Effect Scores

The effect scores may be:

- displayed;
- created;
- modified;
- deleted;
- interpreted by the use of value functions.

The options are self-explanatory, except for the last one. The theoretical background of value functions was described in section III.4.1. The option to use value functions is subdivided. They may be:

- displayed;
- created;
- modified.

The display of value functions was illustrated in Chapter III (refer to Figures III.4 and III.5).

To create a value function several items need to be defined. First the range of effect scores needs to be defined. The user is asked for this definition; default values are the minimum and maximum value of the effect scores considered for one attribute. Next the user has to define whether the minimum value is liked most or least. An example: suppose the costs range from 0 ECU (minimum) to 5 million ECU (maximum) and the social acceptability of countermeasures from 0 (minimum; serious repercussions) to 4 (maximum; no effects). It is obvious that for costs the minimum value will be preferred and for social effects the maximum. Last the shape of the value function has to be defined. The default value is a linear one, that is, a straight line between minimum and maximum. This process is shown in Figure IV.9.

Effect scores: value functions				
Leaf nodes	minimum	maximum	relation	trend
Individual dose	2	200000	linear	-
Collective dose	0	124000	linear	-
Disposal costs	0	1060	linear	-
Other costs	0	1.65 E +08	linear	-
Public response	0	100	linear	-
International relations	0	100	linear	-

Figure IV.9: RADE-AID - example of defining constraints for value functions.

The user has options to change the default linear shape of the value function. A value function is then represented by segmented linear functions. It consists of several line segments, thus simulating any curved line. Line segments are defined by definition of their first and last point (refer also to Section III.4.1).

The modification of value functions is more or less equal to the creation of them; the concepts and actions are the same.

IV.2.5 Results

The results from the decision analysis are not only presented, they may also be analysed. The presentation offers several ways to view the results; for instance an overall ranking, effect scores per attribute, effects scores per countermeasure, etc. Currently only the overall ranking is implemented in RADE-AID; an example is shown in Figure IV.10.

Ranking	
countermeasure	overall score
i1dilnad	0.99
i1dilrot	0.98
i1nadnad	0.96
i1nadrot	0.95
i2dilnad	0.95
i2dilrot	0.94
i2nadnad	0.93
i2nadrot	0.92
i3dilnad	0.91
i3dilrot	0.89
i3nadnad	0.87
↓ i1disrot	0.86

Figure IV.10: RADE-AID - presentation of overall ranking of countermeasures.

The facilities for sensitivity analysis in RADE-AID enable the user to vary some factors in the decision analysis (for instance, weight factors) to look for corresponding (important) changes in the results. Two ways for performing sensitivity analysis on the results are currently available; both concern the changing of weight factors. An example was already shown in Chapter III (refer to Figure III.9).

IV.3 Technical Implementation

RADE-AID can be used on personal computers (PCs). The requirements for the PC include:

- compatibility with an IBM PC;
- graphical presentation (EGA-card and EGA-screen);
- an internal memory of 640 kB.

The RADE-AID software system is written in conventional software languages, i.e. FORTRAN (for the presentation, see Section IV.1) and C (for the decision logic, see Section IV.2). Both parts make extensive use of a graphical library, i.e. the HALO software package. The menus are also developed with a special purpose software package[19].

The decision logic thus addresses one objective of RADE-AID as a DSS: the provision of assistance to a decision-maker in determining the optimum course of action and in evaluating the relative merits of several different courses of action. The other objective (displaying both the current radiological situation and its likely consequences) is achieved by graphical presentation of (key values from) the accident scenario and by several presentation techniques (menus, graphics) in the decision logic part of the program.

V ILLUSTRATIVE APPLICATIONS

In order to explore the appropriateness of the decision logic for the management of radiological emergencies, two illustrative applications were considered. These explored the use of the decision logic for decisions on countermeasures against external exposure and on food interdiction. The applications were deliberately stylised both for simplicity and to indicate the possibilities of the system. The purpose of these illustrative applications was solely to demonstrate whether the initial version of the system forms the basis of an appropriate and flexible decision-aiding tool. However, the structures developed for the problems and the associated data are considered to be appropriate for providing assistance with planning.

The two applications were chosen to explore the introduction of very different types of countermeasure, the first involving the potential relocation of people and the potentially resource-intensive operation of decontamination, and the second involving the combinations of actions which could be taken to reduce the exposure of the population from contaminated foods. In addition, different procedures were used for valuing the consequences of countermeasure options in terms of the decision criteria, and for eliciting the relative weights assigned to these criteria. In this way, the use of the system was explored as fully as possible. For the purposes of these illustrations it was assumed that the countermeasures for external exposure and food interdiction are completely independent.

The illustrative applications consider several assumed accident situations and a range of countermeasures options for each. Some of the relevant consequences of taking these countermeasure options have been predicted using radiological and economic models developed under the CEC MARIA programme[20]. Other consequences are intended to be directly assessed by the user, based on supporting information provided by the system.

In order for efficient use to be made of available resources, the investigation of the usefulness of the decision logic was carried out largely in parallel with its development. This enabled the development of the decision logic to take account of insights gained by application of decision analysis techniques to decisions on countermeasures. In order to do this, it was necessary to make use of a commercially available decision analysis software package. One that provided a number of the features which were intended for incorporation in RADE-AID, was HIVIEW[19]; this package was used extensively in exploring and developing the illustrative applications discussed in this section.

The two types of problem (control of external exposure and control of foods) have been structured using the same fundamental criteria. In principle, as discussed in Section II, no countermeasure should be introduced unless it achieves more good than harm (ie it is justified) and it should be introduced in
such as way as to maximise the net benefits (ie its introduction should be optimised). The objective for introducing any countermeasure is therefore that it should be both justified and optimised.

In order to evaluate different courses of action against this objective, a number of attributes were defined, in terms of beneficial and harmful consequences. Three basic types of consequences have been identified as relevant to both types of countermeasure: those concerning health, those concerning monetary costs and those which are of a socio-political nature. For the purposes of these illustrative applications, four high level attributes have been defined as 'health risk avoided', 'monetary costs', 'the public reaction' and 'international reaction'. They are illustrated in Figure V.0.1. In order to explore different valuation procedures, these high level (intermediate) attributes were defined further in different ways for the two applications. These are discussed under the relevant sections.

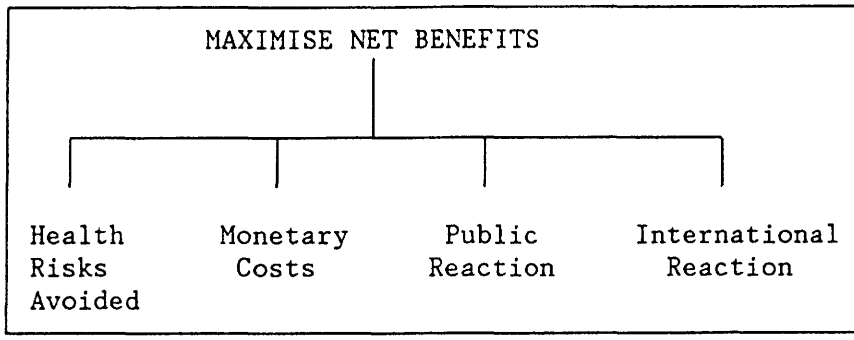


Figure V.0.1: Basic criteria hierarchy used for the illustrative applications.

V.1 Control of External Exposure

One possible long term exposure pathway, following an accidental release of radioactive material, is external exposure from radionuclides deposited on the ground. If this occurs, there are two types of countermeasure which can provide protection for individuals in the contaminated area. The first is removal of the contamination (decontamination). The second is removal of the individuals from the contaminated area (relocation) until the levels of radioactivity have reduced by a combination of natural weathering and radioactive decay. Clearly, these two countermeasures may also be used together, to reduce the time for which the area must be interdicted.

The criterion for introducing relocation is generally specified in terms of a dose rate; for decontamination, a target level of decontamination is commonly defined. The problem for the decision-maker is therefore to determine what countermeasures, if any, should be carried out, and to specify the appropriate criteria for them. (In practice, the problem is more complex, because other aspects of the decision, such as how quickly people from different areas should be moved out, the appropriate dose rate to allow return from relocation and whether some areas should be preferentially decontaminated, also need to be addressed. However these aspects were omitted from the illustrative applications.)

V.1.1 Accident Scenarios

For the purposes of exploring the use of the RADE-AID decision logic, two highly stylised accident situations have been postulated. They are each identical in magnitude and release characteristics, but one is assumed to occur in an area of relatively low population density (site A), whilst the other is assumed to occur in a more densely populated area (site B). The assumed releases are large, representing the rapid release of about 1% of the volatile core inventory of a large (gigawatt) reactor. The characteristics of this release are defined in Table V.1.1, whilst the population distributions used for the two sites (which were taken from real population statistics) are listed in Tables V.1.2 and V.1.3.

Table V.1.1

Characteristics of Release Assumed for Control of External Exposure

Effective Release Height 10 m
Release Duration 0.5 h
Time Before Release 0 h
Warning Time 0 h
Energy of Release 0 Btu/h

Radionuclides Released:

Radionuclides	Amount (Bq)
^{131}I	$3.39\ 10^{16}$
^{132}I	$4.96\ 10^{16}$
^{133}I	$6.81\ 10^{16}$
^{134}I	$7.84\ 10^{16}$
^{135}I	$6.40\ 10^{16}$
^{88}Kr	$2.34\ 10^{16}$
^{134}Cs	$3.85\ 10^{15}$
^{137}Cs	$2.29\ 10^{15}$

V.1.2 Decision Attributes

As stated earlier, for the purposes of these illustrative applications of RADE-AID, four high level decision attributes were identified as being relevant to decisions on countermeasures, namely, the health risk avoided, the monetary cost and the public and international reaction. It is recognised that there may be additional important attributes for decisions on countermeasures, if so, it is intended that these will be determined in the next phase of the project, through collaboration with decision-makers. However, these four are sufficient for the purposes of demonstrating the usefulness of the RADE-AID system.

For the control of external exposure applications, it was decided, wherever possible, to enable all the valuations of consequences to be carried out indirectly, (ie using value functions) using a number of precisely defined attributes to characterise the high level ones. The

Table V.1.2

Population Distribution Assumed for Site A

Lower Distance (km)	Sector Population (Degrees Clockwise from North)											
	0.0-30.0	30.0-60.0	60.0-90.0	90.0-120.0	120.0-150.0	150.0-180.0	180.0-210.0	210.0-240.0	240.0-270.0	270.0-300.0	300.0-330.0	330.0-0.0
0.0	2	4	3	7	6	4	7	6	4	6	4	4
1.0	8	7	6	16	20	18	16	2	13	15	21	13
2.0	37	30	6	30	52	32	17	0	14	28	61	52
3.0	230	146	40	99	161	131	39	0	27	108	216	169
5.0	3275	249	2	37	130	112	18	17	952	1507	241	950
10.0	284	250	74	170	44	110	159	1142	1432	3104	277	68
15.0	468	462	100	411	148	540	383	1401	860	1340	158	34
20.0	1011	784	247	2309	146	2578	2534	184	466	1097	1639	1314
25.0	70811	28103	13890	4260	2989	4903	7660	0	10623	6202	36536	45657
50.0	0	166375	231640	52812	25468	7106	19610	0	579	0	26521	8287
75.0	0	1335082	330906	135564	23631	15133	24292	0	0	0	0	0
100.0	83158	2411023	2622562	2457445	360500	623970	386384	36950	0	0	0	45985
150.0	3386728	4461817	4725291	11112938	12324397	2880165	873362	16904	0	0	1401616	2246508
TOTALS	3546012.0	8404332.0	7924767.0	13766098.0	12737692.0	3534802.0	1314481.0	56606.0	14970.0	13407.0	1467290.0	2349041.0

Table V.1.3

Population Distribution Assumed for Site B

Lower Distance (km)	Sector Population (Degrees Clockwise from North)											
	0.0-30.0	30.0-60.0	60.0-90.0	90.0-120.0	120.0-150.0	150.0-180.0	180.0-210.0	210.0-240.0	240.0-270.0	270.0-300.0	300.0-330.0	330.0-0.0
0.0	44	3	0	0	0	0	0	2	5	5	32	58
1.0	160	0	0	0	0	0	1	20	22	94	264	346
2.0	224	0	0	0	0	0	0	7	84	324	693	773
3.0	241	0	0	144	33	0	30	76	342	6630	16226	5997
5.0	1152	0	0	29885	6792	43722	71940	20076	32267	1764	20656	35905
10.0	0	0	0	16149	18688	14469	61231	87878	21544	159	4681	3847
15.0	0	0	0	10738	8711	6500	4319	17903	2069	13021	48452	4320
20.0	0	0	0	5973	1207	1187	3659	4087	16660	22717	20536	12472
25.0	0	0	0	20072	7974	8267	32739	54880	118474	135595	684918	437582
50.0	0	0	0	0	80958	92440	102418	12895	5987	12868	224319	174662
75.0	0	0	0	0	62605	153390	874822	52974	17065	16830	10324	27688
100.0	0	0	0	0	365014	787608	3385774	1679749	217673	195246	63401	33151
150.0	1176	0	0	0	928395	18438590	14366120	3900862	614983	1574184	3529446	895164
TOTALS	2997.0	3.0	0	82961.0	1480377.0	19546173.0	18903053.0	5831409.0	1047175.0	1979437.0	4623948.0	1631965.0

derivation of these will be discussed in turn, under the general headings of the four high level attributes.

Health Risks

For the purposes of these applications, three aspects of this attribute were considered: the individual and collective doses avoided by the public, and the collective doses received by workers implementing any countermeasures. These attributes could equally well have been expressed in terms of health risks rather than doses. However there are a large number of health risks which could result from exposure to ionising radiation, and the predicted magnitude of each of these would be required in order to appropriately assess the consequences of each countermeasure option. This would require a large number of attributes to be specified, which would make the hierarchy somewhat cumbersome to use, and the results more difficult to interpret. By specifying the attributes in terms of dose, only one attribute is required to define each. It is judged that the benefit obtained by keeping the number of attributes small, in terms of ease and clarity of presentation of the results, far outweighs the advantage of presenting the reduced health risks in terms of the risks of specific injuries, rather than dose.

Since the only exposure pathway considered for these illustrative applications is long term external exposure, the appropriate dose quantity is effective dose equivalent. Therefore, the attributes used to define the objectives are collective effective dose avoided by the public, collective effective dose received by workers and individual effective dose avoided by the public.

The attribute of individual dose avoided requires more discussion. There will be a range of individual doses received, following implementation (or otherwise) of countermeasures, from zero to the difference between the intervention dose criterion and the highest dose potentially received. It is therefore not straightforward to define a single attribute which characterises all the individual doses avoided. However, a decision on the optimum intervention level is, in fact, the identification of the best intervention level out of a set of possible intervention levels. In other words, it is the marginal change in individual dose avoided, as the postulated intervention level is changed, that is of major importance for the decision. An attribute defined in terms of the intervention level itself is therefore the appropriate indicator for individual dose avoided.

The individual dose attribute chosen for the illustrative applications was the perceived acceptability of the health risk posed by the intervention level. It was recognised that the value assigned to this attribute might well be influenced by factors other than health considerations (eg socio-political factors, such as intervention levels set or planned in other countries). However, provided such factors were not accounted for a second time as socio-political attributes (ie double-counting is avoided), this should not be a cause for concern.

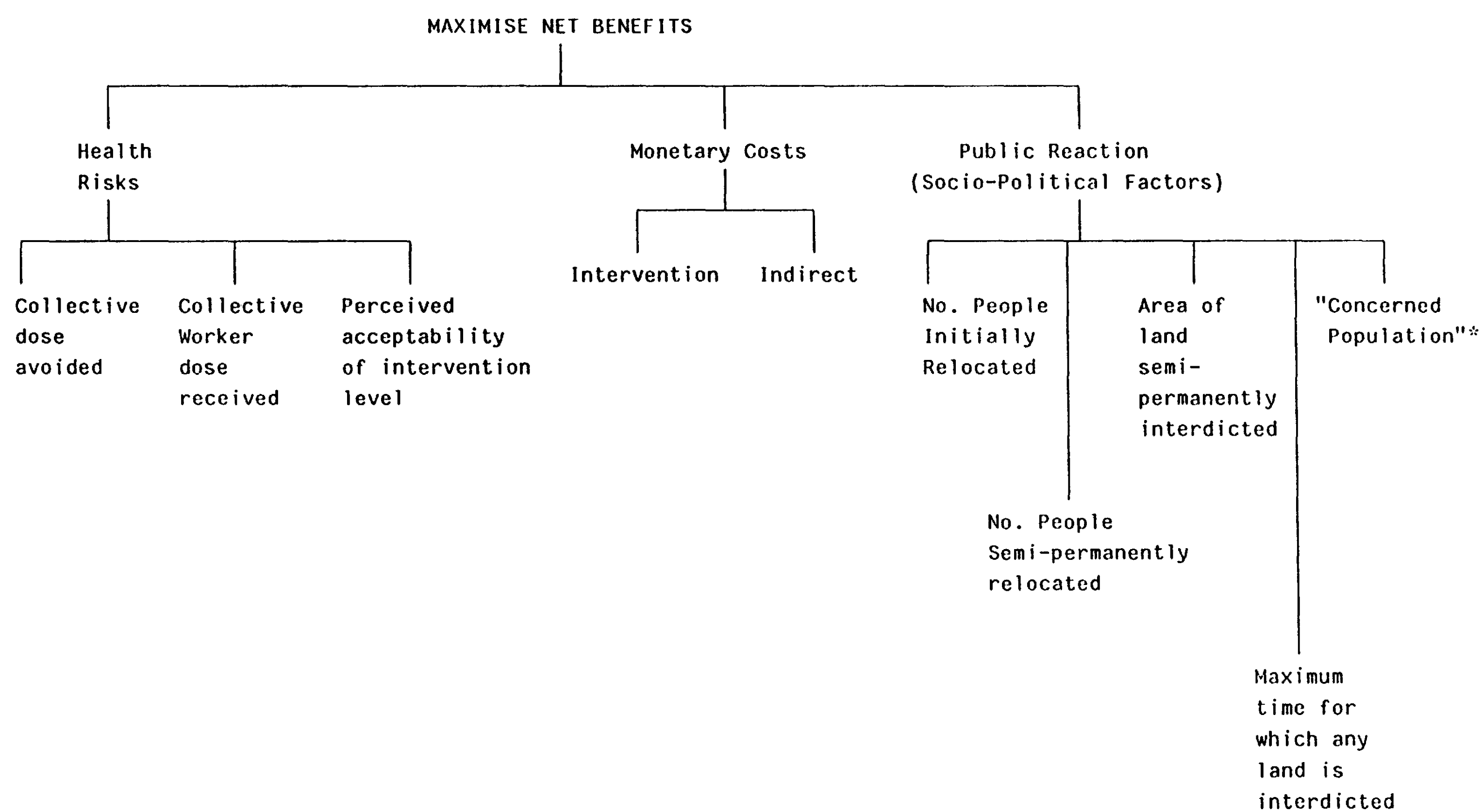
Therefore for the purposes of the illustrative applications, three attributes were defined as criteria for health concerns, 'collective effective dose avoided', 'worker collective effective dose received' and 'the perceived acceptability of the intervention level'. These are shown in Figure V.1.1.

Monetary Costs

Decisions on countermeasures may have significant implications in terms of monetary costs. Clearly, a decision to introduce a countermeasure will require the direct expenditure of resources. In addition, there may be indirect monetary costs, for example, lost economic activity resulting from the relocation of individuals or interdiction of property. Even if countermeasures are not taken, there may be economic penalties resulting from the adverse response of individuals and governments.

The different monetary costs resulting from decisions on countermeasures may be superficially similar (they can all be expressed in the same units), but they may be viewed as of differing significance in influencing the decision. Some costs are direct costs, in that resources need to be found to pay for them, whilst others are indirect costs, that is, money which is not earned, rather than money which must be spent. Some of the costs may also be incurred many years in the future, in which case the decision-maker may wish to reduce their value, using a discount rate.

It was therefore considered useful to characterise the high level attribute of monetary costs in terms of three low level attributes: direct ('intervention') costs, indirect costs and 'lost overseas trade and



*No. people close to area of interdiction, but not, themselves, relocated.

Figure V.1.1: Criteria Hierarchy used for Control of External Exposure Illustrative Applications investment'. In this way different weights and valuation scales could be applied to each. For the illustrative applications, however, the third attribute was not considered further, since no simple model has been developed to predict lost overseas trade and investment following decisions on countermeasures. (In the event of a real accident, it is likely that the decision-maker would seek access to expert judgement on the likely consequences of his decision.) Therefore for the purposes of the illustrative applications the monetary costs arm of the decision hierarchy was characterised by two attributes, intervention costs and indirect costs, as shown in Figure V.1.1.

Public and International Reaction

Of the high level attributes, these are the most difficult for which to assign quantifiable low level attributes. Various factors which contribute to the public and international response can be identified, for example, verbal and written criticism by pressure groups, population movements away from the affected area, changes in voting trends, political pressure from other countries. However, it is not easy to be sure that all relevant factors have been identified, and some of these factors are very difficult to quantify in terms of the consequences of various countermeasures decisions.

Recognising this difficulty, the use of direct valuation for scoring the consequences of countermeasures against the socio-political objectives was explored for the control of foods applications (Section V.2). However, in order to test the RADE-AID system as fully as possible, it was decided to use indirect scoring for the control of external exposure applications. Therefore a subset of attributes was identified, each of which could be fully quantified. Five attributes were defined, and these are discussed below. In defining these attributes, it was recognised that they were merely pointers to the socio-political problems, and, indeed, did not encompass all the factors relevant to the definition of these problems. However, it was judged that by employing these, the usefulness of the system for indirect vaulation of socio-political factors could be explored.

The five attributes are all concerned with the reaction of the public to the actions taken, since it was felt that little extra would be gained by investigating the international response objective in more depth. In fact, apart from economic international reaction, which really belongs under the monetary costs arm of the decision hierarchy (and was mentioned in the preceeding section), it was felt that international pressure was likely to be of relatively low importance in influencing decisions on relocation and decontamination. In addition, it was decided not to choose an attribute to represent the influence of intervention levels set in other countries or recommended internationally on the public's reaction. This was because it was not clear how much such an attribute would overlap with the attribute 'perceived acceptability of intervention level' defined for the health arm, and it is important to avoid double-counting of factors. Moreover, for the purposes of illustrating the application of the system, the possible omission of such an attribute was not considered important, (although it was recognised that for emergency planning and response purposes it would be important to take account of international standards and guidance).

The five attributes chosen were: the number of people initially relocated, the number of people semi-permanently relocated, the area interdicted semi-permanently, the maximum time for which any land would be interdicted and the number of people within a given distance of the restricted area (ie those who are most likely to consider themselves at risk because they have been excluded from the countermeasures taken). These are discussed in turn.

The number of people initially relocated from an area is likely to have a major influence on the perceived severity of the accident and its consequences. It may also influence the public perception of how caring the authorities are, in their response to the accident (eg whether they are putting people or money first), although this link is probably more complex, (for example, it may be thought necessary to remove people from their homes who do not want to leave). There are also considerations of individual and social disruption which play a part here, and the need to overcome practical difficulties such as transportation and re-housing. In terms of the perceived severity of the accident and the practical difficulties, it is clearly undesirable to relocate large numbers of people. However, in terms of satisfying the demand for protective action to be taken, the relationship between numbers of people relocated and public response is not so clear; at the very least, it may tend to off-set the strong preference for keeping numbers of people relocated to a minimum, which is indicated by the other factors.

The number of people relocated semi-permanently is another indicator of the level of individual and social disruption created by the countermeasure. If people are relocated only for short periods of time (ie months) then they may tolerate temporary housing and a less well-planned supporting infrastructure, because the relocation will be clearly temporary. For longer term relocation, people will have to start making new lives in new communities, finding alternative employment and seeking adequate education facilities for their children. In such circumstances, it is likely that those individuals would be unwilling to return to their original homes, when the interdiction had been removed. The divide between temporary and semi-permanent relocation is clearly not a fixed quantity; it will strongly depend on national and individual circumstances. However, it is likely that people will start settling into new communities fairly quickly, once it is clear that the relocation is likely to last longer than a number of months. Therefore, for the illustrative application, a time period of two years was judged appropriate for defining semi-permanent relocation. The number of people still relocated after two years is therefore assumed to be an indicator of the potential number of people who will suffer severe disruption to their lives, and who will require significant investment in terms of housing and the development of facilities if this disruption is to be mitigated.

The interdiction of land and property may affect people from outside the area, as well as those who are relocated from it. For example, the land may be a tourist area, or considered to be of special scientific or scenic interest. As a result, there may be pressure on the authorities to restore the land, from individuals not directly involved in the countermeasures. Initially the public may accept the need for interdiction, as an emergency measure. However, in time, increasing pressure to release the land will be exerted, as individuals expect to be able to resume their former lifestyles and activities. Therefore the attribute 'area of land interdicted semi-permanently' was defined. This provides a measure of the unpopularity of interdicting land for significant periods of time. As with the attribute 'number of people relocated semi-permanently', there is no general time period which can be defined as semi-permanent for all post accident situations. However, for the purposes of the applications described here, a time period of two years was chosen.

The area of land interdicted will also contribute to the public's perception of the scale of the accident. When relocation is initially carried out, this perception is already taken into account by the attribute 'number of people relocated'; the definition of an attribute 'area interdicted initially' would therefore result in double-counting. However, the effect on people's perception of the accident created by the total duration of the interdiction, is not otherwise taken into account. Whilst some area of land is still interdicted, the consequences of the release will be perceived as a continuing problem. Therefore a fourth attribute was defined, 'the maximum time for which any land is interdicted'.

Finally, the reaction of the public will also include the reaction of those who are not directly involved in the countermeasures, but who think they may be at risk. Those living in close proximity to the interdicted area may be concerned that they, too, should have been relocated. They may also face practical problems, such as restrictions on their normal movements, or they may be unable to work because their employment is based within the interdicted area. The social scale of this problem is likely to be related to the number of people who are living relatively close to the interdicted area. It is recognised that the individual disruption caused will not be linked to the total number of people involved, but for the purposes of the illustrative applications, this was considered to be of lesser importance than the collective concern. Therefore, the fifth attribute was defined as 'number of potentially concerned people' and these were taken to be all those living within 5 km of the interdicted area.

These five low level attributes are shown in Figure V.1.1.

V.1.3 Countermeasures Options

The possible countermeasures options at each site were defined to be a set of five different intervention levels for relocation, ranging from 5 mSv y^{-1} to 100 mSv y^{-1} (ie 5, 10, 30, 50 and 100 mSv y^{-1}). Since much of the land around site A was assumed to be agricultural or park land, it was assumed that decontamination of the land would not be carried out (or at least, only in relatively small areas). However, for site B, which was assumed to be mainly urban or industrial, the option of decontamination was also considered. For the purposes of the illustrative applications, only a single level of decontamination was considered, namely reduction in the external dose rate by a factor of three throughout the whole area. This is clearly a highly stylised assumption, but is adequate to illustrate the use of RADE-AID.

Given the above assumptions, a total of 10 countermeasures options were identified for site B and 5 for site A, as listed in Table V.1.4.

Table V.1.4

Countermeasures Opions Assumed for Control of External Exposure Applications

Reference		Relocation Intervention Level of Dose (mSv y^{-1})	Whether decontamination by a factor of 3 assumed
Site A:	NODEC5	5	No
	NODEC10	10	No
	NODEC30	30	No
	NODEC50	50	No
	NODEC100	100	No
Site B:	NODEC5	5	No
	DEC5	5	Yes
	NODEC10	10	No
	DEC10	10	Yes
	NODEC30	30	No
	DEC30	30	Yes
	NODEC50	50	No
	DEC50	50	Yes
	NODEC100	100	No
	DEC100	100	Yes

V.1.4 Prediction of Effect scores

The attribute effect scores resulting from adoption of each of the identified countermeasures options were calculated, using the models and assumptions described in Annex H. These consequences are listed in Table V.1.5. There are marked differences between the consequences predicted for site A and site B, and between the countermeasures involving decontamination and those not involving decontamination for site B.

It is useful to examine the effect scores and the differences between them in more detail. Such examination provides deeper insight into the decision problem, and enabling the decision-maker to do this easily is one of the primary aims of RADE-AID.

For site A, the public collective doses avoided vary by about a factor of three, from 300 to 900 man Sv, whilst in the absence of

Table V.1.5: Effectscores for Control of External Exposure Illustrative Applications

Attribute	SITE A COUNTERMEASURES OPTIONS(1)					SITE B COUNTERMEASURES OPTIONS(1)									
	NODEC5	NODEC10	NODEC30	NODEC50	NODEC100	NODEC5	DEC5	NODEC10	DEC10	NODEC30	DEC30	NODEC50	DEC50	NODEC100	DEC100
Collective Dose Avoided (man Sv)	$8.7\ 10^{2}$	$5.5\ 10^{2}$	$4.3\ 10^{2}$	$3.8\ 10^{2}$	$3.2\ 10^{2}$	$3.3\ 10^{4}$	$3.3\ 10^{4}$	$3.0\ 10^{4}$	$3.0\ 10^{4}$	$2.3\ 10^{4}$	$2.3\ 10^{4}$	$2.0\ 10^{4}$	$2.0\ 10^{4}$	$1.2\ 10^{4}$	$1.2\ 10^{4}$
Collective Worker Dose (man Sv)	0	0	0	0	0	0	90	0	72	0	55	0	49	0	39
Perceived(2) Acceptability of Intervention Level	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Intervention costs (£)	$2.1\ 10^{5}$	$2.9\ 10^{4}$	$3.2\ 10^{3}$	$1.5\ 10^{3}$	$4.8\ 10^{2}$	$8.8\ 10^{5}$	$1.5\ 10^{9}$	$6.3\ 10^{5}$	$5.6\ 10^{8}$	$4.2\ 10^{5}$	$1.2\ 10^{8}$	$3.9\ 10^{5}$	$6.6\ 10^{7}$	$2.3\ 10^{5}$	$2.3\ 10^{7}$
Indirect costs (£)	$2.0\ 10^{8}$	$2.9\ 10^{7}$	$3.3\ 10^{6}$	$1.5\ 10^{6}$	$3.4\ 10^{5}$	$1.9\ 10^{9}$	$1.4\ 10^{9}$	$1.3\ 10^{9}$	$8.8\ 10^{8}$	$6.8\ 10^{8}$	$4.0\ 10^{8}$	$5.4\ 10^{8}$	$3.5\ 10^{8}$	$2.2\ 10^{8}$	$2.0\ 10^{8}$
No. People Initially Relocated	$3.5\ 10^{4}$	$4.8\ 10^{3}$	$5.4\ 10^{2}$	$2.5\ 10^{2}$	$8.1\ 10^{1}$	$1.5\ 10^{5}$	$1.5\ 10^{5}$	$1.1\ 10^{5}$	$1.1\ 10^{5}$	$7.0\ 10^{4}$	$7.0\ 10^{4}$	$6.5\ 10^{4}$	$6.5\ 10^{4}$	$3.8\ 10^{4}$	$3.8\ 10^{4}$
No. People Semi-permanently Relocated	$7.9\ 10^{2}$	$3.2\ 10^{2}$	$6.8\ 10^{1}$	$5.0\ 10^{1}$	$2.0\ 10^{1}$	$7.4\ 10^{4}$	$4.4\ 10^{4}$	$6.6\ 10^{4}$	$3.4\ 10^{4}$	$3.4\ 10^{4}$	0	$1.7\ 10^{4}$	0	0	0
Area of Land Semi-permanently interdicted (km^2)	70	29	6.6	3.2	0.75	70	16	29	6.6	6.6	0.75	3.2	0.56	0.75	0.3
Maximum time for which any land interdicted (y)	50	32	20	10	6	50	30	32	20	20	7	10	5	6	3
"Concerned" Population	$2.1\ 10^{4}$	$1.1\ 10^{4}$	$8.5\ 10^{3}$	$6.5\ 10^{3}$	$2.3\ 10^{3}$	$2.2\ 10^{5}$	$2.2\ 10^{5}$	$1.4\ 10^{5}$	$1.4\ 10^{5}$	$1.4\ 10^{5}$	$1.4\ 10^{5}$	$1.5\ 10^{5}$	$1.5\ 10^{5}$	$1.4\ 10^{5}$	$1.4\ 10^{5}$

Notes:

1) For definition of countermeasures options, see Table V.1.4.

2) Attribute, "perceived acceptability of intervention level" valued by direct valuation, therefore no effect score calculation for this attribute.

decontamination the assumed worker doses are zero. For the monetary attributes, it is the indirect costs which are dominant for all assumed intervention levels, again because no decontamination of the area is considered and so the only intervention costs are assumed to be those associated with transporting people from the area. Both the intervention and indirect costs span three orders of magnitude, the indirect costs ranging from about £3 10^5 to £2 10^8 and the intervention costs ranging from about £500 to £200,000. Some of the effect scores for the socio-political attributes also show a wide variation. For example the number of people initially relocated varies between about 80 and 40,000 and the maximum time for which any land is interdicted ranges from 6 years to 50 years. Other attributes show less significant variations; the effect scores for the number of people relocated semi-permanently and the area of land interdicted semi-permanently are much more similar (20-1000 and about 1- 70 km^2, respectively). The effect scores for the attribute 'concerned population', are perhaps a little surprising. Given that the population distribution used is based on a real location (ie it is not uniform), it might be expected that the number of people living close to the boundary of an interdicted area would only partially reflect the magnitude of the intervention level. However, for site A, the numbers of these people consistently reduce with increasing intervention level; an indication that any localised variations in the population distribution around site A are relatively small.

For site B, it is helpful to consider the predicted effect scores in terms of the two groups of countermeasures options, those with decontamination and those for which it was assumed no decontamination would be carried out. In the 'no decontamination cases', the collective doses avoided are much larger than for site A, although, again, they vary by about a factor of three. The monetary costs are again dominated by the indirect costs, these being considerably higher than for site A, but having a smaller range (ie £10^8 to £10^9). The socio-political consequences indicate that although the area affected is the same as that predicted for site A (due to the assumption that the dispersion and deposition of radionuclides is very similar for the two sites, see Annex H), the dense population distribution means that large numbers of people are directly affected for all intervention levels, unlike the situation for site A. The number of people indirectly affected (ie the 'concerned population') is also very large and varies very little between intervention levels. Due to the dispersion and deposition assumptions, the maximum time for which any land is interdicted is the same as for site A, varying from 6 years to 50 years.

The main differences in consequences for the 'decontamination' options for site B are that the maximum interdiction times are reduced, as are the areas of land semi-permanently interdicted and the numbers of people relocated semi-permanently, while the direct monetary costs and worker doses are increased. However, the total monetary costs are less than a factor of two higher than for the corresponding 'no decontamination' options. Therefore, unless significantly different weight is attached to direct costs compared with indirect costs, it is unlikely that the costs of decontamination will strongly influence a decision on the best countermeasures option for the situation.

V.1.5 Valuation of Consequences

Having studied the effect scores, RADE-AID was then used to assign values to them. As a first approximation, linear value scales were assumed, with the least favourable outcome assigned a value of 0 and the most favourable, a value of 1. These values are shown in Table V.1.6.

The assignment of weights was carried out using the cross-attribute indifference method provided by RADE-AID. In this way, the lengths of each value scale were taken into account, as well as the intrinsic importance of each attribute. The weights assigned are listed in Table V.1.7; weights sum to unity for each of the health, monetary costs and socio-political arms.

Table V.1.7

Attribute Weights Assigned for the Control of External Exposure Illustrative Applications

Attribute	Relative Weight within Hierarchy Arm (%)
Collective dose avoided	30
Collective worker dose	5
Received acceptability of intervention level	65
Intervention costs	90
Indirect costs	10
No. people initially relocated	60
No. people semi-permanently relocated	10
Area of land semi-permanently interdicted	10
Maximum time for which any land interdicted	10
"Concerned" population	10

Some discussion of the weights is useful. Clearly, since the weights indicate levels of preference, they are in no sense 'absolute'; the weights assigned in these illustrative applications are not intended to represent the weights which decision makers would assign, but solely reflect the judgement of the authors. However, by exploring the sensitivity of the resulting ranking of options to the assigned weights, useful information can be obtained concerning the likely outcome of decisions. In these applications, relatively little weight was attached to the monetary atributes, because it was considered that although these had some influence on the decision, they should not be the dominant considerations. Moreover, it was judged that, for monetary costs of a similar magnitude, direct costs should be assigned higher weight than indirect costs, since these would actually have to be paid.

With regard to the health attributes, the change in preference for the lowest to the highest collective doses avoided was judged to be about a factor of 2-3 smaller than the range in preference for adopting the different intervention levels of dose. The corresponding preference range for worker collective doses received was judged to be very small. However, it was assumed that each worker's dose would be kept within established dose limits, and so the increase in individual risks would be controlled. Therefore, the acceptability and collective dose avoided

Table V.1.6: Valuation of Attributes for Control of External Exposure Illustrative Applications

Attribute	SITE A					SITE B									
	COUNTERMEASURES OPTIONS (1)					COUNTERMEASURES OPTIONS (1)									
	NODEC5	NODEC10	NODEC30	DODEC50	DODEC100	NODEC5	DEC5	NODEC10	DEC10	DODEC30	DODEC30	NODEC50	DEC50	NODEC100	DEC100
Collective Dose Avoided (man Sv)	.02	.01	.004	.002	0	1	1	.89	.89	.68	.68	.59	.59	.37	.37
Collective Worker Dose (man Sv)	1	1	1	1	1	1	0	1	.20	1	.39	1	.46	1	.57
Perceived (2) Acceptability of Intervention Level	1	.95	.74	.53	0	1	1	.95	.95	.74	.74	.53	.53	0	0
Intervention costs (Z)	1	1	1	1	1	1	0	1	.63	1	.92	1	.96	1	.98
Indirect costs (Z)	.89	.98	1	1	1	0	.24	.29	.53	.64	.78	.71	.81	.88	.89
No. People Initially Relocated	.76	.97	1	1	1	0	0	.29	.29	.52	.52	.56	.56	.74	.74
No. People Semi-permanently Relocated	.99	1	1	1	1	0	.40	.11	.55	.55	1	.78	1	1	1
Area of Land Semi-permanently interdicted (km^2)	0	.59	.91	.96	.99	0	.77	.59	.91	.91	.99	.96	.99	.99	1
Maximum time for which any land interdicted (y)	0	.38	.64	.85	.94	0	.43	.38	.64	.64	.91	.85	.96	.94	1
"Concerned" Population	.91	.96	.97	.98	1	0	0	.38	.38	.37	.37	.34	.34	.38	.38

Notes:

1) See table V.1.4 for option definitions.

attributes were assigned weights in the ratio of about 2:1, and the worker dose received attribute was assigned a fairly small weight.

For the socio-political attributes, two approaches were considered: an emphasis on the minimisation of short-term disruption, and, secondly, an emphasis on the longer term consequences. The first approach resulted in the assignment of the weights listed in Table V.1.7, ie most weight being assigned to the attribute of initial population moved. The second approach would have resulted in significantly more weight being attached to the attributes number of people semi-permanently relocated and maximum interdiction time. The effect of this approach is discussed later. It was judged that the attributes of area of land interdicted semi-permanently and the concerned population should not be assigned high weight, using either approach, since the ranges of consequences predicted for these were small compared with those for the other attributes.

V.1.6 Ranking

Using these relative weights within each 'arm' of the hierarchy yields the three sets of intermediate rankings shown in Table V.1.8. For both sites, the ranking for the health attributes corresponds to increasing dose intervention levels, even when the countermeasures involving decontamination are considered. This is because the predicted worker doses are relatively low and so their impact on the overall weighted health score is low.

The ranking for monetary costs reflects whether the assumed countermeasures include decontamination; all those including decontamination being ranked very low, whilst those which do not include decontamination are ranked much more highly. This means that for site A there is very little difference in preference revealed between the five countermeasures options, on monetary grounds. For site B, the ranking is highest for the highest intervention levels, since these result in the lowest monetary costs.

The socio-political weighted scores for the sites also indicate a preference for higher dose intervention levels. This is because the attributes chosen to define the socio-political objectives are generally measures of individual and societal disruption, which increase with decreasing intervention level. As discussed in Section V.1.2, an attribute reflecting the reassurance provided by the countermeasure was not included, partly because this is catered for, to some extent, by the attribute 'perceived acceptability of risk' in the health arm. However, if such an additional attribute had been defined, then this would have

Table V.1.8: Intermediate Weighted Values For Each Hierarchy Arm For The Control of External Exposure Illustrative Applications

	SITE A					SITE B										
	COUNTERMEASURES OPTIONS[1]					COUNTERMEASURES OPTIONS[1]										
Attribute	NODEC5	NODEC10	NODEC30	NODEC50	NODEC100	NODEC5	DEC5	NODEC10	DEC10	NODEC30	DEC30	NODEC50	DEC50	NODEC100	DEC100
Health	.71	.67	.53	.40	.05	1	.95	.93	.89	.74	.71	.57	.54	.16	.14
Monetary Costs	.99	1	1	1	1	.90	.02	.93	.62	.96	.91	.97	.95	.99	.97
Socio-Political Factors	.65	.88	.95	.98	.99	0	.16	.32	.42	.56	.64	.63	.67	.78	.78

Note:

1) See table V.1.4 for option definitions.

tended to alter the ranking in favour of intermediate intervention levels.

The ranking of the 'no decontamination', relative to the 'decontamination' options for site B, is interesting. Unlike the ranking for monetary costs, the options are generally ranked in pairs, with the two options for an intervention level of dose of 5 mSv y^{-1} being the least favoured, and those for 100 mSv y^{-1} being the most favoured. This mirrors (inversely) the weighted scores for the health attributes, and indicates that decontamination of the area, by a factor of three, has a relatively small impact on the numbers of people and areas of land affected, compared with changes in the intervention level used for relocation.

The overall weights assigned to the three arms of health, monetary costs and socio-political factors, reflected a judgement that health objectives should always have the most important influence on decisions and that monetary costs should have the least. Therefore, as a starting point, the weights were assigned in the ratio 60:10:30 for the health, monetary and socio-political attributes, respectively. The ranking resulting from these applications is shown in Table V.1.9.

Table V.1.9

Overall ranking for countermeasures options for control of external exposure illustrative applications[1]

	Option[2]	Overall Value
Site A:	NODEC10	0.77
	NODEC5	0.72
	NODEC30	0.70
	NODEC50	0.63
	NODEC100	0.43
Site B:	NODEC10	0.75
	DEC10	0.72
	NODEC30/DEC30	0.71
	NODEC5	0.69
	NODEC50	0.63
	DEC5/DEC50	0.62
	NODEC100	0.43
	DEC100	0.42

Notes:

1) Assuming relative weights for health, monetary costs and socio-political factors to be in the ratio 60:10:30.

2) See Table V.1.4 for option definitions.

It can be seen that, given the assumed weights and value functions, the most preferred countermeasure option for site A is relocation at an intervention level of dose of 10 mSv y^{-1}. The corresponding preferred option for site B is the same, that is, an intervention level of dose of 10 mSv y^{-1} for relocation, with no decontamination assumed. The reason why the preferred option for both sites is the same can be seen by inspection of the contributing weighted values for the three objectives arms. Although the weighted value for the health arm is lower for site A than for site B (ie the collective dose avoided for site A is lower than for site B for the same intervention level), the reverse is true for the weighted value of the socio-political arm (ie few people are disrupted at site A). The indirect monetary costs incurred at site A are also lower, but these have been assumed to be of relatively little importance to the decision, (ie monetary cost is only assigned a weight of 10%).

V.1.7 Sensitivity of the Ranking to the Assumed Weights

RADE-AID helps the user to investigate the sensitivity of the ranking in several ways. First, by presenting the weighted values for each objectives arm, general trends may be observed. In the illustrative example, assigning all weight to the health arm would result in a preferred option of relocation at an intervention level of 5 mSv y^{-1} without decontamination, whilst assigning all weight to the monetary or the socio-political arm (as defined by the five attributes assumed here, which generally favour reduced disruption) would result in a preference for a high intervention level.

However, it is unlikely that such extreme assumptions would be made. It is therefore more useful to investigate the sensitivity of the ranking to smaller variations in the weights. For this illustrative application, the sensitivity of the ranking of the most preferred options for site B has been investigated. This is shown in Figures V.1.2-V.1.4 for changes in the relative weights of the health, monetary and socio-political arms. From these, it can be seen that a 10% increase in the weight of the socio-political arm, or a 10% decrease in the weight of the health arm, would change the preferred option from relocation at 10 mSv y^{-1} without decontamination, to 30 mSv y^{-1} with decontamination. Figure V.1.3 shows that if essentially zero weight is assigned to the monetary arm, then the preferred option becomes relocation at 10 mSv y^{-1} with decontamination.

It is interesting to examine which countermeasures options would never be preferred, regardless of the relative weights assigned (but assuming the problem structure and attribute values are as given in these examples). It can be seen from Figures V.1.2-V.1.4 that relocation at 5 mSv y^{-1} with decontamination would never be the preferred option. Similar investigations for the sensitivity of the ranking to the weights assigned to each attribute within the three main arms, also indicates that that option would never be optimum.

Investigation of the sensitivity of the ranking to the weights of the attributes also reveals some other interesting information. Figure V.1.5 shows the influence of changing the weight assigned to the worker collective dose received. In interpreting this Figure, it should be remembered that the total weight assigned to an attribute is the product of its relative weight within its arm of the hierarchy, and the relative weight of that arm (ie the total weight for worker dose in this example is 0.05 x .6, that is 0.03). It can be seen that, if the relative weights assigned to the other attributes are left unchanged, then changing the weight assigned to this attribute cannot alter the most preferred countermeasure option. Conversely, Figure V.1.6 shows the sensitivity of the ranking to the weight assigned to the number of people semi-permanently relocated. A fairly small increase in the weight assigned to this attribute would result in a preference for a relocation intervention level of 30 mSv y^{-1} with decontamination.

Finally, Figure V.1.7 shows the sensitivity of the ranking to changes in the weight assigned to the attribute perceived acceptability of the intervention level. This attribute has the highest single total weight of all the attributes (39%) and so it might be thought that the overall ranking would be fairly sensitive to changes in its magnitude. However, as Figure V.1.7 shows, this is not the case, the total weight would need to be reduced to about 20% or increased to over 70% before a change in the preferred ranking was obtained. On the other hand, the attribute of intervention costs has a fairly small total weight (9%), yet Figure V.1.8 indicates that a reduction in its weight by about 6% would result in relocation at an intervention level of 10 mSv y^{-1} together with decontamination being the preferred option.

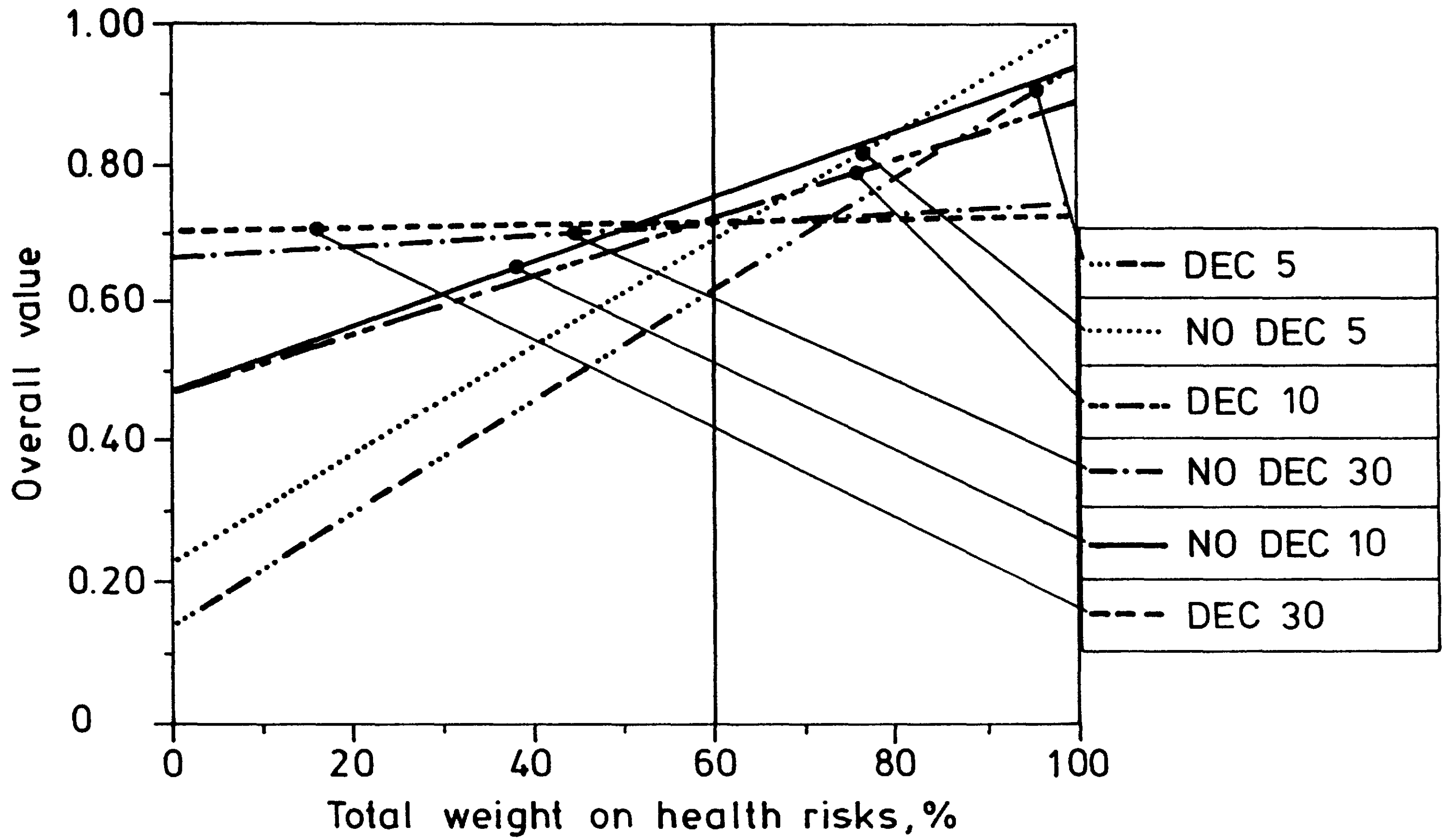


Figure V.1.2. Sensitivity of ranking to assumed weight on health arm

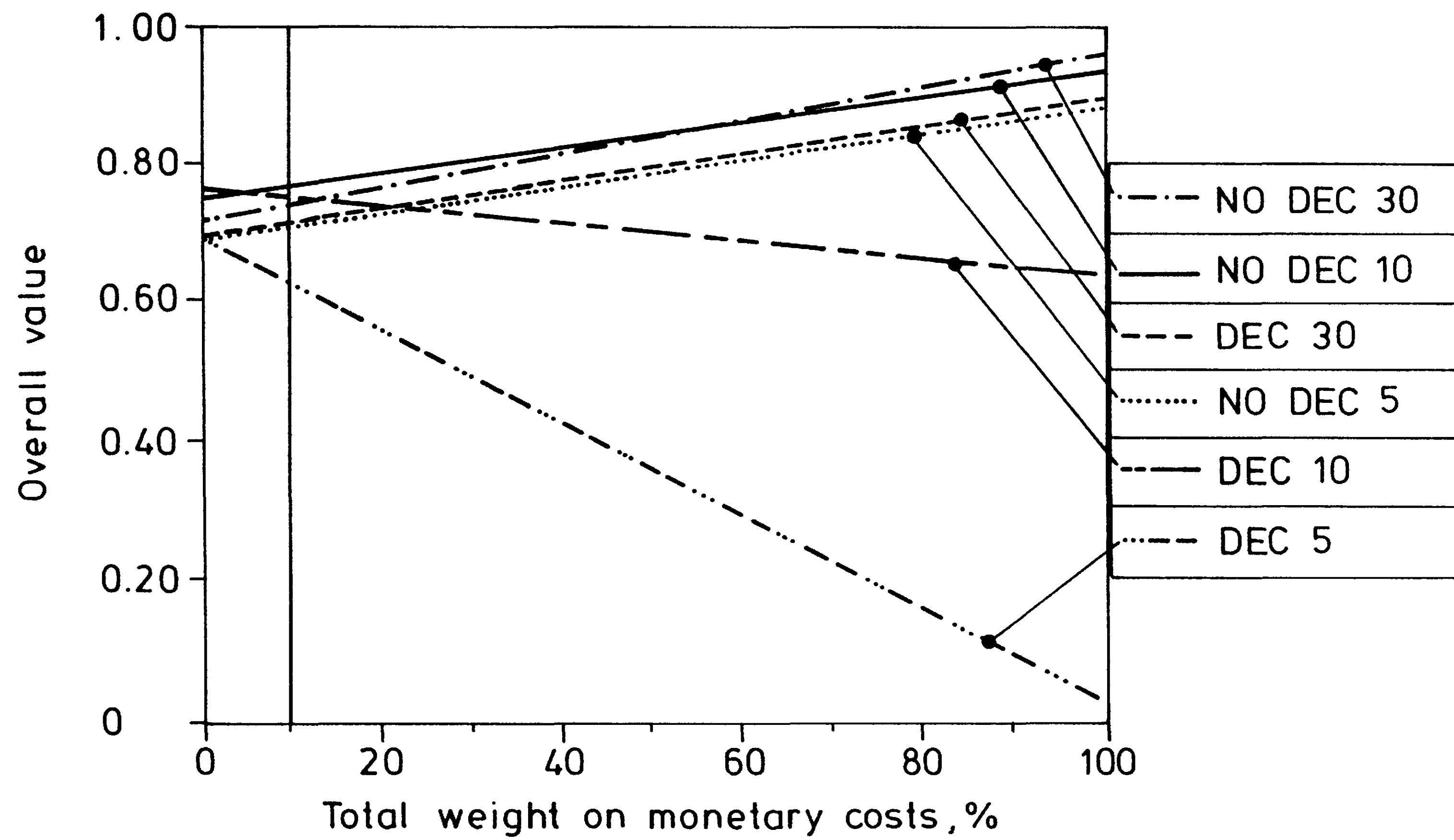


Figure V.1.3. Sensitivity of ranking to assumed weight on monetary arm

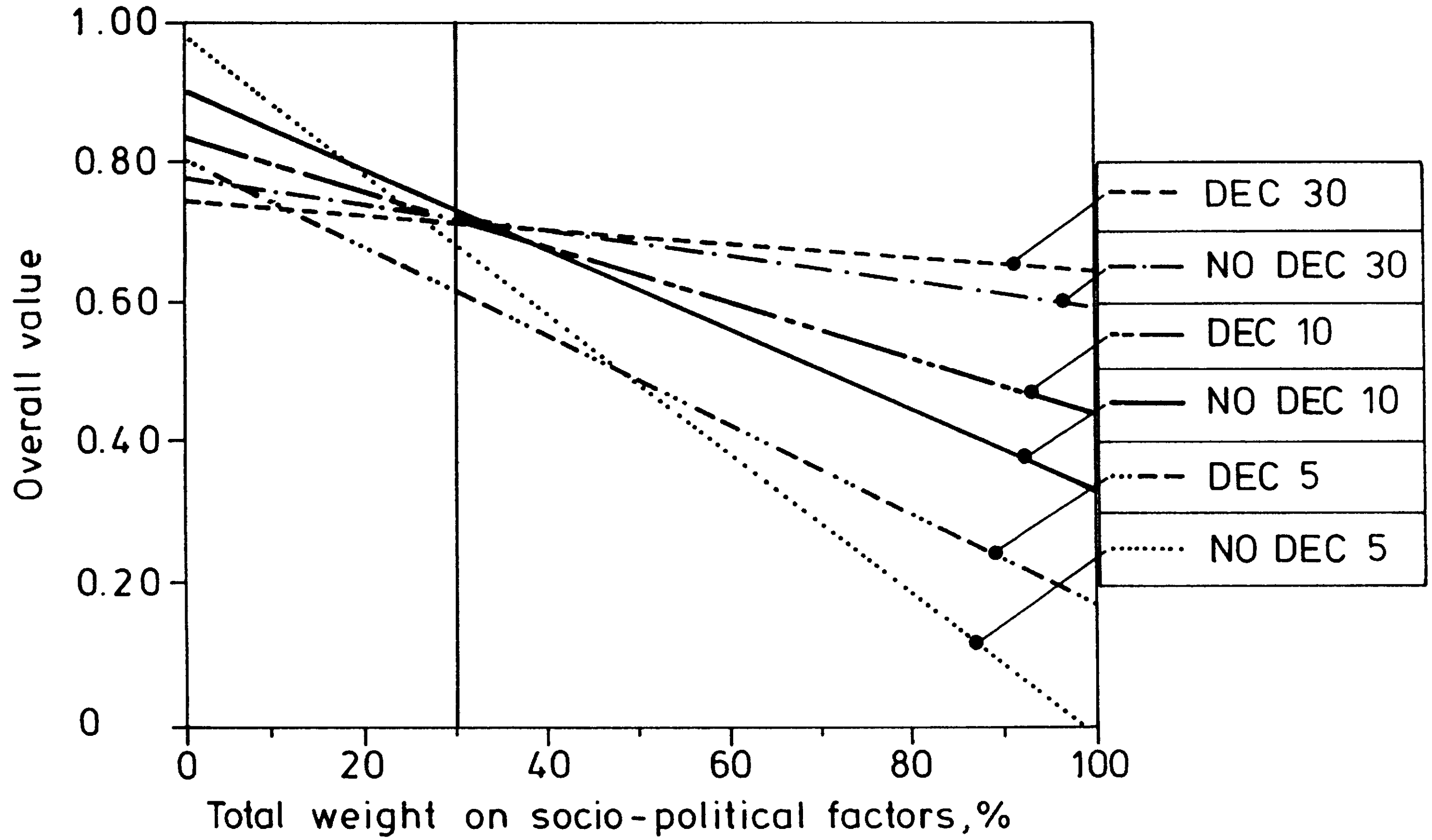


Figure V.1.4. Sensitivity of ranking to assumed weight on socio-political arm

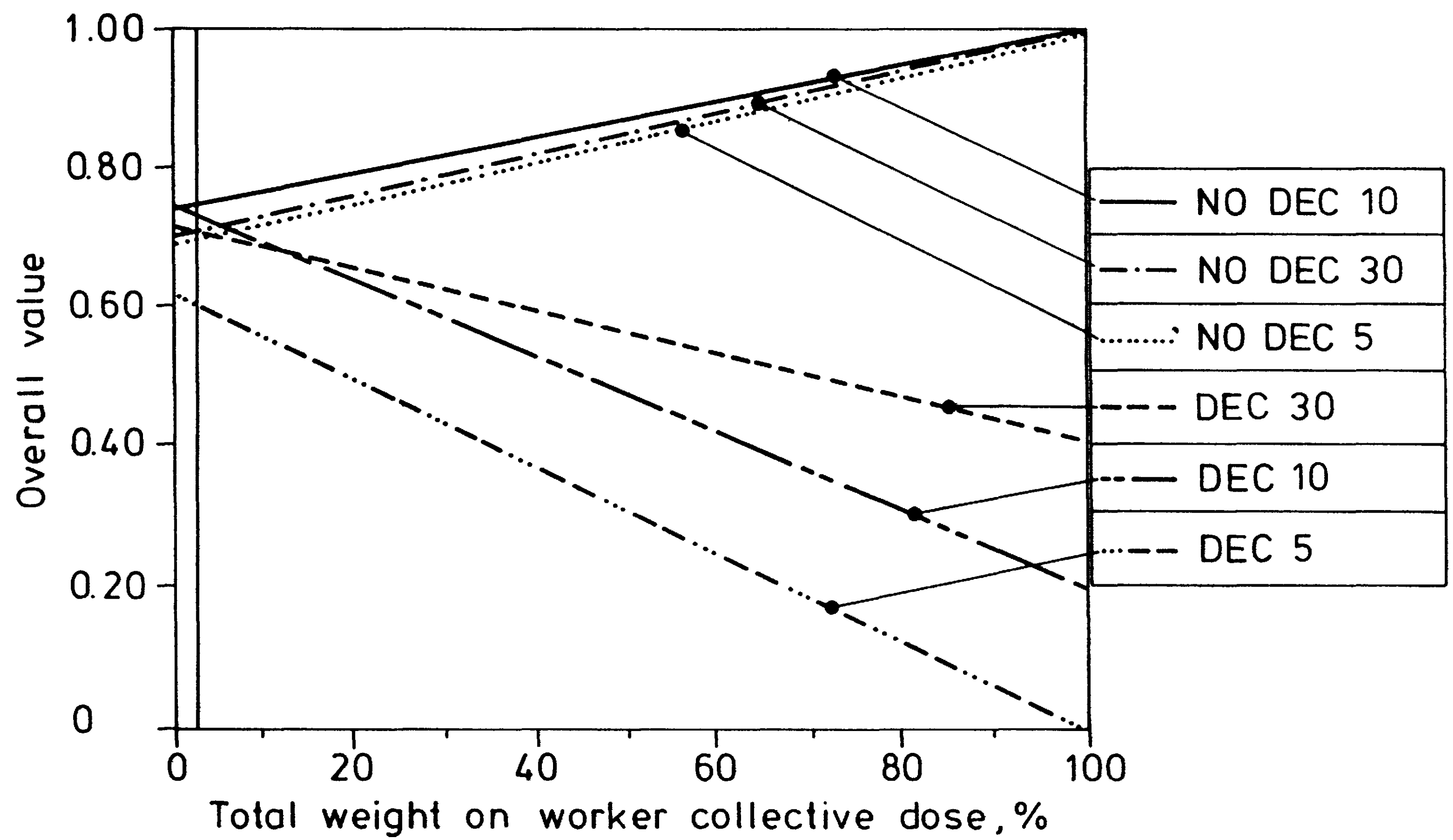


Figure V.1.5. Sensitivity of ranking to assumed weight on collective worker dose

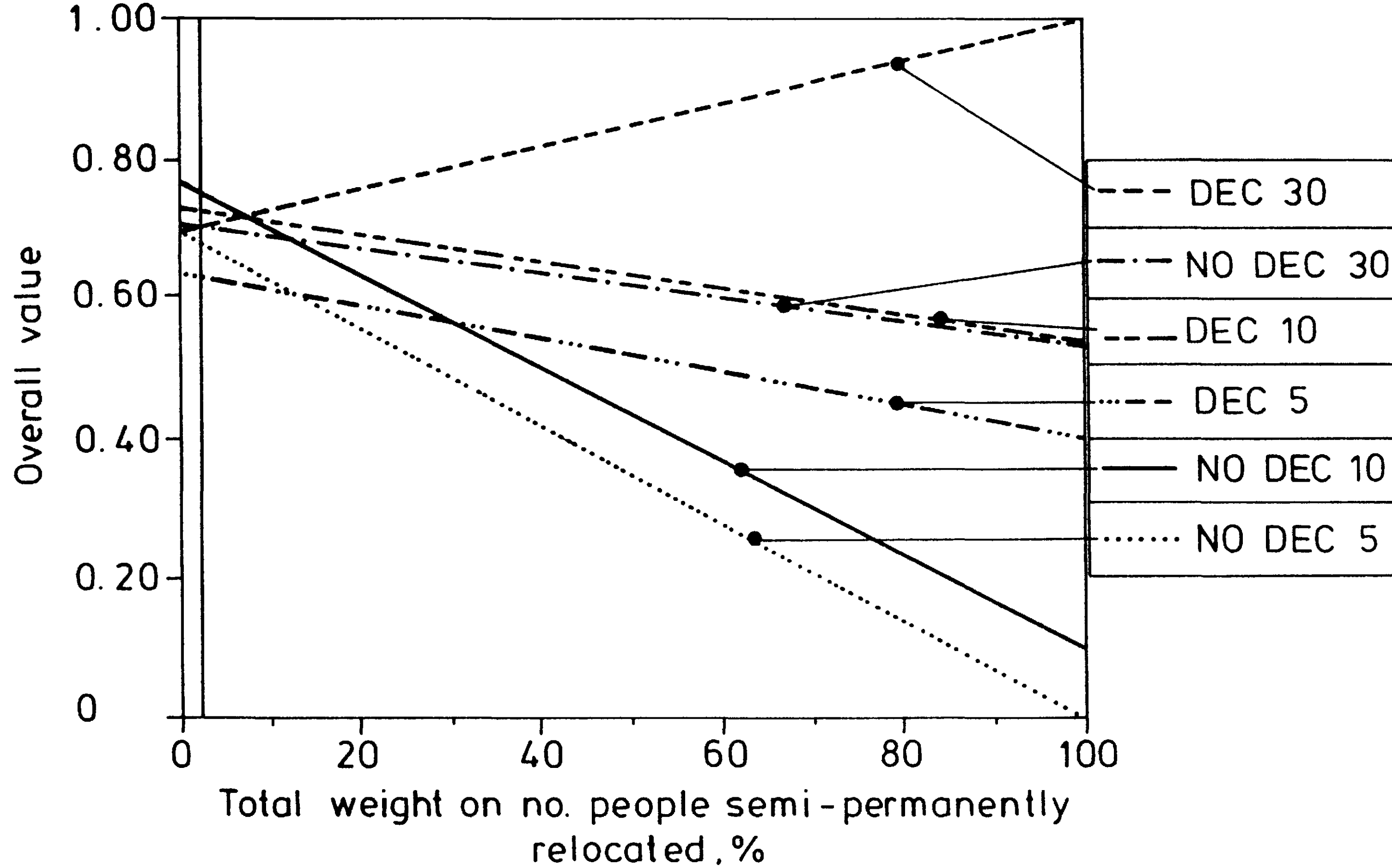


Figure V.1.6. Sensitivity of ranking to assumed weight on number of people semi-permanently relocated

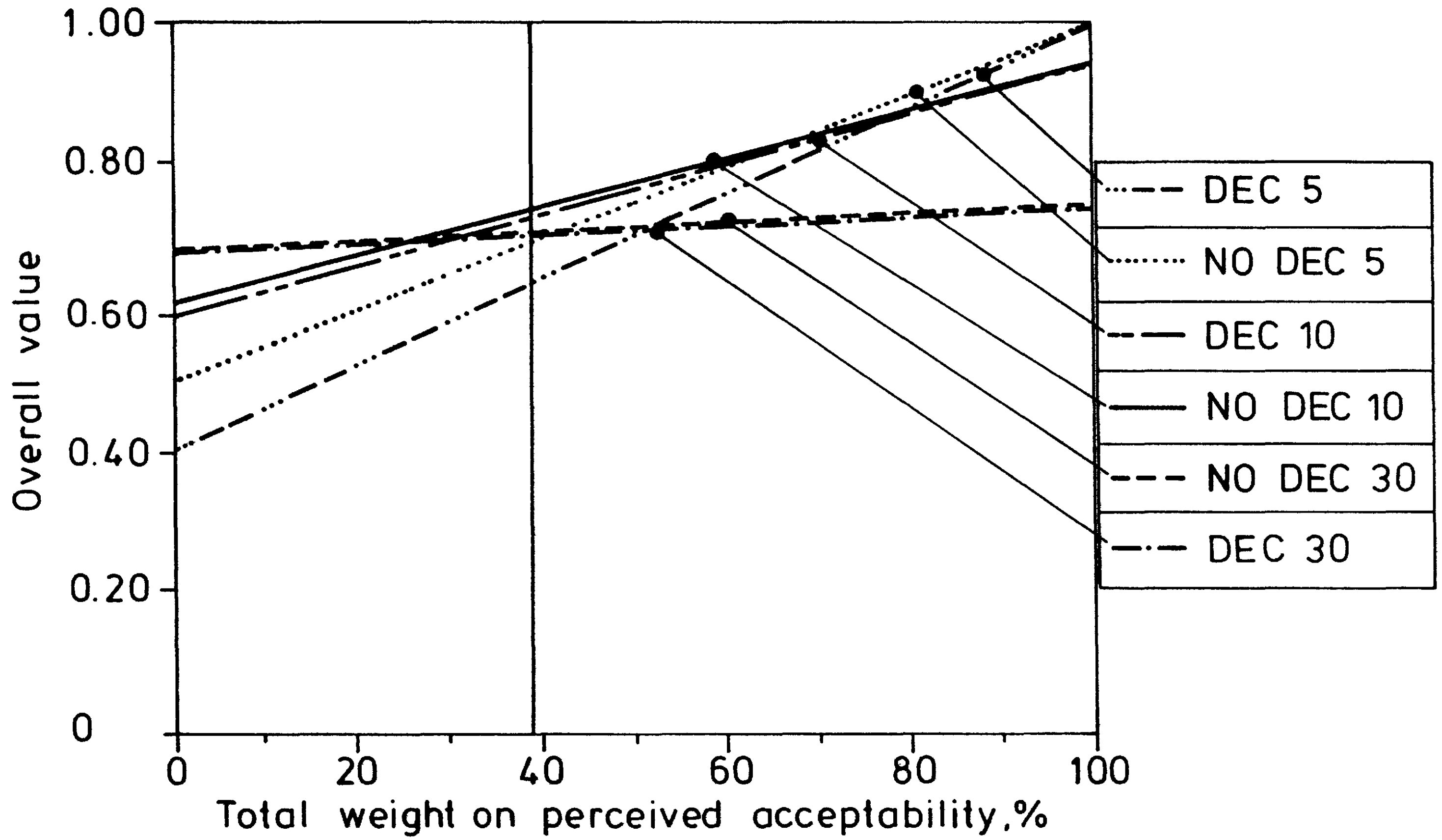


Figure V.1.7. Sensitivity of ranking to assumed weight on perceived acceptability of intervention level

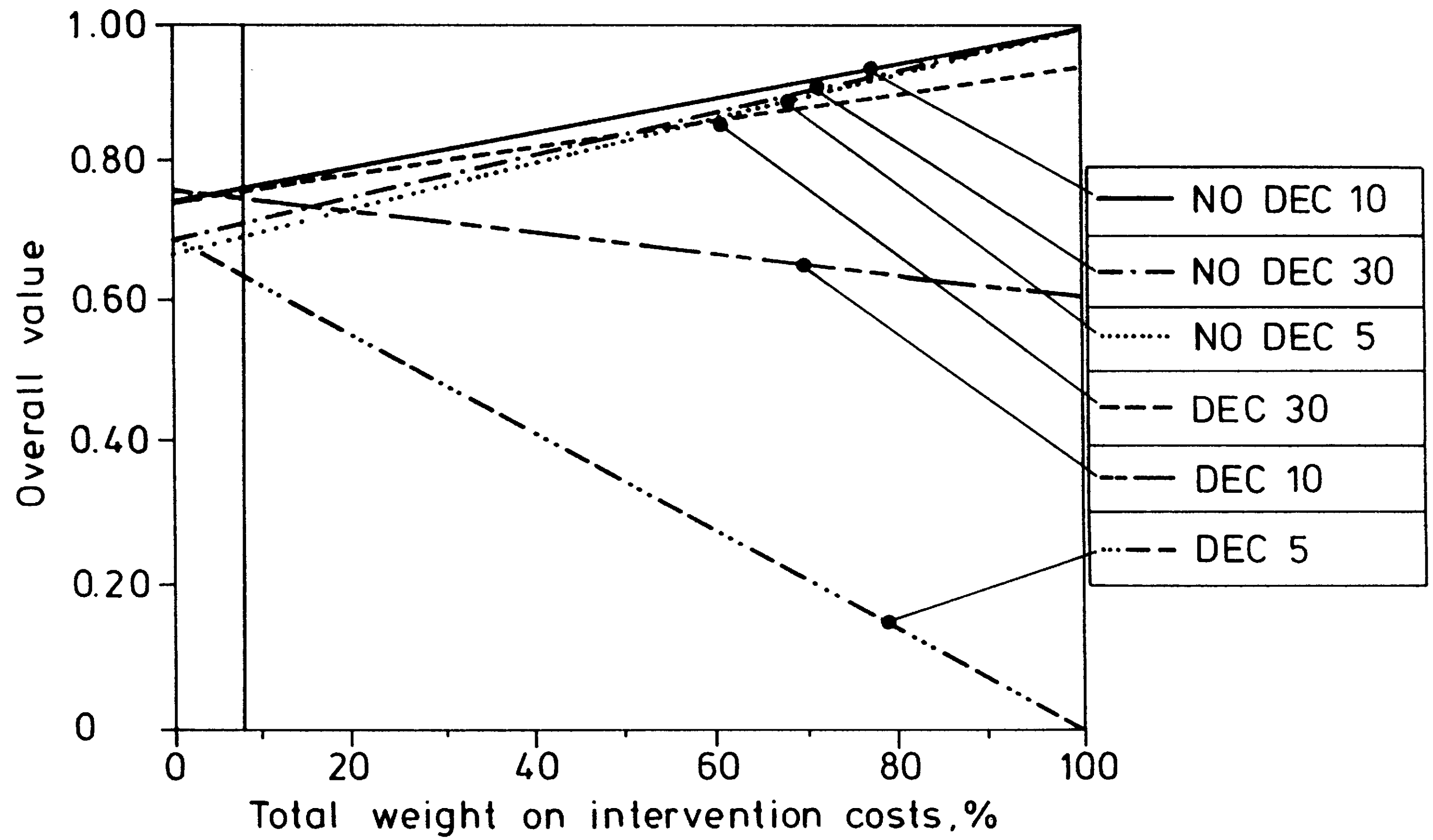


Figure V.1.8. Sensitivity of ranking to assumed weight on intervention costs

Having used the graphical displays of RADE-AID to obtain general information on the sensitivity of the ranking to the assigned weights, additional full analyses can be carried out, using revised weights, and the quantitative results considered. Table V.1.10 shows the comparison of ranking between two sets of relative weights; the first assumes the health, monetary and socio-political arms are asigned weights in the ratio 60:10:30 (ie the weights discussed above) and the second assigns the weights in the ratio 45:10:45. It can be seen that, whilst the preferred option for site A is unchanged, that for site B has changed from relocation at 10 mSv y^{-1} without decontamination, to relocation at 30 mSv y^{-1} with decontamination.

Table V.1.10

Illustrative Sensitivity of Ranking of Countermeasures for Control of External Exposure to the Relative Weights Assigned to Health, Monetary Costs and Socio-Political Factors

Option(1)		Overall Value Base Case(2)	Overall Value Variation(3)
Site A:	NODEC10	0.77	0.88
	NODEC5	0.72	0.71
	NODEC30	0.70	0.77
	NODEC50	0.63	0.72
	NODEC100	0.43	0.57
Site B:	NODEC10	0.75	0.66
	DEC10	0.72	0.65
	NODEC30	0.71	0.68
	DEC30	0.71	0.70
	NODEC5	0.69	0.54
	NODEC50	0.63	0.64
	DEC5	0.62	0.50
	DEC50	0.62	0.64
	NODEC100	0.43	0.52
	DEC100	0.43	0.51

Notes:

1) See Table V.1.4 for option definitions.

2) Health, monetary costs and socio-political factors in the ratio 60:10:30.

3) Health, monetary costs and socio-political factors in the ratio 45:10:45.

V.1.8 Sensitivity to the Value Functions Assigned

The above illustrations assumed linear value functions for the valuing of the scores for each attribute. RADE-AID enables the user to assign non-linear value functions. The effect of using non-linear value functions is to alter the relative preference for the outcomes of the countermeasures options within a single attribute. This, in turn may influence the overall ranking of options.

It is beyond the scope of these illustrative applications to fully explore the implications of assuming non-linear value functions. However, it is interesting to look at some of the ways in which non-linear value functions can influence the overall ranking. In order to do this, the effects of using three different value functions for the attribute 'perceived acceptability of intervention level' were compared. The three value functions were linear, convex and concave.

RADE-AID enables the user to specify non-linear value functions as a series of straight line segments, each node being initially defined as the mid-point between the nodes on either side. For the present application, a simple two segment curve was specified. For the convex value function, the mid-point score was defined to have a value of 0.75, whilst for the concave value function the mid-point score was defined to have a value of 0.25. The three value functions are illustrated in Figure V.1.9.

Table V.1.11 compares the rankings obtained using these three value functions, for both the sets of relative weights discussed above. It can be seen that, although the change in value function has not changed the preferred option, in the case of the convex function, and the 60% relative weight on health, the ordering for the second, third and fourth options has changed, whilst, in the case of the concave function and the 45% relative weight on health, the relocation at 30 mSv y^{-1} options are equally favourable with the 10 mSv y^{-1} option. Clearly, the form of the value function can impact upon the overall ranking of options and therefore the ability to define non-linear functions is an important feature of RADE-AID.

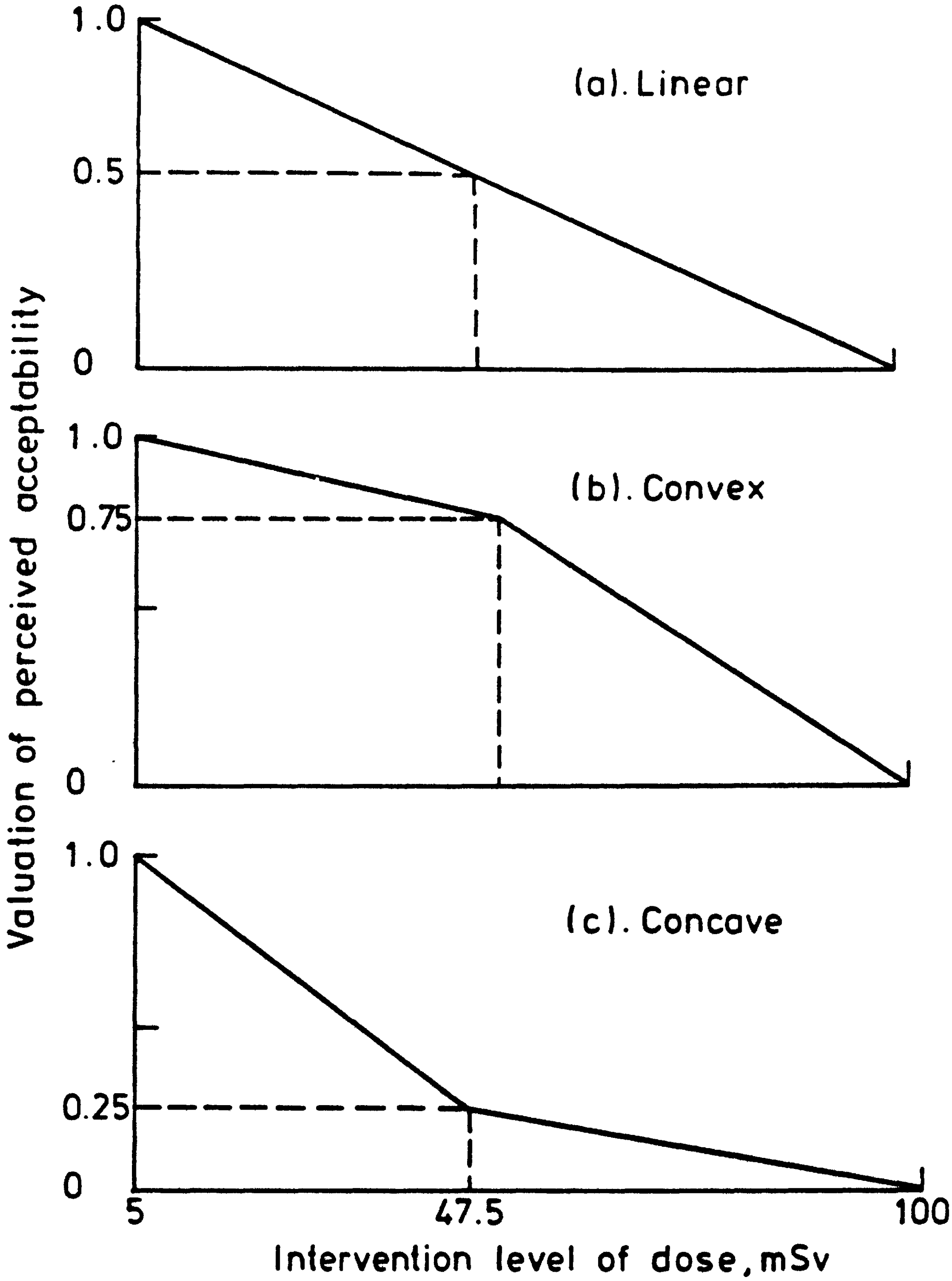


Figure V.1.9: Value Functions Assumed

Table V.1.11: Illustrative Sensitivity of Ranking of Countermeasures for Control of External Exposure to the Shape of the Value Function used for a Single Attribute

BASE CASE[3]

	SITE A					SITE B									
	COUNTERMEASURES OPTIONS(1)					COUNTERMEASURES OPTIONS(1)									
	NODEC5	NODEC10	NODEC30	NODEC50	NODEC100	NODEC5	DEC5	NODEC10	DEC10	NODEC30	DEC30	NODEC50	DEC50	NODEC100	DEC100
LINEAR	.72	.77	.70	.63	.43	.69	.62	.75	.72	.71	.71	.63	.62	.43	.42
CONVEX	.72	.77	.75	.70	.43	.69	.62	.76	.73	.75	.75	.70	.69	.43	.42
CONCAVE	.72	.75	.64	.52	.43	.69	.62	.74	.71	.64	.64	.51	.51	.43	.42

VARIATION[4]

	SITE A					SITE B									
	COUNTERMEASURES OPTIONS(1)					COUNTERMEASURES OPTIONS(1)									
	NODEC5	NODEC10	NODEC30	NODEC50	NODEC100	NODEC5	DEC5	NODEC10	DEC10	NODEC30	DEC30	NODEC50	DEC50	NODEC100	DEC100
LINEAR	.71	.80	.77	.72	.57	.54	.50	.66	.65	.68	.70	.64	.64	.52	.51
CONVEX	.71	.80	.80	.77	.57	.54	.50	.66	.66	.71	.73	.69	.69	.52	.51
CONCAVE	.71	.78	.72	.64	.57	.54	.50	.65	.64	.63	.64	.55	.56	.52	.51

Notes:

1) For shapes of value function see Figure V.1.9.

2) See Table V.1.4 for option definitions.

3) Health, monetary costs and socio-political factors in the ratio 60:10:30.

4) Health, monetary costs and socio-political factors in ratio 45:10:45.

V.2 Control of Food

Internal radiation exposure of members of the public as a result of ingestion of contaminated foods may be limited by the imposition of food bans. In the present context, food bans include all methods by which consumption of contaminated food may be prevented, whether by disposing of contaminated food or by reducing its contamination using processing or storage before it is available for consumption. Following the Chernobyl accident, food was banned if the concentrations of radionuclides in it exceeded given intervention levels. This approach was used in the stylised applications of RADE-AID for food bans.

If a decision is taken to ban food containing activity greater than a specified intervention level, then it is necessary to determine how food exceeding these levels should be dealt with, and also, how future contamination of foods above the intervention levels can best be avoided (eg, natural or forced decontamination of land, or feeding alternative feeds to livestock). Such decisions may be quite complex. For example there may be several radionuclides to control (each with different physical and chemical properties), and the ease with which control measures may be applied may vary with soil type, weather conditions and the agricultural practices of the area. Moreover, there will exist external constraints in terms of the resources (eg, equipment and storage facilities) which can be utilised. Some possible courses of action may result in additional doses to workers or even to the general population.

For the illustrative application of RADE-AID it was decided to consider only the imposition of grain bans. The harvesting of grain occurs discretely (and has been assumed here to occur only once a year) and this makes it easier to model the consequences of taking different countermeasures. However, it is judged that the consideration of grain bans provides a sufficient demonstration of the potential of RADE-AID as a decision-aiding system for the control of other foods.

V.2.1 Accident Scenarios

For the example applications, four releases were considered which cover a broad range of characteristics with respect to the temporal and spatial extent of foodbans:

- Type A: Release in summer with short ban times ($t_b < 90$ d) and small areas with bans.

- Type B: Large release in winter with significant long term contamination of a relatively small area.
- Type C: Release in summer with moderate ban times (30 d < tb < 1 a) and relatively small affected areas.
- Type D: Large release in summer with significant long term contamination and grain bans over large distances.

The nuclide spectrum was restricted to I-131 (type A) and to a mixture of the isotopes I-131, Cs-134 and Cs-137 (types B, C, D), which were shown to be the main contributors to the ingestion doses after airborne releases from LWRs in many accident consequence assessments. The release fractions of the nuclides were taken from the release category FK2 of the German Risk Study - Phase A[21].

V.2.2 Countermeasure Alternatives

In this Section, a general overview over the action types considered is given; details about the actions and the action models are described in Annex I.

In the sense of decision making, taking no action at all is also an action in its own right. Taking no action, regardless of the accident, means to choose an intervention level[22] of infinity for the decision about foodbans. Given any intervention level (IL) other than infinity, foodbans may occur, and, as the basic consequence, the affected food is not allowed to be distributed for human consumption. In this case, there are several ways to deal with the contaminated foodstuff itself or the agricultural land where it is produced. Some of the possible actions for grain are listed in Table V.2.1 ("No action" is included in the list):

Table V.2.1
Types of action for grain

(1) NOACT No action	IL = ∞
(2) UPLOU Plough under (normal farm ploughing) (3) DISPO Disposal (4) STORE Storage (5) DI UT Dilution (6) NADEC Natural decontamination of soil (7) ROTSL Removal of the top soil layer	when given IL is exceeded

Actions (2)-(5) are aimed at the destruction of immature or mature crops growin on the fields, or at a decrease of the specific activities in the harvesed grain below the intervention level, so it can be used for human consumption. It is assumed, that for ban-times exceeding one year in a given grid element, i.e. when more than the first crop after the accident is affected, grain will not be produced after the first harvest in this area, so that the actions (2)-(5) apply only to the first year's crop.

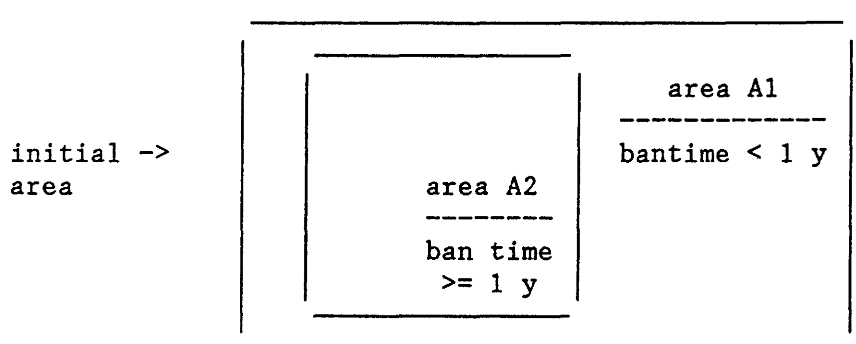
Actions (6) and (7) relate to the contamination of future crops caused by long-term processes, such as root uptake and resuspension. Deep ploughing is also an action of this type; it is conceptually similar to the removal of the top soil layer. However, the decision as to whether deep ploughing can be carried out or not in a given area depends strongly on the soil type and requires very detailed data; this action type was not considered for the illustrative applications.

Selection of alternatives

In order to choose a range of possible courses of actions (action alternatives) for grain for the illustrative applications, it is useful to distinguish between

- the area(s), in which the estimated foodban duration tb is < 1 year ("areas A1), and
- the area(s), in which the estimated foodban duration tb is ≥ 1 year ("areas A2):

Figure V.2.1
Distinction of different foodban areas



Size and location of the initial area and of the areas A1 and A2 do not only depend on the accident scenario, but, by their definition, also on the intervention level. For a given accident scenario, one of the four possibilities will occur:

- No ban area at all, e.g. always as the consequence of "no action (NOACT)",
- A1 only, typically for a release where, with respect to the ingestion pathways, I-131 dominates,
- A2 only, e.g. for a major release with significant fractions of Cs-134 and Cs-137,
- A1+A2, e.g. for the above release, with the main area being of type A2 and some parts at the edge of the plume of type A1).

The one which will actually occur depends on the intervention level.

Excluding the removal of top soil layer, which is discussed below, and disregarding any practicability aspect at this stage, all action types listed in Table V.2.1 could be useful actions in both areas A1 and A2 in the first year after the accident. Since it is unlikely that grain will be produced in the following years, in areas where the foodbans were estimated to affect more than the first harvest, for areas A2 after the first year only the action type "wait until by natural decontamination processes the land is usable again (NADEC)" remains. So, a list of possible action alternatives will include the action alternatives (1) to (5) shown in Table V.2.2.

From Table I.1 and Table I.7 in Annex I it is obvious that the expenditure for the removal of the top soil layer is rather high with respect to equipment requirements and to costs, making it senseless to consider this action type in area A1. On the other hand, for area A2 it might be a useful action; in this case, however, no other action types are possible for this area. Together with the actions for possible areas with tb < 1 year, this leads to the combinations (6) to (10) in Table V.2.2.

Table V.2.2
Action alternatives considered

		tb<1a	tb≥1a		tb<1a	tb≥1a
(0) NOACT	(1)	NADEC	NADEC	(6)	NADEC	ROTSL
	(2)	UPLOU	NADEC	(7)	UPLOU	ROTSL
	(3)	DISPO	NADEC	(8)	DISPO	ROTSL
	(4)	STORE	NADEC	(9)	STORE	ROTSL
	(5)	DILUT	NADEC	(10)	DILUT	ROTSL

With "NOACT" included and three ILs for the actions (1)-(10), 31 action alternatives can be derived from Table V.2.2.

Of course, the list in Table V.2.2 is not complete, because other combinations of action types can also be thought of, for instance "disposal of the most contaminated part of the harvest and dilution of the rest", or "removal of the top soil layer in the most contaminated part of area A2 and natural decontamination in the rest". Models for action alternatives of this type require a definition of what is 'the most contaminated part'. One way to do this is to set up one or more "sub-intervention level(s)" to guide which part of harvest or area belongs to which action type, adding for each combination of action types IL times sub-IL new action alternatives to the ones already considered. Since the total number of action alternatives is already rather large, the action type combinations used for the illustrative applications were restricted to those given in Table V.2.2

Reduction of number of alternatives

For certain ban durations or contamination levels, the following components of the action alternatives from Table V.2.2 are excluded by assumptions made in the action type models described in Annex I:

1 All components referring to tb ≥ 1 a where tb is < 1 year.

2 The ROTSL - component because R ≥ fr (see Table I.1).

3 The STORE - component where the estimated ban duration exceeds a certain time limit (in this case 1 year).

If all grid elements belong to the same category with respect to one or more of the constraints above, some of the action alternatives from Table V.2.2 can be omitted because they do not apply by definition or because they become redundant with others:

- "A1 only": by leaving out the components referring to tb ≥ 1 y, action alternatives (1)-(5) and (6)-(10) become identical, and half of them can be ignored.
- "Always tb ≥ 1 y": all action alternatives containing the STORE component.
- "A2 only and always R ≥ fr": all action alternatives containing the ROTSL component; this condition is very unlikely, though.
- "Always tb < 90 d": all AAs containing the DILUT component. This was introduced basically to eliminate the DILUT action combinations completely from the list for those cases when the ban times are short in all grid elements.

All these conditions were identified and superfluous alternatives were eliminated from further consideration. However, it should be noted that the conditions may change with the IL, so that action alternatives can disappear or reappear in the list of possible alternatives when analysing the same accident scenario with different intervention levels, as will be seen in Section V.2.4.

In situations where different grid elements belong to different categories of constraints, it is not possible to eliminate complete alternatives. In addition, if, in a grid element where by some constraint an action type is excluded, it is assumed that no other action type is carried out instead, the grid element does not contribute to the overall consequences. This is incorrect, because something has to be done in this area. Then the decision logic operates with input data inadequate for the situation when working out the ranking of the action alternatives, thus giving results which will be correct in form but wrong in meaning.

For this reason, in such "mixed conditions" the total consequences were calculated assuming the following action type substitutes in grid elements where the primary action types do not apply:

- DISPO instead of STORE
- NADEC instead of ROTSL if R ≥ fr.

For each of the action combinations (1) to (10) from Table V.2.2 three intervention levels were considered:

Table V.2.3
Intervention levels (Bq/kg) for grain products

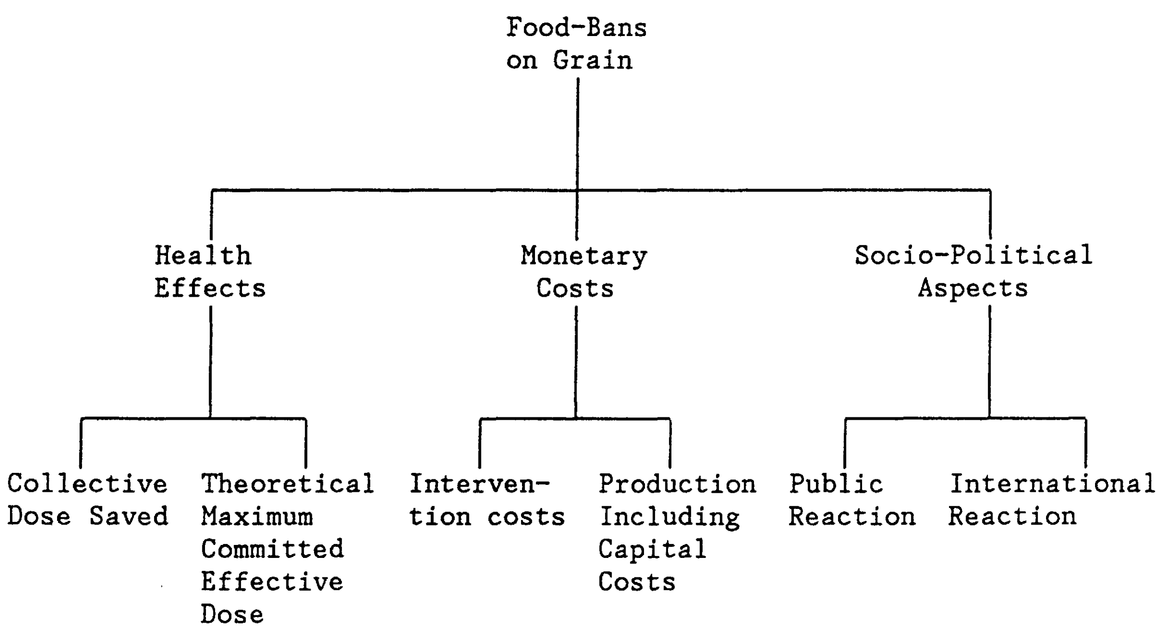
IL1 IODINE 2.00E+04	IL2 IODINE 2.00E+03	IL3 IODINE 2.00E+02
IL1 CESIUM 1.25E+04	IL2 CESIUM 1.25E+03	IL3 CESIUM 1.25E+02

The middle set of intervention levels is the one in the EC regulation[23], the first and the third are one order of magnitude higher and lower, respectively.

V.2.3 Decision Attributes for Grain

The decision-tree for grain is shown in Figure V.2.2. It consists of three main branches to account for the health, monetary and socio-political aspects of the decision process. Six attributes for the quantification of these aspects were chosen, two for each branch, splitting each main branch into two sub-branches:

Figure V.2.2
Decision tree for grain



The decision tree is considered to be basic in the sense that it allows a fairly complete quantification of the problem with a minimal number of attributes. It does not cover all aspects possibly relevant for coming to a decision, for instance the time dependence and the physical practicability are not yet represented; the reasons for these restrictions are discussed below.

The attributes used for the illustrative applications are listed in Table V.2.4 and discussed below.

Table V.2.4
Attributes for the decision tree

(f)	collective effective dose
(f)	theoretical maximum individual committed effective dose
(f)	total costs for intervention
(f)	total costs for lost production
(d)	public reaction to the action ("How will the general public like the decision")
(d)	international reaction to the action ("How will other states like the decision")

Note

d = direct preferencing; f = functional preferencing

V.2.3.1 Health Branch

General population

The estimated number of health effects avoided by a countermeasure is the most direct measure for the effectiveness of the action concerning the collective health in the general population; other, more indirect quantities, are the collective risk saved or the collective effective dose saved.

Although the number of health effects avoided is the most obvious attribute for the collective public health, it was decided to use the collective effective dose, because it has several practical advantages:

- Dose is a quantity somewhat less uncertain than the number of health effects or risk, both by the way to calculate it and the data employed in the calculations.
- It is a single quantity; the number of health effects would require a breakdown into several categories, e.g. fatal cancers, non-fatal cancers and genetic effects, because each category will have different weights associated with it.

The disadvantages are that the collective dose saved is possibly a less easy quantity for decision makers to assign value functions to, and that, depending on the dose-risk relationship assumed, it may not be possible to infer directly from the collective effective dose saved the numbers of health effects avoided.

The collective dose contains no information about the range of individual doses in the population. However, the post-Chernobyl discussion showed that the dose to a member of the critical group is important to the decision maker. On these grounds, the quantity "theoretical maximum individual committed effective dose (TMID)" was chosen as an attribute for the individual dose aspect. However, it is recognised that the maximum thyroid dose will also be important in assessing the impact of releases containing iodine. The TMID is the dose an individual belonging to the critical group (defined both by consumption and dose per unit intake) would receive, if he or she consumed the food over one year contaminated with activities per unit mass identical to the intervention levels. It should be noted, that this quantity depends only on the IL and not on the action alternative and therefore does not help to discriminate between different action alternatives.

Concerning the time distribution of the dose (both collective and individual), the example calculations show that for a release in summer the majority of the dose is delivered in the first year, and for a release in winter, the contribution from the following years dominate. Although corresponding time dependent values for the dose saved could also be calculated, e.g. the dose saved in the first year and the dose saved in the following years, it is not easy to see how to assign value functions and weights to them which are independent of the actual situation. Therefore, at present, only the total values are used as attributes.

Workers

The radiation exposure of workers is limited by law and therefore may not be useful to distinguish between different countermeasures. On the other hand, the dose limits for workers may be exceeded for some action alternatives but not for others. If they are, additional effort is required, either by providing protective gear or by a frequent exchange of the personnel, and this will certainly influence the ranking of the action alternatives.

It is likely that for smaller accidents problems of this type do not arise. However, this cannot be taken for granted in all accident situations, exposure pathways and especially action types. In reference

24 it is pointed out that the radiation hazard to workers involved in the decontamination of rural areas must be estimated in order to be able to prevent unacceptable exposure, or, for the milk pathway, it was concluded after an example calculation for the production of milk powder from milk contaminated with I-131, that "the personnel radiation hazard causes the most serious problems"[22].

For the accident scenarios considered for the illustrative applications, it is assumed that the dose limit for workers is never exceeded when carrying out the grain actions. A proof of this assumption requires the assessment of the potential doses to the workers, which result from the different exposure pathways (mainly deposition on skin / inhalation of resuspended radioactive material, and groundshine) for the various forms of human activity, i.e. operating harvest machines, farm ploughs, scrapers etc. Given the uncertainty inherent in predicting such doses, and the illustrative nature of these applications, the worker aspect was not included in the decision hierarchy.

V.2.3.2 Monetary Costs Branch

The monetary consequences for an action alternative for grain can be divided into two categories[25,26]:

1. *Intervention costs*: all costs arising from the treatment of the banned foodstuffs or agricultural areas affected by the bans, and the costs for monitoring foodstuffs or areas for about the estimated ban duration.
2. *Production losses and capital losses*: all costs coming from the loss of the foodstuffs (purchases from other producers, income of farmers etc., and depreciation of capital).

The costs for the first category have to be paid directly; the second category is a "passive" source of monetary consequences. Therefore, it can be expected that different value functions or weights will be assigned to each category, justifying the two-armed structure of the monetary branch of the decision tree.

It is possible to subdivide the "passive" branch into its different contributors, namely the gross output, contributing in the first year, the gross domestic product, contributing in years two and three, and the capital costs, contributing in the remaining years (see Section I.4.5.1 in Annex I). This breakdown was not made here, because, in the authors' opinion, there are no arguments to interpret or weight the costs in the first year differently from those in years two and three, or the capital costs differently from the others, the latter mainly because example calculations have shown that in general the capital costs give the smallest contributions to the total costs.

V.2.3.3 Socio-Political Branch

As for the monetary costs, two different categories can be distinguished for the socio-political consequences:

1. Reaction of the public in the state which has to decide on the countermeasures (national reaction).
2. Reactions of the governments and the public in other states affected somehow by the decision, e.g. by having to monitor foodstuffs imported from the primary country when the ILs are higher than the national ones (international reaction).

Both aspects may be very important for the decision maker, but they are difficult to quantify. There exist quantities which are known to influence the national reaction, e.g. the amount of grain banned as a function of time, and possibly similar quantities can be found for the international reactions. However, it can be difficult to derive value functions for such attributes, bearing in mind that they must either represent averages of some kind over different population groups or even nations, or be representative for some subgroup. In the latter case, the weight for the corresponding branch must reflect the importance the decision maker attributes to this sub-group in comparison to other branches. In addition, it is difficult to find out and predict population reactions when these may be governed by factors such as the desire to avoid any risk from nuclear industrial activity, however small it may be.

Another problem when assigning value functions and weights is that many of the consequences are directly correlated, e.g. the areas affected, the amount of food bannned, and the costs. At present, it is not clear that this correlation does not inhibit the concurrent use of such attributes because they are not preference-independent.

On these grounds it was decided not to structure the socio-political branch in more detail and to recommend a direct scoring by subjective judgement. Persons who are requested to generate value functions and weights for the various action alternatives should be aware of the whole spectrum of consequences and take them into account when judging the national and international reactions. For this, the following aspects may be of importance:

- the areas affected by the bans
- the duration of the bans
- the amount of food banned
- the necessity and possibility of food imports to replace the lost national production
- the increase of costs for the food product for the consumers
- the willingness of the people to buy a foodproduct which is processed to decrease the contamination level
- the population group which dominates the general public reaction (e.g. the farmers or the general population)
- the intervention level (compared to internationally accepted levels or levels applied in neighbouring states)

One may note that most of the items listed above depend on the time. If the time dependence turns out to be of major importance to the decision maker, then attributes must be defined which reflect the time aspect; for the time being, this rather complicated set of problems was left aside.

V.2.3.4 Practicability Aspect

Of the action types from Table V.2.1, DISPO, STORE, DILUT and ROTSL require physical resources in order to be carried out:

- Disposal capacity for DISPO, e.g. access to storage facilities for radioactive waste.
- Storage capacity for STORE.
- Uncontaminated grain for DILUT.
- Scrapers, road graders, bulldozers etc. for ROTSL.

The availability of such resources may be a limiting factor for the physical practicability of corresponding action types. Such a limit can probably not be defined independently of the accident scenario, because it may depend on the size of the accident and the international surroundings: for instance, considering the EC as a whole, neighbouring countries may offer their own resources if the accident consequences are restricted to one country, or be unable to do so if larger parts of the EC are affected. It was therefore decided to leave out the practicability aspect from the decision hierarchy for the time being.

V.2.4 Discussion of the Accident Consequences

The calculation of the deposited activities was performed with the German accident consequence assessment code system UFOMOD[21] (subsystem NL) for one weather sequence. The accident consequences were calculated as described in Annex I, with foodchain transport model data for July 1st for the release types A, C and D and for January 1st for the release type B.

To provide a picture of the extent of the bans for the different release types, the maximum distances where grain bans are estimated and the amount of produce affected by the bans are shown in Tables V.2.5 and V.2.6 as a function of time.

As discussed in Section V.2.3, the following attributes were identified to be relevant for the decision logic:

- the total costs for the intervention, CI
- the total costs for lost production and lost capital, CP
- the collective committed dose equivalent saved, CDS (effective dose or thyroid dose)
- the theoretical maximum individual committed dose equivalent, TMID (effective dose or thyroid dose)

The values of CI and CP for the different action alternatives are listed in Table V.2.7, those for CDS in Table V.2.8 (release type A: thyroid dose; all other release types: effective dose). Table V.2.8 also contains the fractions saved of the reference collective dose, FREFCD. The action alternative NOACT always scores zero on CI, CP and CDS and is omitted from the tables.

The values for TMID are not given, since they are by definition proportional to the intervention level and thus do not differ for different action alternatives with the same IL.

Other results, such as the detailed breakdown of the costs into the different components and the time dependences of the individual and collective doses are not shown here, but provided considerable help for the interpretation of the results.

In the following, the accident consequences for the different release types are briefly discussed in order to facilitate the interpretation of the outcome of the decision logic.

V.2.4.1 Release Type A

Because of the short radioactive half life of I-131 (8 days), the grain bans are of short duration for all three intervention levels. The maximum ban time is 3 months, so that only actions in the first year are required, making all action alternatives containing the ROTSL component superfluous. Moreover, dilution need not to be considered because of the very short ban time. This largely reduces the list of possible action alternatives.

The values for the attribute "intervention costs" show a clear distinction both with respect to all action alternatives and to the intervention levels.

The actions NADEC, UPLOU and DISPO lead to a loss of the total first harvest in the affected areas, independent of the ban durations. Therefore, for a given IL, the values of CP and of CDS (here: for the thyroid), respectively, are the same for the three actions, which means that they cannot be distinguished by these two attributes. However, the corresponding values are clearly distinct for the different intervention levels.

For the action STORE, the crops from the affected areas are stored for some time and afterwards used for human consumption, so that (approximately) no costs due to the loss of production and capital arise; the collective dose saved is about 85% to 95% of the reference collective dose, dependent on the intervention level.

V.2.4.2 Release Type B

Since the release is in winter, the direct contamination of standing crops is not relevant. However, the activity levels in the soil are so high that the long-term contamination of the crops by root uptake is significant and the duration of the bans, if any, is rather long due to the presence of the long-lived caesium isotopes in the release.

The highest intervention level does not lead to any bans. For the ILs 2 and 3, the foodbans are estimated to last between about 6 months and 50 years, so that the long term components of the action alternatives may come into operation. The first components of the action alternatives apply to the winter seed of the first year, which was already present on the fields at the time of the accident. However, storage is not taken into account here, since the ban time is rather long for this measure, and dilution is certainly a more reasonable action in this case.

The total intervention costs for release type B comprise both the costs for the short term and the long term actions. For all action alternatives containing the ROTSL component, the intervention costs are dominated by the costs for the removal of the top soil layer and therefore do not differ in the values for this attribute for a given IL. The other action alternatives are sufficiently spread in the CI-values to allow a ranking by this attribute.

For CP, DILUT gives only contributions from the following years, ROTSL only from the first year (where it applies: there is a small area in which the contamination is so high that it cannot be reduced below the IL3; in this residual area, NADEC is assumed). Since the costs for the production and capital losses in year one are about three times higher in the case of IL2 and about the same in the case of IL3 as the costs from all following years, the spread in the total CP between the different action alternatives at the same intervention level is only moderate.

Table V.2.5
Maximum distance (km) for grain bans with durations tb ≥ ti

	0d	7d	30d	90d	180d	1a	2a	5a	10a	20a	50a
A IL1	10	10	0	0	0	0	0	0	0	0	0
A IL1	90	80	10	0	0	0	0	0	0	0	0
A IL1	175	150	80	0	0	0	0	0	0	0	0
B IL1	0	0	0	0	0	0	0	0	0	0	0
B IL2	30	30	30	30	30	30	30	10	10	10	0
B IL3	90	90	90	90	90	90	90	90	80	80	30
C IL1	80	80	80	80	80	0	0	0	0	0	0
C IL2	90	90	90	90	90	0	0	0	0	0	0
C IL3	400	400	400	400	400	0	0	0	0	0	0
D IL1	400	400	400	400	400	0	0	0	0	0	0
D IL2	500	500	500	500	500	30	30	10	10	10	10
D IL3	500	500	500	500	500	90	90	90	80	80	30

Table V.2.6
Produce with bans with durations tb ≥ ti

		0d	7d	30d	90d	180d	1a	2a	5a	20a	50a
A	IL1	3.2E+6	1.9E+6	0.0E+0	0.0E+0	0.0E+0	0.0E+0	0.0E+0	0.0E+0	0.0E+0	0.0E+0
A	IL2	4.2E+7	2.6E+7	2.6E+6	0.0E+0	0.0E+0	0.0E+0	0.0E+0	0.0E+0	0.0E+0	0.0E+0
A	IL3	1.9E+8	1.3E+8	3.0E+7	0.0E+0	0.0E+0	0.0E+0	0.0E+0	0.0E+0	0.0E+0	0.0E+0
B	IL1	0.0E+0	0.0E+0	0.0E+0	0.0E+0	0.0E+0	0.0E+0	0.0E+0	0.0E+0	0.0E+0	0.0E+0
B	IL2	1.1E+7	1.1E+7	1.1E+7	1.1E+7	1.1E+7	9.0E+6	5.0E+6	2.6E+6	1.3E+6	0.0E+0
B	IL3	6.5E+7	6.5E+7	6.5E+7	6.5E+7	5.8E+7	5.3E+7	4.8E+7	3.7E+7	2.8E+7	1.2E+7
C	IL1	2.9E+7	2.9E+7	2.9E+7	2.9E+7	2.9E+7	0.0E+0	0.0E+0	0.0E+0	0.0E+0	0.0E+0
C	IL2	8.0E+7	8.0E+7	8.0E+7	7.6E+7	7.6E+7	0.0E+0	0.0E+0	0.0E+0	0.0E+0	0.0E+0
C	IL3	4.5E+8	4.5E+8	4.0E+8	4.5E+8	3.6E+8	0.0E+0	0.0E+0	0.0E+0	0.0E+0	0.0E+0
D	IL1	4.5E+8	4.5E+8	4.0E+8	4.5E+8	3.6E+8	0.0E+0	0.0E+0	0.0E+0	0.0E+0	0.0E+0
D	IL2	8.6E+8	8.6E+8	8.6E+8	8.6E+8	8.4E+8	1.1E+7	9.0E+6	2.6E+6	1.3E+6	0.0E+0
D	IL3	1.3E+9	1.3E+9	1.3E+9	1.3E+9	1.3E+9	6.2E+7	5.0E+7	3.7E+7	2.8E+7	1.2E+7

*Note: 3.2E+06 is $3.2\ 10^6$

Table V.2.7
Estimated costs of actions

	CI	CP		CI	CP
A IL1 NADEC	0.00E+00	8.62E+05	B IL1 NADEC/NADEC	- not grainbans	
			B IL1 NADEC/ROTSL	- not grainbans	
A IL1 UPLOU	2.91E+04	8.62E+05	B IL1 UPLOU/NADEC	- not grainbans	
			B IL1 UPLOU/ROTSL	- not grainbans	
A IL1 DISPO	2.52E+06	8.62E+05	B IL1 DISPO/NADEC	- not grainbans	
			B IL1 DISPO/ROTSL	- not grainbans	
A IL1 STORE	2.71E+03	0.00E+00	B IL1 STORE/NADEC	- not applicable -	
			B IL1 STORE/ROTSL	- not applicable -	
A IL1 DILUT	- not applicable -		B IL1 DILUT/NADEC	- not grainbans	
			B IL1 DILUT/ROTSL	- not grainbans	
A IL2 NADEC	0.00E+00	1.13E+07	B IL2 NADEC/NADEC	0.00E+00	4.58E+06
			B IL2 NADEC/ROTSL	7.09E+08	3.03E+06
A IL2 UPLOU	3.82E+05	1.13E+07	B IL2 UPLOU/NADEC	1.02E+05	4.58E+06
			B IL2 UPLOU/ROTSL	7.09E+08	3.03E+06
A IL2 DISPO	3.31E+07	1.13E+07	B IL2 DISPO/NADEC	8.85E+06	4.58E+06
			B IL2 DISPO/ROTSL	7.10E+08	3.03E+06
A IL2 STORE	4.28E+04	0.00E+00	B IL2 STORE/NADEC	- not applicable-	
			B IL2 STORE/ROTSL	- not applicable-	
A IL2 DILUT	- not applicable -		B IL2 DILUT/NADEC	0.00E+00	1.55E+06
			B IL2 DILUT/ROTSL	7.09E+08	2.40E+06
A IL3 NADEC	0.00E+00	4.97E+07	B IL3 NADEC/NADEC	0.00E+00	2.93E+07
			B IL3 NADEC/ROTSL	3.44E+09	1.96E+07
A IL3 UPLOU	1.68E+06	4.97E+07	B IL3 UPLOU/NADEC	5.82E+05	2.93E+07
			B IL3 UPLOU/ROTSL	3.44E+09	1.96E+07
A IL3 DISPO	1.45E+08	4.97E+07	B IL3 DISPO/NADEC	5.05E+07	2.93E+07
			B IL3 DISPO/ROTSL	3.45E+09	1.96E+07
A IL3 STORE	2.43E+05	0.00E+00	B IL3 STORE/NADEC	- not applicable -	
			B IL3 STORE/ROTSL	- not applicable-	
A IL3 DILUT	- not applicable -		B IL3 DILUT/NADEC	0.00E+00	1.21E+07
			B IL3 DILUT/ROTSL	3.44E+09	1.64E+07
C IL1 NADEC	0.00E+00	7.65E+06	D IL1 NADEC/NADEC	0.00E+00	1.19E+08
			D IL1 NADEC/ROTSL	- not applicable -	
C IL1 UPLOU	2.58E+05	7.65E+06	D IL1 UPLOU/NADEC	4.03E+06	1.19E+08
			D IL1 UPLOU/ROTSL	- not applicable -	
C IL1 DISPO	2.23E+07	7.65E+06	D IL1 DISPO/NADEC	3.49E+08	1.19E+08
			D IL1 DISPO/ROTSL	- not applicable -	
C IL1 STORE	4.18E+05	0.00E+00	D IL1 STORE/NADEC	5.86E+06	0.00E+00
			D IL1 STORE/ROTSL	- not applicable -	
C IL1 DILUT	0.00E+00	0.00E+00	D IL1 DILUT/NADEC	0.00E+00	0.00E+00
			D IL1 DILUT/ROTSL	- not applicable -	
C IL2 NADEC	0.00E+00	2.12E+07	D IL2 NADEC/NADEC	0.00E+00	2.31E+08
			D IL2 NADEC/ROTSL	8.94E+08	2.28E+08
C IL2 UPLOU	7.16E+05	2.12E+07	D IL2 UPLOU/NADEC	7.70E+06	2.31E+08
			D IL2 UPLOU/ROTSL	9.01E+08	2.28E+08
C IL2 DISPO	6.21E+07	2.12E+07	D IL2 DISPO/NADEC	6.67E+08	2.31E+08
			D IL2 DISPO/ROTSL	1.55E+09	2.28E+08
C IL2 STORE	1.12E+06	0.00E+00	D IL2 STORE/NADEC	2.10E+07	5.26E+06
			D IL2 STORE/ROTSL	9.06E+08	3.03E+06
C IL2 DILUT	0.00E+00	0.00E+00	D IL2 DILUT/NADEC	0.00E+00	2.23E+06
			D IL2 DILUT/ROTSL	8.94E+08	3.03E+06
C IL3 NADEC	0.00E+00	1.19E+08	D IL3 NADEC/NADEC	0.00E+00	3.65E+08
			D IL3 NADEC/ROTSL	3.97E+09	3.54E+08
C IL3 UPLOU	4.03E+06	1.19E+08	D IL3 UPLOU/NADEC	1.18E+07	3.65E+08
			D IL3 UPLOU/ROTSL	3.98E+09	3.54E+08
C IL3 DISPO	3.49E+08	1.19E+08	D IL3 DISPO/NADEC	1.03E+09	3.65E+08
			D IL3 DISPO/ROTSL	4.95E+09	3.54E+08
C IL3 STORE	5.86E+06	0.00E+00	D IL3 STORE/NADEC	6.65E+07	2.98E+07
			D IL3 STORE/ROTSL	3.99E+09	1.94E+07
C IL3 DILUT	0.00E+00	0.00E+00	D IL3 DILUT/NADEC	0.00E+00	1.33E+07
			D IL3 DILUT/ROTSL	3.97E+09	1.94E+07

Table V.2.8
Collective committed dose equivalent saved

	CDS	FREFCD		CDS	FREFCD
A IL1 NADEC	7.88E+02	100.0%	B IL1 NADEC/NADEC	- not grainbans -	
			B IL1 NADEC/ROTSL	- not grainbans -	
A IL1 UPLOU	7.88E+02	100.0%	B IL1 UPLOU/NADEC	- not grainbans -	
			B IL1 UPLOU/ROTSL	- not grainbans -	
A IL1 DISPO	7.88E+02	100.0%	B IL1 DISPO/NADEC	- not grainbans -	
			B IL1 DISPO/ROTSL	- not grainbans -	
A IL1 STORE	6.66E+02	84.5%	B IL1 STORE/NADEC	- not applicable -	
			B IL1 STORE/ROTSL	- not applicable -	
A IL1 DILUT	- not applicable -		B IL1 DILUT/NADEC	- not grainbans -	
			B IL1 DILUT/ROTSL	- not grainbans -	
A IL2 NADEC	2.79E+03	100.0%	B IL2 NADEC/NADEC	2.51E+03	100.0%
			B IL2 NADEC/ROTSL	2.30E+03	91.7%
A IL2 UPLOU	2.79E+03	100.0%	B IL2 UPLOU/NADEC	2.51E+03	100.0%
			B IL2 UPLOU/ROTSL	2.30E+03	91.7%
A IL2 DISPO	2.79E+03	100.0%	B IL2 DISPO/NADEC	2.51E+03	100.0%
			B IL2 DISPO/ROTSL	2.30E+03	91.7%
A IL2 STORE	2.57E+03	92.2%	B IL2 STORE/NADEC	- not applicable -	
			B IL2 STORE/ROTSL	- not applicable -	
A IL2 DILUT	- not applicable -		B IL2 DILUT/NADEC	2.08E+03	82.8%
			B IL2 DILUT/ROTSL	2.26E+03	90.0%
A IL3 NADEC	3.74E+03	100.0%	B IL3 NADEC/NADEC	1.00E+04	100.0%
			B IL3 NADEC/ROTSL	9.70E+03	96.7%
A IL3 UPLOU	3.74E+03	100.0%	B IL3 UPLOU/NADEC	1.00E+04	100.0%
			B IL3 UPLOU/ROTSL	9.70E+03	96.7%
A IL3 DISPO	3.74E+03	100.0%	B IL3 DISPO/NADEC	1.00E+04	100.0%
			B IL3 DISPO/ROTSL	9.70E+03	96.7%
A IL3 STORE	3.64E+03	97.4%	B IL3 STORE/NADEC	- not applicable -	
			B IL3 STORE/ROTSL	- not applicable -	
A IL3 DILUT	- not applicable -		B IL3 DILUT/NADEC	9.29E+03	92.6%
			B IL3 DILUT/ROTSL	9.68E+03	96.5%
C IL1 NADEC/NADEC	1.75E+04	100.0%	D IL1 NADEC/NADEC	2.29E+06	100.0%
			D IL1 NADEC/ROTSL	- not applicable -	
C IL1 UPLOU/NADEC	1.75E+04	100.0%	D IL1 UPLOU/NADEC	2.29E+06	100.0%
			D IL1 UPLOU/ROTSL	- not applicable -	
C IL1 DISPO/NADEC	1.75E+04	100.0%	D IL1 DISPO/NADEC	2.29E+06	100.0%
			D IL1 DISPO/ROTSL	- not applicable -	
C IL1 STORE/NADEC	3.56E+03	20.3%	D IL1 STORE/NADEC	4.63E+05	20.2%
			D IL1 STORE/ROTSL	- not applicable -	
C IL1 DILUT/NADEC	0.00E+00	0.0%	D IL1 DILUT/NADEC	0.00E+00	0.0%
			D IL1 DILUT/ROTSL	- not applicable -	
C IL2 NADEC/NADEC	2.11E+04	100.0%	D IL2 NADEC/NADEC	2.34E+06	100.0%
			D IL2 NADEC/ROTSL	2.34E+06	100.0%
C IL2 UPLOU/NADEC	2.11E+04	100.0%	D IL2 UPLOU/NADEC	2.34E+06	100.0%
			D IL2 UPLOU/ROTSL	2.34E+06	100.0%
C IL2 DISPO/NADEC	2.11E+04	100.0%	D IL2 DISPO/NADEC	2.34E+06	100.0%
			D IL2 DISPO/ROTSL	2.34E+06	100.0%
C IL2 STORE/NADEC	4.28E+03	20.3%	D IL2 STORE/NADEC	1.45E+06	61.9%
			D IL2 STORE/ROTSL	1.45E+06	61.9%
C IL2 DILUT/NADEC	0.00E+00	0.0%	D IL2 DILUT/NADEC	2.46E+03	0.1%
			D IL2 DILUT/ROTSL	1.22E+06	52.2%
C IL3 NADEC/NADEC	2.29E+04	100.0%	D IL3 NADEC/NADEC	2.35E+06	100.0%
			D IL3 NADEC/ROTSL	2.35E+06	100.0%
C IL3 UPLOU/NADEC	2.29E+04	100.0%	D IL3 UPLOU/NADEC	2.35E+06	100.0%
			D IL3 UPLOU/ROTSL	2.35E+06	100.0%
C IL3 DISPO/NADEC	2.29E+04	100.0%	D IL3 DISPO/NADEC	2.35E+06	100.0%
			D IL3 DISPO/ROTSL	2.35E+06	100.0%
C IL3 STORE/NADEC	4.63E+03	20.3%	D IL3 STORE/NADEC	2.13E+06	90.5%
			D IL3 STORE/ROTSL	2.13E+06	90.5%
C IL3 DILUT/NADEC	0.00E+00	0.0%	D IL3 DILUT/NADEC	9.68E+03	0.4%
			D IL3 DILUT/ROTSL	2.07E+06	88.1%

Due to the long term nature of the contamination, only about 10% to 20% of the reference collective dose comes from the first year, the rest from the following years, so that the spread in the values for this attribute is not very wide.

V.2.4.3 Release Type C

Although the release contains caesium isotopes with radioactive half-lives greater than one year, there is not sufficient contamination of the soil to lead to food bans exceeding one year even with the lowest intervention level, so that the long term components of the action alternatives are superfluous. In contrast to release type A, however, the time dependence of the contamination and thus of the bans is governed by weathering processes rather than radioactive decay, making the ban times somewhat longer and dilution an additional possible action type in the first year.

Again, the intervention costs CI is the only attribute giving a clear distinction for all action alternatives and intervention levels. The values for CP show the same behaviour as for release type A; DILUT and STORE both score zero, because the affected produce is used for consumption after treatment.

With dilution, no collective dose is saved by definition. Storage saves somewhat less of the reference collective dose than for release type A because the collective dose is caused to a major part by Cs-134 and not by I-131. All other action types save 100% of the reference collective dose.

V.2.4.4 Release Type D

For this release, the maximum extent of the bans was artificially limited to 500 km. Although the distance for the cut is arbitrary, it was introduced to account for the fact that an optimization of countermeasures is only possible within a restricted area governed by the same political administration, e.g. one member state of the EC, and that the bans for a very large release may well exceed the area of optimization.

Apart from the highest intervention level, the distance limit is always exceeded. The ban duration is at least between three and six months, but only the ILs 2 and 3 lead to ban durations longer than one year and may require the long term action types. However, for both intervention levels, there is a small area where the contamination is so high that it cannot be reduced below the IL with ROTSL; in this residual area, natural decontamination is assumed. NADEC is also the only allowed first component of the action alternatives in all areas where the top soil layer is removed. In areas with ban durations greater than 1 year, disposal is assumed instead of storage for the action alternative STORE/NADEC.

The highest intervention level, IL1, leads to the same time dependence of the bans as release type C. Although the areas and the amount of produce affected are much larger, all results for IL1 of release type D show a similar behaviour than for type C and require no further explanations.

The intervention costs show a similar behaviour as for release type B with a dominant contribution from ROTSL where it is considered. The amount of produce for which storage does not lead to a reduction of the activity below the IL increases with decreasing intervention level, and for IL2, the costs for disposal of the untreatable part of the crops are about 60% of the storage costs, for IL3, however, the costs are more than twice as large, thus dominating the total intervention costs CI.

As for release type B, the costs due to the production losses seem to separate the action alternatives containing STORE or DILUT from those which do not. However, other than for release type B, the first year's costs are always dominant, so that the differences between actions containing ROTSL, saving the CP-components from the following years, and those which do not, almost vanish.

For the ILs 2 and 3, about 99% to 95% of the collective reference dose comes from the first year. Action alternatives containing the DILUT or STORE component save nothing or only some part of the first year's contribution they act on; all other action alternatives save the total reference collective dose.

For the ILs 2 and 3, one can generally observe that the differences in the results between the two intervention levels are less pronounced than for the other release types due to the distance cut.

V.2.5 Discussion of the Decision Analysis Results

V.2.5.1 Evaluation Matrix

According to the decision tree for the banning of grain described in Section V.2.3 (Figure V.2.2), the action alternatives are evaluated on the four physically quantifiable attributes: collective dose saved, individual dose, direct and indirect monetary costs; and on the two socio-political attributes "public reaction" and "international reaction". As was explained in Section V.2.3.3, for the latter attributes no physical quantities were identified which could serve as measures for the ranking, and the direct valuation technique was applied to assign preference values between 0 and 100 to the action alternatives (Table V.2.9). The values were derived by the authors by subjective judgement and are as follows:

a) Public reaction:

- "No action" as a reaction of the authorities to a foodstuff contamination will probably be considered as the worst of all possible actions so was assigned a value of zero on the preference scale.
- The lower the intervention level, the better the public opinion, because of risk aversion as a general behaviour in the case of non-self-made risks. Values of 20, 70 and 100 were assigned for IL1, IL2 and IL3.
- It seems reasonable to assume that actions which lead finally to the destruction of the affected foodstuffs will be preferred to those bringing the foodstuffs back to the market, and that storage, which actually reduces the collective dose, will be preferred to dilution, which does not. 10 to 20 points less were assigned for storage and dilution relative to the other actions.
- No distinction between natural decontamination, ploughing under and disposal, so all three actions are given the same preference values.

b) International reaction

- The intervention level in the EC regulation, IL2, is liked best by the neighbouring countries so has a value 100 on the preference scale.
- Intervention levels higher than IL2 will require the monitoring of imported foodstuffs, whereas intervention levels lower than IL2 will not, but might cause the population in the neighbouring countries to demand the same higher safety standard and lead to internal political problems. It was assumed that monitoring is considered worse, and "no action" again the least desirable alternative ie, values of 0 for NOACT, 20 for IL1 and 70 for IL3.

Table V.2.9
Preference values for socio-political aspects

	public	intern.		public	intern.
A NOACT	0	0	B NOACT	0	0
A IL1 NADEC	20	20	B IL1 NADEC/NADEC	- no grainbans -	
			B IL1 NADEC/ROTSL	- no grainbans -	
A IL1 UPLOU	20	20	B IL1 UPLOU/NADEC	- no grainbans -	
			B IL1 UPLOU/ROTSL	- no grainbans -	
A IL1 DISPO	20	20	B IL1 DISPO/NADEC	- no grainbans -	
			B IL1 DISPO/ROTSL	- no grainbans -	
A IL1 STORE	10	10	B IL1 STORE/NADEC	- not applicable -	
			B IL1 STORE/ROTSL	- not applicable -	
A IL1 DILUT	- not applicable -		B IL1 DILUT/NADEC	- no grainbans -	
			B IL1 DILUT/ROTSL	- no grainbans -	
A IL2 NADEC	70	100	B IL2 NADEC/NADEC	50	100
			B IL2 NADEC/ROTSL	50	100
A IL2 UPLOU	70	100	B IL2 UPLOU/NADEC	50	100
			B IL2 UPLOU/ROTSL	50	100
A IL2 DISPO	70	100	B IL2 DISPO/NADEC	50	100
			B IL2 DISPO/ROTSL	50	100
A IL2 STORE	50	80	B IL2 STORE/NADEC	- not applicable -	
			B IL2 STORE/ROTSL	- not applicable -	
A IL2 DILUT	- not applicable -		B IL2 DILUT/NADEC	30	80
			B IL2 DILUT/ROTSL	30	80
A IL3 NADEC	100	70	B IL3 NADEC/NADEC	100	50
			B IL3 NADEC/ROTSL	100	50
A IL3 UPLOU	100	70	B IL3 UPLOU/NADEC	100	50
			B IL3 UPLOU/ROTSL	100	50
A IL3 DISPO	100	70	B IL3 DISPO/NADEC	100	50
			B IL3 DISPO/ROTSL	100	50
A IL3 STORE	80	50	B IL3 STORE/NADEC	- not applicable -	
			B IL3 STORE/ROTSL	- not applicable -	
A IL3 DILUT	- not applicable -		B IL3 DILUT/NADEC	80	30
			B IL3 DILUT/ROTSL	80	30
C NOACT	0	0	D NOACT	0	0
C IL1 NADEC	20	20	D IL1 NADEC/NADEC	20	20
			D IL1 NADEC/ROTSL	- not applicable -	
C IL1 UPLOU	20	20	D IL1 UPLOU/NADEC	20	20
			D IL1 UPLOU/ROTSL	- not applicable -	
C IL1 DISPO	20	20	D IL1 DISPO/NADEC	20	20
			D IL1 DISPO/ROTSL	- not applicable -	
C IL1 STORE	0	10	D IL1 STORE/NADEC	10	10
			D IL1 STORE/ROTSL	- not applicable -	
C IL1 DILUT	0	0	D IL1 DILUT/NADEC	10	10
			D IL1 DILUT/ROTSL	- not applicable -	
C IL2 NADEC	70	100	D IL2 NADEC/NADEC	50	100
			D IL2 NADEC/ROTSL	50	100
C IL2 UPLOU	70	100	D IL2 UPLOU/NADEC	50	100
			D IL2 UPLOU/ROTSL	50	100
C IL2 DISPO	70	100	D IL2 DISPO/NADEC	50	100
			D IL2 DISPO/ROTSL	50	100
C IL2 STORE	50	80	D IL2 STORE/NADEC	30	80
			D IL2 STORE/ROTSL	30	80
C IL2 DILUT	30	80	D IL2 DILUT/NADEC	30	80
			D IL2 DILUT/ROTSL	30	80
C IL3 NADEC	100	70	D IL3 NADEC/NADEC	100	50
			D IL3 NADEC/ROTSL	100	50

Table V.2.9
Preference values for socio-political aspects

	public	intern.		public	intern.
C IL3 UPLOU	100	70	D IL3 UPLOU/NADEC	100	50
			D IL3 UPLOU/ROTSL	100	50
C IL3 DISPO	100	70	D IL3 DISPO/NADEC	100	50
			D IL3 DISPO/ROTSL	100	50
C IL3 STORE	70	50	D IL3 STORE/NADEC	80	30
			D IL3 STORE/ROTSL	80	30
C IL3 DILUT	50	50	D IL3 DILUT/NADEC	80	30
			D IL3 DILUT/ROTSL	80	30

- For the same reasons as for the public reaction, 10 to 20 points less for storage and dilution compared to the other actions, which were not distinguished between each other.

Only those action alternatives appear in the evaluation matrix, which have non-zero values in the physically quantifiable attributes. Intervention levels not leading to foodbans for the given action scenario (e.g. IL1 for release type B), were evaluated as "no action" under the socio-political aspects.

V.2.5.2 Value functions

For simplicity and because of lack of knowledge about decision makers preferences, linear value functions were assumed between the minimum and maximum values of each attribute. The slopes are positive (i.e. the highest values are the most preferred) for the collective dose saved and the socio-political aspects, and negative (i.e. the lowest values are the most preferred) for all other aspects.

V.2.5.3 Weights

As the base case, equal weights were applied, assuming a uniform importance of all attributes. To investigate the influence of changes in the weights for the health branch and the socio-political branch, sensitivity studies were performed by varying the relative weights for the collective dose saved and the theoretical maximum individual committed dose (TMID) between 0.0 and 1.0 while taking values of 0.33 and 0.0 as weights for the socio-political branch:

Figure V.2.3
Weights for the attributes

- Food-Bans on Grain
  - Health Effects 0.33 (0.5)
    - Collective Dose Saved — 0.5
    - Theoretical Maximum Committed Effective Dose — 0.5
  - Monetary Costs 0.33 (0.5)
    - Intervention Costs — 0.5
    - Production Including Capital Costs — 0.5
  - Socio-Political Aspects 0.33 (0.0)
    - Public Reaction — 0.5
    - International Reaction — 0.5

V.2.5.4 Ranking and Sensitivity Analyses

The ranking of the action alternatives after the weighted summation of all values is given in Table V.2.10 for the release types A - D and the base case weights. It is obvious that "no action" has the lowest rank for all release situations considered. The highest ranks are in general given to those actions initiated on the basis of the currently recommended intervention level IL2. Higher intervention levels are mostly ranked low.

For each intervention level, single action alternatives are difficult to distinguish, since the rank numbers differ only slightly. In general, natural decontamination, ploughing under and storage are more preferred than dilution, disposal and removal of top soil layer. These results are also valid, if the socio-political aspects get zero weight. This is mainly caused by the high variation in the economic costs for the actions described in the previous chapter.

To illustrate the influence of changes in the weights for the collective dose saved and TMID on the ranking, the results of the sensitivity analyses are shown in graphical form in Figure V.2.4 - V.2.7 for the base case and in Figure V.2.8 - V.2.11 without the socio-political branch.

The general tendency is that the higher the individual doses (quantified as TMID) are weighted, the more the currently recommended intervention level IL2 is preferred. On the other hand, higher weights for the collective dose saved lead to a ranking where action alternatives with the lower intervention level become dominant, because, in general, these will save more collective dose. This tendency is also observed if the socio-political branch is neglected entirely, although the latter strengthens this trend due to the higher preferences assigned to alternatives with the lower IL.

The conclusions drawn from the decision analyses should be regarded as typical results which can be obtained with RADE-AID and not as qualitative or quantitative predictions for the scenarios considered. This would require sound value functions and weights broadly agreed on by people involved in decision-making on nuclear emergency actions which are not available at this stage. However, they clearly demonstrate the usefulness of the RADE-AID methodology to structure the decision problem, to identify relevant attributes and to show the influence of the decision-makers preferences on the decisions finally made.

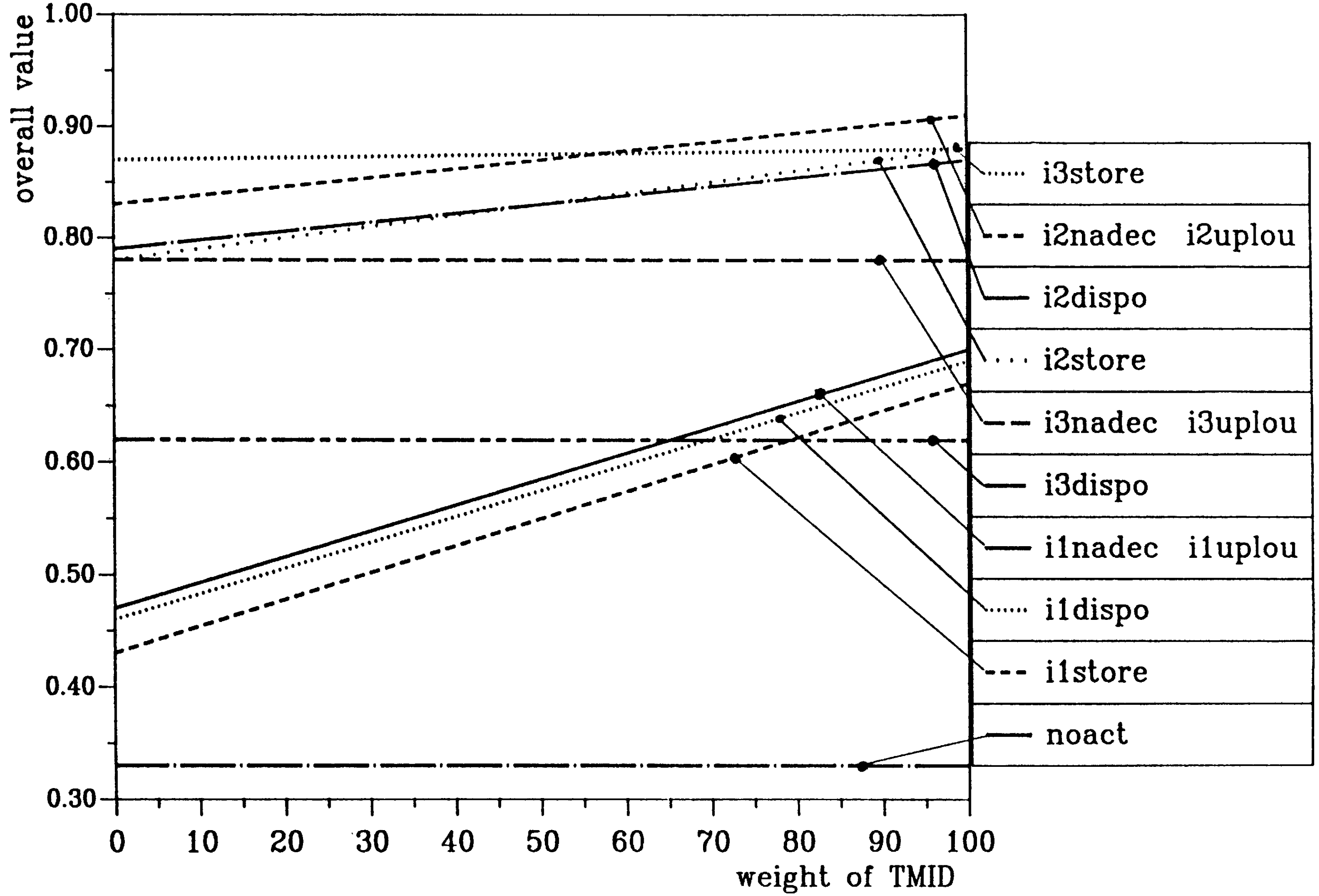


Figure V.2.4: Sensitivity analysis for release type GRAINA - base case

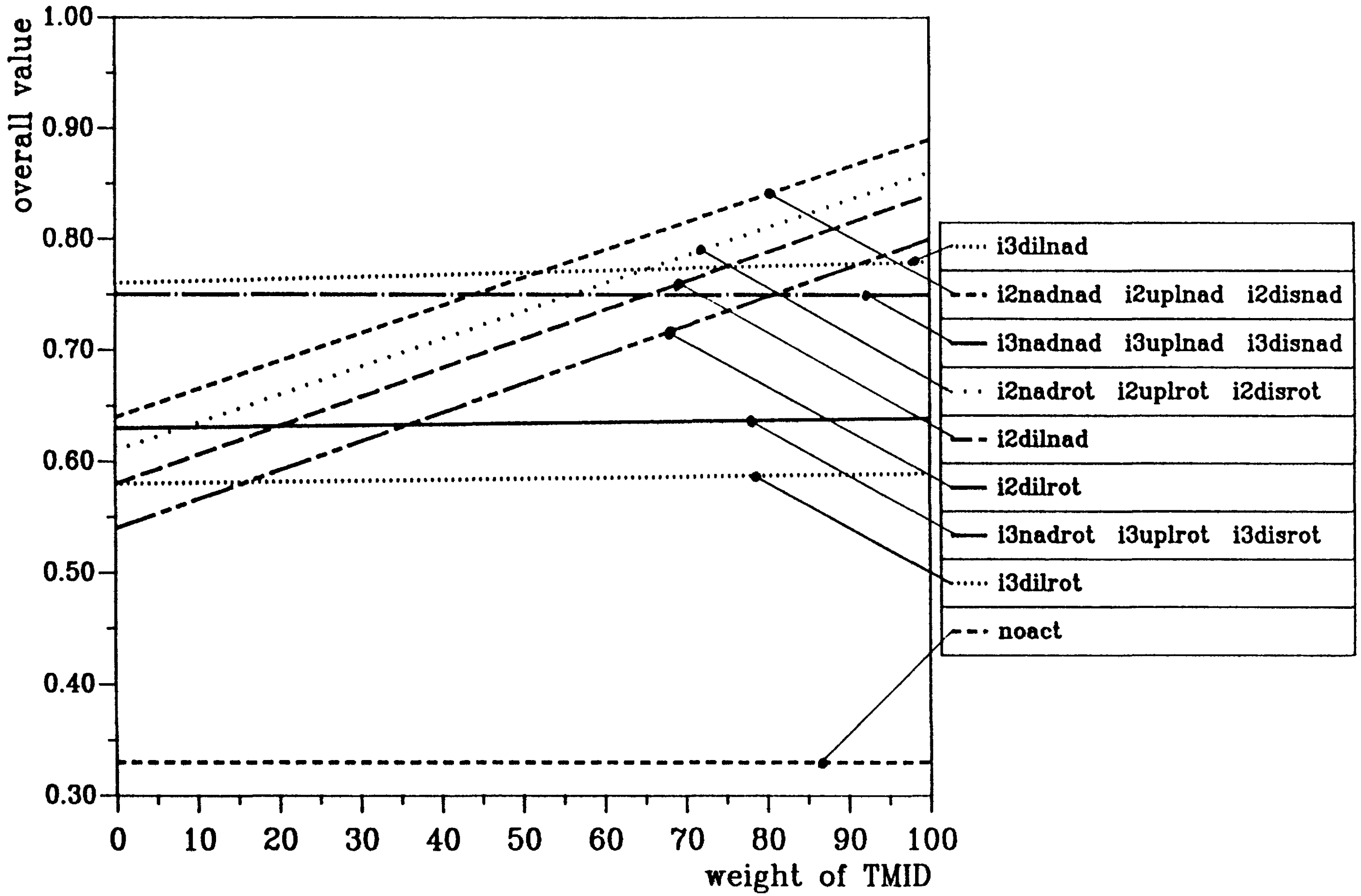


Figure V.2.5: Sensitivity analysis for release type GRAINB - base case

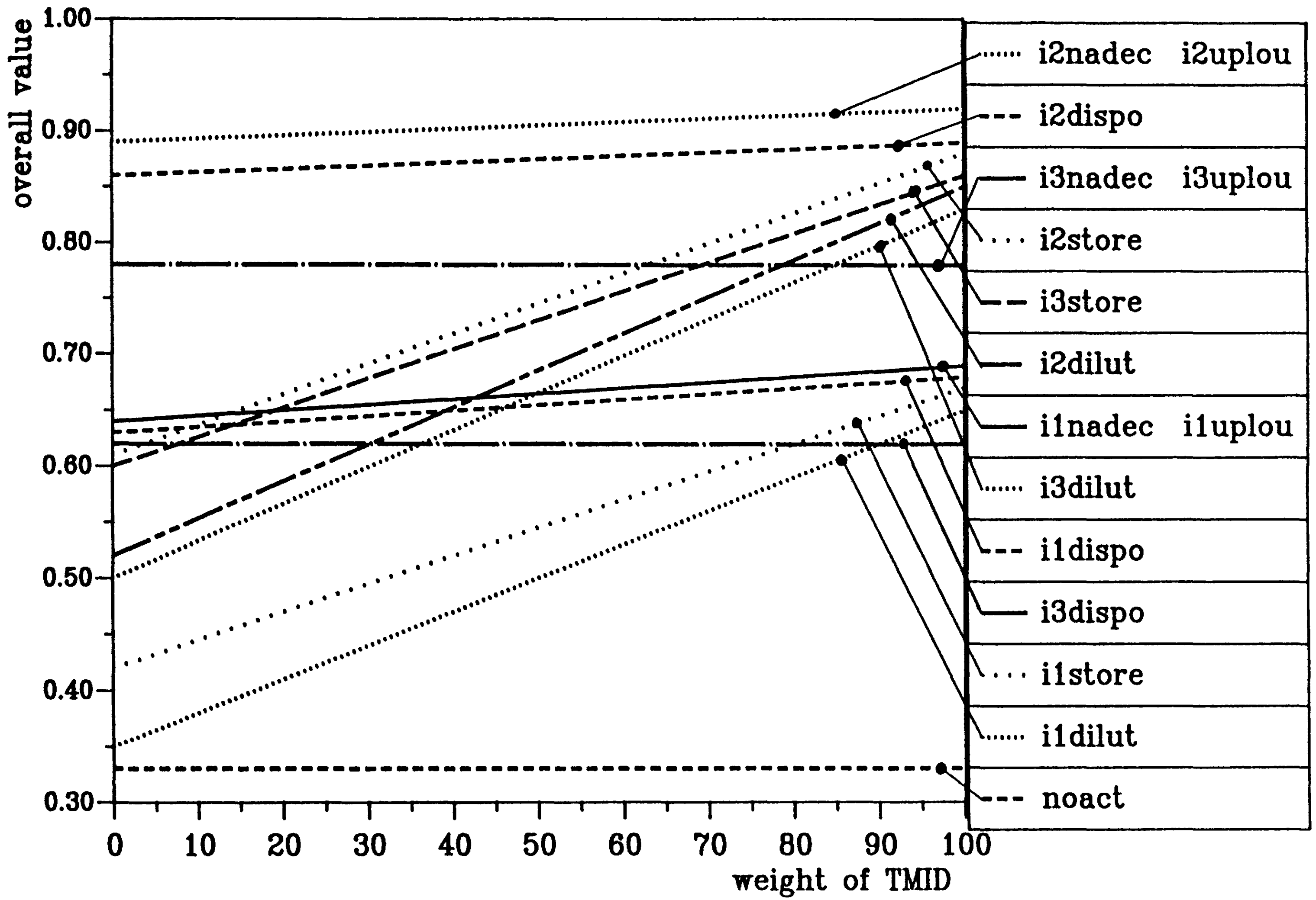


Figure V.2.6: Sensitivity analysis for release type GRAINC - base case

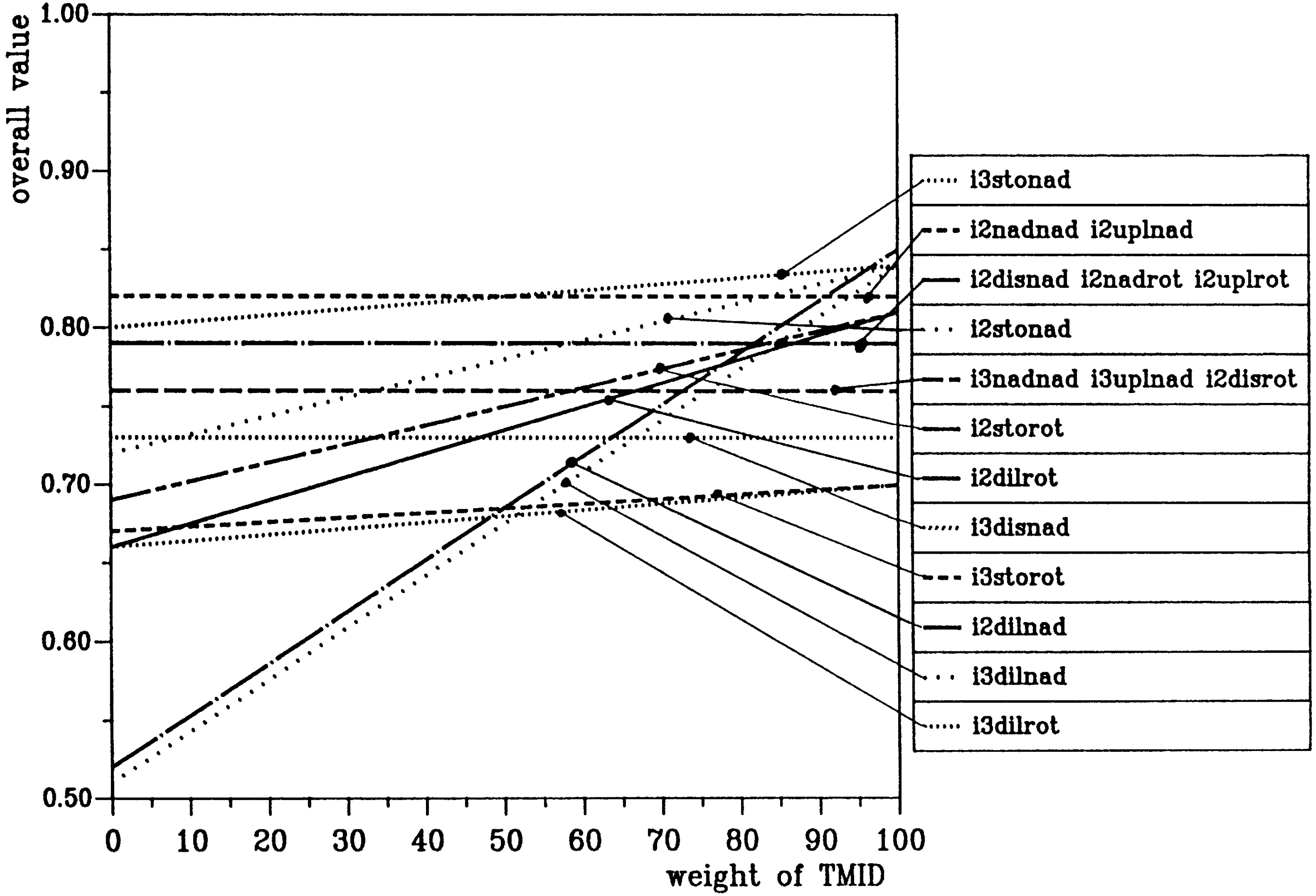


Figure V.2.7: Sensitivity analysis for release type GRAIND - base case

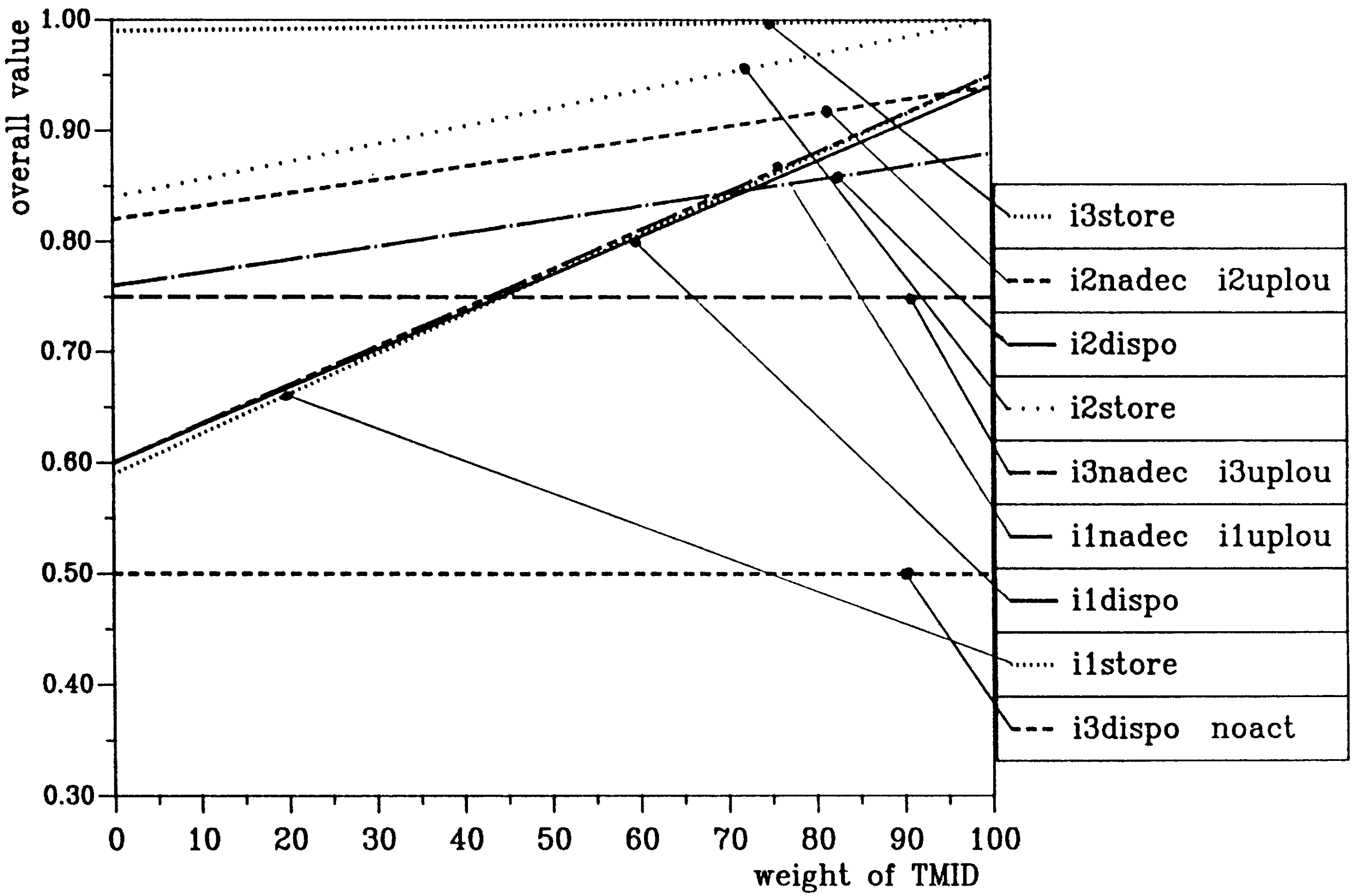


Figure V.2.8: Sensitivity analysis for release type GRAINA without socio-political aspects

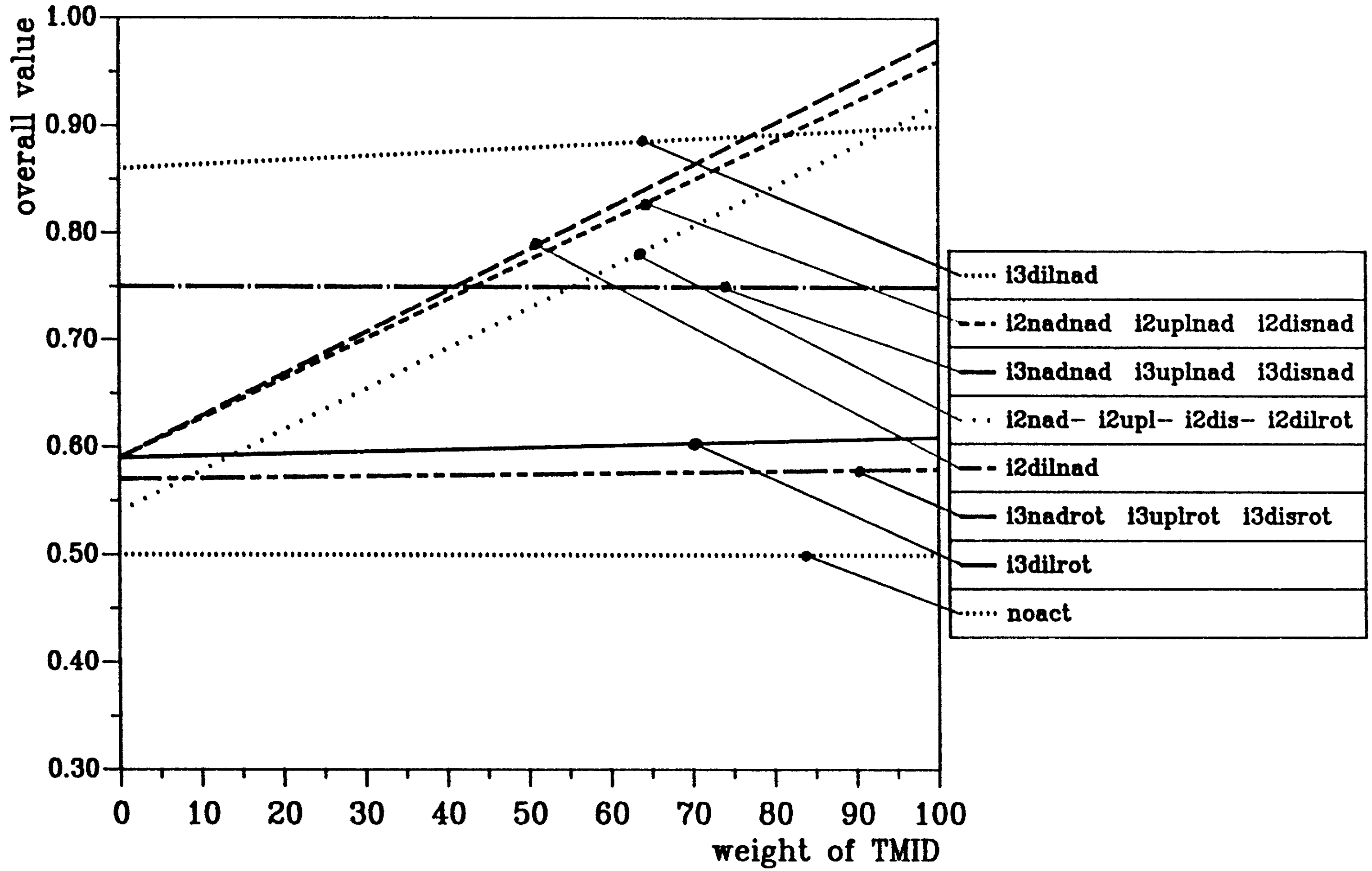


Figure V.2.9: Sensitivity analysis for release type GRAINB without socio-political aspects

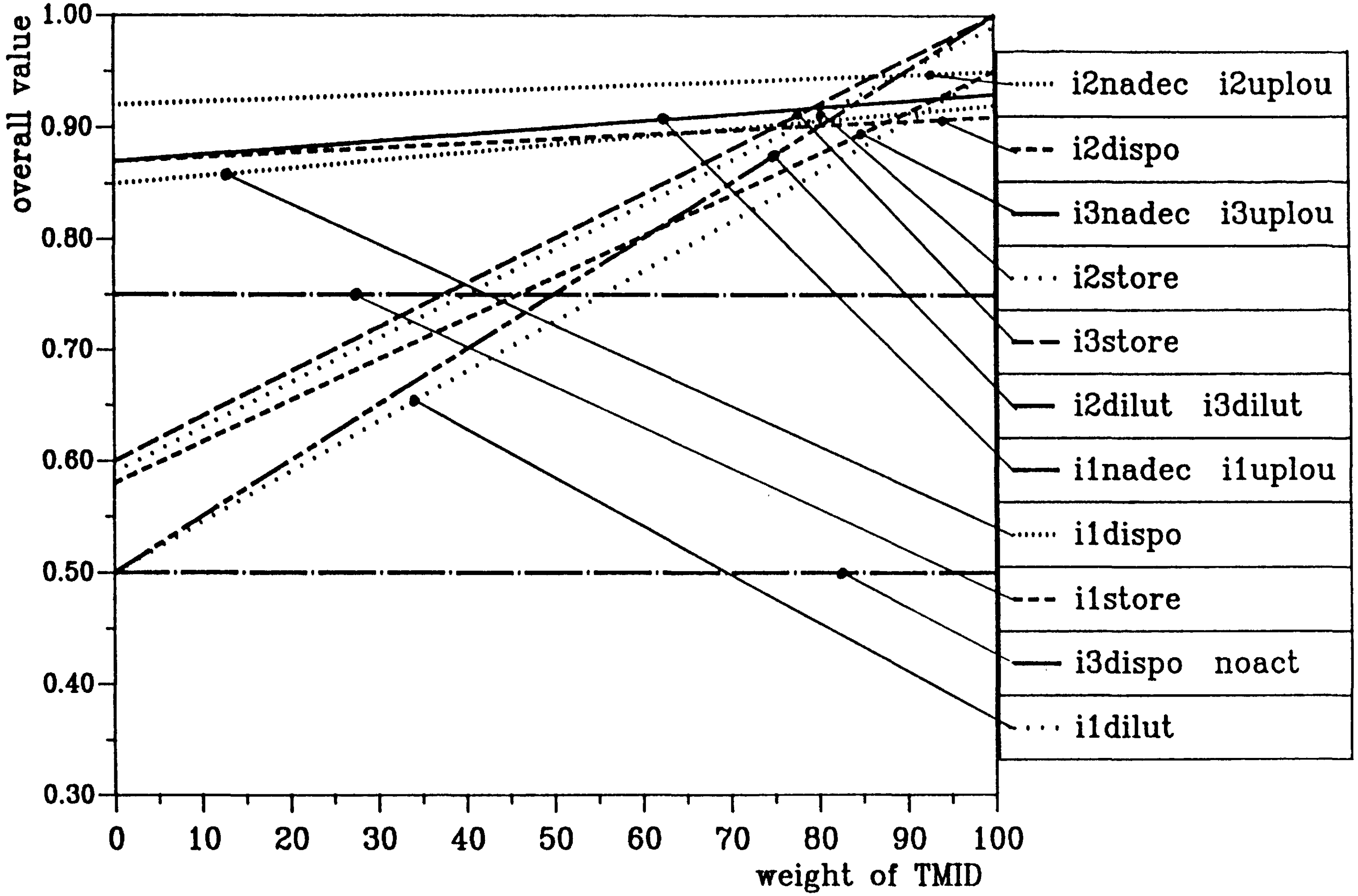


Figure V.2.10: Sensitivity analysis for release type GRAINC without socio-political aspects

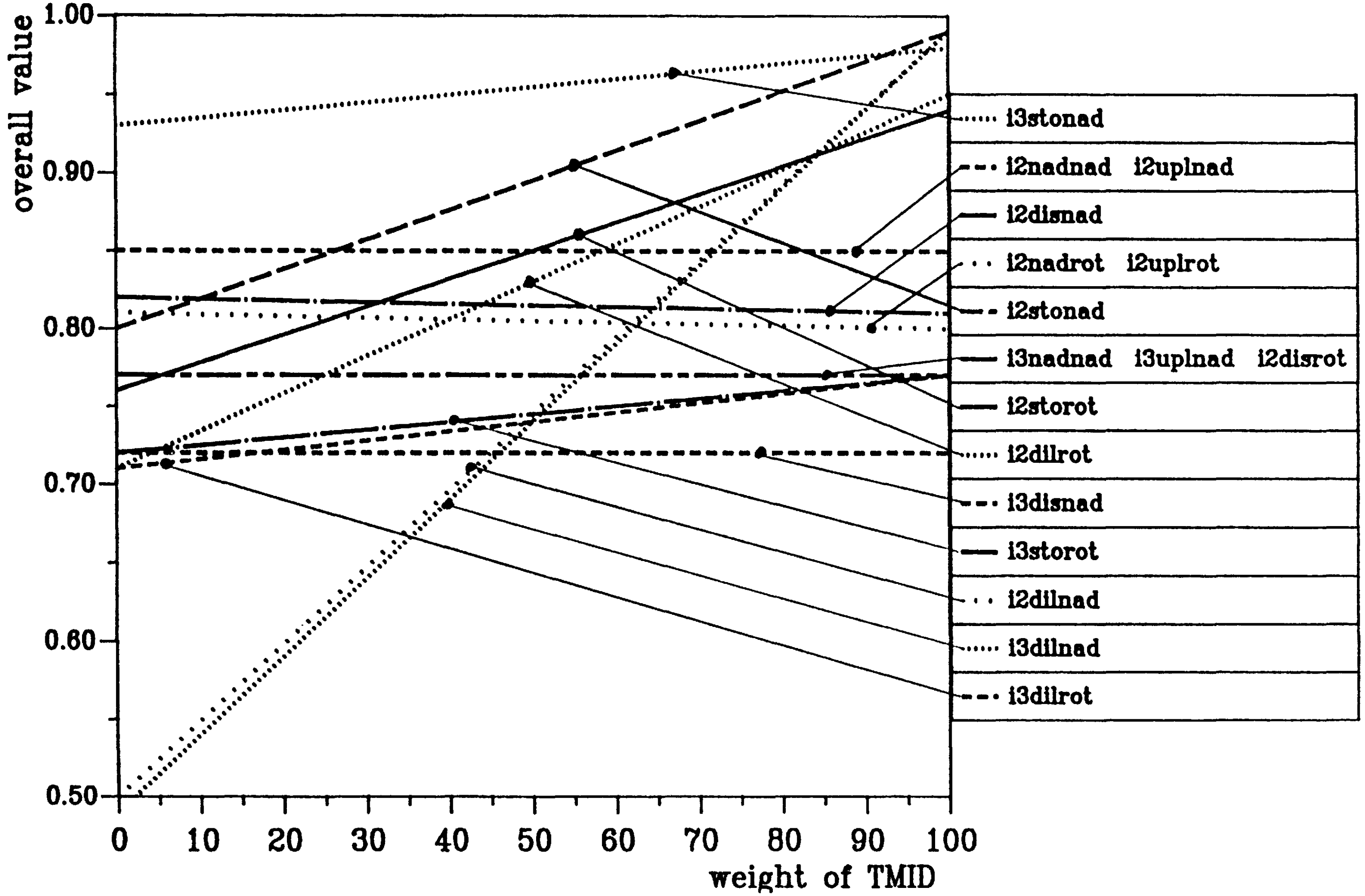


Figure V.2.11: Sensitivity analysis for release type GRAIND without socio-political aspects

Table V.2.10
Ranking of action alternatives

Release type A		Release type B	
IL3 STORE	0.88	IL3 DILUT/NADEC	0.77
IL2 NADEC	0.87	IL2 NADEC/NADEC	0.76
IL2 UPLOU	0.87	IL2 UPLOU/NADEC	0.76
IL2 DISPO	0.83	IL2 DISPO/NADEC	0.76
IL2 STORE	0.83	IL3 NADEC/NADEC	0.75
IL3 NADEC	0.78	IL3 UPLOU/NADEC	0.75
IL3 UPLOU	0.78	IL3 DISPO/NADEC	0.75
IL3 DISPO	0.62	IL2 NADEC/ROTSL	0.74
IL1 NADEC	0.58	IL2 UPLOU/ROTSL	0.74
IL1 UPLOU	0.58	IL2 DISPO/ROTSL	0.74
IL1 DISPO	0.58	IL2 DILUT/NADEC	0.71
IL1 STORE	0.55	IL2 DILUT/ROTSL	0.67
NOACT	0.33	IL3 NADEC/ROTSL	0.63
IL3 ULPOU/ROTSL	0.63		
IL3 DISPO/ROTSL	0.63		
IL3 DILUT/ROTSL	0.58		
NOACT	0.33		

Release type C		Release type D	
IL2 NADEC	0.91	IL3 STORE/NADEC	0.82
IL2 UPLOU	0.91	IL2 NADEC/NADEC	0.82
IL2 DISPO	0.88	IL2 UPLOU/NADEC	0.82
IL3 NADEC	0.78	IL2 DISPO/NADEC	0.79
IL3 UPLOU	0.78	IL2 NADEC/ROTSL	0.79
IL2 STORE	0.75	IL2 UPLOU/ROTSL	0.79
IL3 STORE	0.73	IL2 STORE/NADEC	0.78
IL2 DILUT	0.68	IL3 NADEC/NADEC	0.76
IL1 NADEC	0.67	IL3 UPLOU/NADEC	0.76
IL1 UPLOU	0.67	IL2 DISPO/ROTSL	0.76
IL3 DILUT	0.67	IL2 STORE/ROTSL	0.75
IL1 DISPO	0.66	IL2 DILUT/ROTSL	0.73
IL3 DISPO	0.62	IL3 DISPO/NADEC	0.73
IL1 STORE	0.54	IL3 STORE/ROTSL	0.68
IL1 DILUT	0.50	IL2 DILUT/NADEC	0.68
NOACT	0.33	IL3 DILUT/NADEC	0.68
IL3 DILUT/ROTSL	0.68		
IL1 NADEC/NADEC	0.66		
IL1 UPLOU/NADEC	0.66		
IL1 DISPO/NADEC	0.65		
IL3 NADEC/ROTSL	0.63		
IL3 UPLOU/ROTSL	0.62		
IL3 DISPO/ROTSL	0.59		
IL1 STORE/NADEC	0.55		
IL1 DILUT/NADEC	0.52		
		NOACT	0.33

V.3 Discussion

The illustrative applications demonstrated that RADE-AID can form a useful tool in the determination of decisions on countermeasures. A number of aspects of its usefulness were highlighted, and these are discussed below.

The structuring of the problems in terms of the decision hierarchies and the identification of factors relevant to the decision helped in the thorough exploration of the problem and an explicit consideration of which were the key objectives. This meant that when the consequences of taking various actions were presented, their significance was more readily appreciated and quantified.

The explicit consideration of all types of consequences and the presentation of information relating to them provided useful insights into the decision problem. For example, consequences which might generally be considered important might be shown to be unimportant for a particular accident scenario, or consequences could be identified as being a potentially very significant factor in the decision.

The explicit assigning of weights and values also deepened understanding of the decision problem. It encouraged thorough consideration of each of the attributes and their relative importance. It also required the user to properly assimilate the information provided by the consequence predictions, so that meaningful values and weights could be assigned. Thus, this step, again, encouraged deeper insights into the decision problem, and therefore, into the best solutions.

The overall ranking of the countermeasures options, by the system, in terms of the expressed preferences of the user, were helpful in two respects. First, they often clearly indicated countermeasures options which could be excluded from further consideration (ie those at the bottom of the ranking order). Second, they triggered re-evaluation of those options which were ranked towards the top of the ordering. This was particularly important in cases where the initial ranking appeared to be counter-intuitive. In this case, re-examination of the problem and the weights and values assigned would reveal the reasons for this ordering. It was then possible to decide whether the inputs required changing, or whether, in fact, the overall ranking did, indeed, reflect the relative merits of the options.

The facilities for exploring the sensitivity of the ranking to the assigned weights were found to be particularly helpful. Using these displays, it could be clearly seen which inputs were dominating the ranking, and those to which the overall ranking was most sensitive. Where the ranking was sensitive to a particular value, the accuracy of the prediction leading to the assignment of that value could be assessed and conclusions reached concerning the robustness of the evaluation. Similarly, where the ranking was sensitive to the magnitude of a particular weight, the degree of belief in that weight could be assessed and conclusions drawn. Equally, the sensitivity analyses could be used to show the range of possible rankings which might reasonably be achieved by varying the values and weights within what were judged to be reasonable bounds. In this way, options could be identified which would never be optimum, and also the range of options which could be reasonably justified could be seen.

VI. CONCLUSIONS

The choice of the appropriate type and level of intervention aimed at mitigating the radiation exposure of the population after radioactive contamination of the environment requires a balance to be achieved between a variety of competing objectives, whose magnitudes may vary with the accident characteristics and whose relative importance may be sensitive to political and social value judgements. The radiological decision-aiding system, RADE-AID, uses decision analysis techniques to compare and rank different intervention strategies considering both directly quantifiable factors and also factors of a socio-political nature. By interacting directly with the user, RADE-AID can help the decision-maker to explore the consequences of and reasons for his decisions. It should be emphasised that RADE-AID is not intended to replace the role and judgement of the decision-maker. It is intended as a decision-aiding tool, not a decision-making machine. Given a decision problem with competing objectives, a decision-maker must necessarily assess the consequences of various alternatives and value them according to a set of objectives. This process may be achieved intuitively or explicitly. The advantage of performing the analysis explicitly, using formal techniques is that the process is clearly structured and it is less likely that important factors are overlooked. Moreover, by indicating which aspects of the problem are crucial to the decision and which are not, resources can be channelled more optimally, in terms of obtaining the information necessary for formulating the decision.

One of the important features of the RADE-AID system is that it enables trade-offs between the benefits and harmful consequences of taking different courses of action to be explicitly addressed and explored. These trade-offs are based on the judgement of the decision-maker. They depend on the decision-maker's assessment of the relative desirability of taking each action, with respect to their consequences, and on the relative importance he attaches to each type of consequence. Trade-offs are personal; there can be no objective or universal rules for making them. However, techniques have been developed within the framework of decision analysis for combining the judgements of a group decision-makers, or even the general population, if this is considered desirable.

A prototype version of RADE-AID has been developed, which is available to interested institutions on a research basis. In this phase of the project, emphasis has been placed on development of an appropriate decision logic and procedures for eliciting value judgements and weights from the user. Subsequent development will include enhanced facilities for presentation of supporting information.

In order to explore the appropriateness of the RADE-AID decision logic, some highly stylised applications have been developed. These consider the implementation of relocation (with or without decontamination) to reduce external exposure and the imposition of food bans to reduce internal exposure. These demonstrated that use of RADE-AID can help the user to gain more and deeper insights into the decision problem, and so help him determine the appropriate course of action more clearly. Equally, areas where improvements in the system would be beneficial were highlighted. These were generally aspects of the system which had been previously identified for development in the next phase of the project.

Future work will concentrate on the presentation of supporting data and extensions to the decision logic and sensivity analysis functions. However, the most important aspect of future work will be to discuss the application of RADE-AID with decision-makers. If RADE-AID is to be of assistance to decision-makers then it is important that its further development should be carried out in conjunction with them. In this way, features of the system can be tailored to their requirements and guidance on objective hierarchies can be provided to support their valuations of the decision problem.

VII. REFERENCES

[1] Winterfeldt, D, von, Edwards, W, Decision Analysis and Behavioral Research, Cambridge University Press, 1986

[2] Otway, H J, Ewards, W, Application of a simple multi-attribute rating technique to evaluation of nuclear waste disposal sites: a demonstration. Research memorandum RM-77-31, International Institute for Applied Systems Analysis 2361 Laxenburg, Austria, June 1977,

[3] Belton, V, A comparison of the Analytical Hierarchy Process and a simple Multi-Attribute Value function, European Journal of Operational Research 26 7-21, 1986

[4] Wijnmalen, D J D, van, Steen, J F J, van, Herpers, H J, Stolk, D J, Ontwikkeling van een meerdimensionaal besluitvormingsmodel met betrekking tot risicodragende activiteiten. Interimrapport: Inventarisaties en evaluaties m.b.t. besluitvormingssituaties en methoden TNO-report FEL-1986-05 (in Dutch)

[5] Wijnmalen, D J D, Hontelez, J A M, Ontwikkeling van een meerdimensionaal besluitvormingsmodel met betrekking tot risicodragende activiteiten TNO-report FEL-1987-07 (in Dutch)

[6] Bodily, S E, Modern Decision Making McGraw-Hill (1985)

[7] Phantumvanit, D, Nandhabiwat, W, The Nam Choan Controversy: an Environmental Impact Assessment in Practice Environ Impact Assess Rev 1989;9:135-147

[8] Watson, S R, Decision analysis as a replacement for cost/benefit analysis European Journal of Operational Research 7 (1981), 242-248

[9] Saati, T L, The Analytic Hierarchy Process, planning, priority setting, resource allocation, McGraw-Hill, INc. (1980)

Expert Choice "Walk Through" (Trial Version); Decision Support Software, Inc., 1300 Vincent Place, McLean, Virginia 22101, U.S.A.

[10] Merkhofer, M W, Keeney, R L, A Multiattribute Utility Analysis of Alternative Sites for the Disposal of Nuclear Waste Risk Analysis, vol 7., no 2, 1987

[11] ICRP Publication 55, Optimization and Decision-making in Radiological Protection Annals of the ICRP 20, No. 1, (1989)

[12] Hogarth Robin, Judgement and Choice, second edition, John Wiley & Sons (1987)

[13] (University of London), A brief description of Hiview and Equity, Decision Analysis Unit, The London School of Economics and Political Science

[14] Edwards, W, How to use Multiattribute Utility Measurement for Social Decision making IEEE Transactions on systems, man and cybernetics, vol. SMC-7, no. 5, May 1977

[15] Fishburn, P C, Methods of estimating additive utilities Management Science, Vol. 13, No 7, March, 1967

[16] Belton, V, Vickers, S, Use of a simple multi-attribute value function incorporating Visual Interactive Sensitivity Analysis for Multiple Criteria Decision Aid. Paper presented at the Third International Summer School on Multiple Criteria Decision Aid, Lisbon, July 1988

Demonstration version of VISA; SPV Software products, 12 Sandhurst Close, Canterbury, Kent CT2 7QS, England

[17] Jacquet-Lagreze, E, Siskos, J, Assessing a set of additive utility functions for multicriteria decision- making, the UTA method European Journal of Operational Research 10 (1982), 151-164 PREFCALC, version 3.0; Euro-Decision, BP 57, 78530 BUC, France

[18] Stabell, C B, Decision Support Systems: Alternative Perspectives and School Decision Support Systems 3 (1987), 243-251

[19] C-Worthy Interface Library Reference Guide, Custom Design Systems, Inc., 1985-1988.

[20] CEC, Proceedings of Seminar on Methods for Assessing the Off-site consequences of Nuclear Accidents, Athens, May 7-11 1990, to be published.

[21] J. EHRHARDT et al.. The program system UFOMOD for assesssing the consequences of nuclear accidents. Karlsruhe, KfK-4330 (1988).

[22] J.M. HOWORTH and F.J. SANDALLS. Decontamination and reclamation of agricultural land following a nuclear accident. A literature review. Harwell, AERE-R-12666 (1987).

[23] CEC, Council Regulation (Euratom) No. 3954/87 laying down maximum permitted levels of radioactive contamination of foodstuffs and of feedingstuffs following a nuclear accident or any other case of radiological emergency.

[24] F. van DORP, R. ELEVELD, M.J. FRISSEL. Agricultural measures to reduce radiation doses to man caused by severe nuclear accidents. Brussels, Luxembourg, Report EUR 7370 EN (1981).

[25] Faude, D, Haywood, S M, and Robinson, C A, The Modelling of Economic Consequences in COSYMA. Proceedings of Seminar on Methods for Assessing the Off-site Consequences of Nuclear Accidents, Athens, May 7-11 1990, to be published.

[26] Haywood, S M, Robinson, C A, and Fande, D, Developments in Modelling the Economic Impact of Off-Site Accident Consequences. Proc Sem on Methods for Assessing the Off-site Consequences of Nuclear Accidents, Athens, May 7-11 1990, to be published.

ANNEX A

A BRIEF INTRODUCTION TO UTILITY

Before the coming of the multi-attribute value techniques Von Neuman and Morgenstern developed a theory about the utility of gambles, whose basic principles are described here.

Consider two alternative options a_1 and a_2:

a_1: a certain amount of money m,
a_2: an amount of money M_1 with probability (1-p) or
an amount of money M_2 with probability p.
(NB: $M_1 < m < M_2$)

The utility of alternative a_1 is: $U[a_1] = U(m)$;
the utility of alternative a_2 is: $U[a_2] = (1 - p) \cdot U(M_1) + p \cdot U(M_2)$.

There will be one probability p* such that the utilities of the two options are equal:

$$U(m) = (1 - p^*) \cdot U(M_1) + p^* \cdot U(M_2)$$

The utility is defined on a interval scale and so it is possible to choose arbitrarily:

$$U(M_1) = 0 \text{ and } U(M_2) = 1$$

This means that:

$$U(m) = p^*$$

The quantity "utility" is not generated in a some way but is in fact a input by the decision-maker: when the choice of indifference at probability p*, given m, is made.

For most people the utility function U(m) with $M_2 < m < M_2$ is not a linear function and its trend depends among others things whether you are risk seeking or risk averse.

Example:

A player is confronted with several choices concerning a certain amount of money m and gamble to receive f10,000.- with a probability p. The results are listed in the table.

m	U(m) = p*
0.-	0
2,000.-	0.35
4,000.-	0.65
6,000.-	0.85
8,000.-	0.95
10,000.-	1.00

This means for instance that the player judges a gamble with 35% probability of receiving f10,000.- as worthy as receiving f2,000.- for sure. An interesting remark is that the expecting outcome of this gamble is f3,500.-; this player is obviously risk averse.

By drawing a smooth curve through the points (U(m),m) the utility function can be approximated by a polynomial.

This utility function can be used to compare uncertain outcomes or gambles. For example: does the player prefer gamble A with a 25% probability receiving f6,000.- above gamble B with a 75% probability receiving f2,000.-?

U(f6,000.-) = 0.85   A: expected utility = 25% * 0.85 = 0.2125

U(f2,000.-) = 0.35   B: expected utility = 75% * 0.35 = 0.2625

This player would prefer gamble B.

ANNEX B

EXAMPLES OF TRANSFORMATION OF RANKS INTO WEIGHTS

According to the rank reciprocal rule the weight for attribute i (W_i) is calculated as follows:

$$W_i = \frac{1/R_i}{\sum_{j=1}^{n} 1/R_j} \quad \text{with } R_i,\ R_j = 1,2,3,\ldots,n$$

Example 1:

$$n = 4{:}\quad R_a = 1,\ R_d = 2,\ R_c = 3,\ R_d = 4$$

$$S := \sum_{j=1}^{n} 1/R_j = 1/1 + 1/2 + 1/3 + 1/4 = 25/12$$

$$W_a = 1/S = 0.48,$$
$$W_b = (1/2)/S = 0.24,$$
$$W_c = (1/3)/S = 0.16,$$
$$W_d = (1/4)/S = 0.12$$

In the rank sum weighing procedure, weights are estimated from:

$$W_i = \frac{(n+1-R_i)}{\sum_{j=1}^{n} R_i} \quad \text{with } R_i,\ R_j = 1,2,3,\ldots,n$$

Example 2:

$$n = 4{:}\quad R_a = 1,\ R_b = 2,\ R_c = 3,\ R_d = 4$$

$$S := \sum_{j}^{n} R_j = 1 + 2 + 3 + 4 = 10$$

$$W_a = 4/S = 0.40,$$
$$W_b = 3/S = 0.30,$$
$$W_c = 2/S = 0.20,$$
$$W_d = 1/S = 0.10$$

Rank exponent weights were developed to take into account the decision-maker's judgements about the dispersion of weights.

$$W_i = \frac{(n + 1 - R_1)^z}{\sum_{j=1}^{n} R_j^{\,z}} \quad \text{with } R_i,\ R_j = 1,2,3,\ldots,n$$

The exponent z could be estimated for some convenient pair of attributes, for example the most and least important; only one judgement between a ratio of weights factors is required:

$$z = \frac{\log (W_i / W_j)}{\log ((n + 1 - R_i) / (n + 1 - R_j))}$$

The exponent z can also be estimated for a simple estimate of a weight factor given its rank number, by using the equation for W_i.

Example 3:

$n = 4$ & $z = 2$: $R_a = 1$, $R_b = 2$, $R_c = 3$, $R_d = 4$

$$S := \sum_{j=1}^{n} R_j^{\,2} = 1 + 4 + 9 + 16 = 30$$

$W_a = 4^2/S = 0.53$,
$W_b = 3^2/S = 0.30$,
$W_c = 2^2/S = 0.13$,
$W_d = 1^2/S = 0.03$

ANNEX C

SWING WEIGHTS

The process of swing weights establishes in a fairly natural way, the rank order of the weights, since it rank orders the terms:

$$V(E_1^-, E_2^-, \ldots, E_i^+, \ldots, E_n^-) - V(E_1^-, E_2^-, \ldots, E_i^-, \ldots, E_n^-) = W_i$$

While: $V(E_i^-) = 0$

$$V(E_i^+) = 1$$

$$V(E_1^-, E_2^-, \ldots, E_i^-, \ldots, E_n^-) = \sum_i W_i \cdot V(E_i^-) = 0$$

$$V(E_1^-, E_2^-, \ldots, E_i^+, \ldots, E_n^-) = \sum_{i \leftrightarrow j} W_i \cdot V(E_i^-) + W_i = W_i$$

ANNEX D

CROSS-ATTRIBUTE INDIFFERENCE METHOD

Consider the relative strength of preference between $A(E_i^+,E_j^-)$ and $O(E_i^-,E_j^-)$ and compare this with the relative strength of preference between $B(E_d^-,E_j^+)$ and $O(E_i^-,E_j^-)$: is it greater, equal or smaller(?):

$$V(A[E_i^+,E_j^-]) - V(O[E_i^-,E_j^-]) \gtreqless V(B[E_i^-,E_j^+]) - V(O[E_i^-,E_j^-])$$

This expression is identical to: $W_i \gtreqless W_j$,

While: $V(A) = W_i \cdot V_i(E_i^+) + W_j \cdot V_j(E_j^-) = W_i \cdot 1 + W_j \cdot 0 = W_i$

$V(O) = W_i \cdot V_i(E_1^-) + W_j \cdot V_j(E_j^-) = W_i \cdot 0 + W_j \cdot 0 = 0$

$\rightarrow V(A) - V(O) = W_i - 0 = W_i$, and analog:
$\rightarrow V(B) - V(O) = W_j - 0 = W_j$

To determine how much larger W_i is then W_j, the effect score E_i^+ is reduced to some intermediate level E_i' several times until the indifference judgements has been made:

$$V(C[E_i', E_j^-]) - V(O[E_i^-,E_j^-]) \approx V(B[E_i^-,E_j^+]) - V(O[E_i^-,E_j^-])$$

This implies that: $W_i \cdot V(E_i') \approx W_j$,

and thus: $\frac{W_j}{W_i} = V(E_i')$

While: $V(C) = W_i \cdot V_i(E_i') + W_j \cdot V_j(E_j^-) = W_i \cdot V_i(E_i') + W_j \cdot 0$

$= W_i \cdot V_i(E_i')$

$V(O) = W_i \cdot V_i(E_i^-) + W_j \cdot V_j(E_j^-) = W_i \cdot 0 + W_j \cdot 0 = 0$

$\rightarrow V(C) - V(O) = W_i \cdot V\ (E\ ') - 0 = W_i \cdot V_i(E_i')$, and analog:

$\rightarrow V(B) - V(O) = W_j - 0 = W_j$

Example:

Consider you want to buy a car, and you think the relevant attributes are cost and comfort. The acceptable range for cost has been estimated: \$ 20,000 - \$ 22,000. The acceptable range for comfort has four categories: fair, indifferent, good and excellent, whose values are equally spaced: 0, 1/3, 2/3, 1.

In general you think that cost is much more important than comfort. However, in this case you feel that the relative strength of preference between combinations A and O is greater than the relative strength of preference between the combinations B and O.

$$V(A[\text{excellent}, \$22{,}000) - V(O[\text{fair}, \$22{,}000) >$$
$$V(B[\text{fair}, \$20{,}000) - V(O[\text{fair}, \$22{,}000)$$

This means obviously that given the set of alternative cars, the weight on comfort is larger than on cost.

After some extra examinations you feel that the relative strength of preference between combinations C and O is comparable with the relative strength of preference between the combinations B and O:

$$V(C[\text{good}, \$22{,}000) - V(O[\text{fair}, \$22{,}000) \approx$$
$$V(B[\text{fair}, \$20{,}000) - V(O[\text{fair}, \$22{,}000).$$

This means that:

$$\begin{aligned} W_{comfort} \cdot V_1(\text{good}) &= W_{comfort} \cdot (2/3) \\ &= W_{cost} \cdot 1 \\ \rightarrow W_{comfort}/W_{cost} &= 3/2 \end{aligned}$$

After normalisation: $W_{comfort} = 0.60$ and $W_{cost} = 0.40$

Assuming a linear value-function for cost, a car X which costs \$21,000 and has a comfort estimated as "indifferent", will be valuated as:

$$\begin{aligned} V(X) &= 0.6 \cdot V_1(\text{indifferent}) + 0.4 \cdot V_2(\$21{,}000) \\ &= 0.6 \cdot (1/3) + 0.4 \cdot 0.5 \\ &= 0.4 \end{aligned}$$

ANNEX E

RELATING WEIGHT FACTORS TO THE SET OF ALTERNATIVES

Consider the following transformations:

$$V'_{ij} = (V_{ij} - M_i)/R_i$$

$$W'_i = W_i \cdot R_i / \sum_i W_i \cdot R_i$$

$$V'_j = \sum_i W'_i \cdot V'_{ij}$$

V_{ij} = value of i - the attribute for alternative j

R_i = range V_{ij} in attribute i over the set of alternatives (j: 1->n) to be evaluated

M_i = minimum value of V_{ij} over those alternatives in attribute i

V_j = overall value of alternative j

$$M_i = V_i(E^-) \leftrightarrow V'_i = 0$$

$$M_i + R_i = V_i(E^+) \leftrightarrow V'_i = 1$$

E^+ = best level effect score

E^- = worst level effect score

The transformed weights W'_i will not be the same as W_i, but they can be normalised and summed to 1.

It is easy to show that V'_j is a linear transformation of V_j, so if V is a value-function then V' is also a value-function. The transformed value-function V' is as appropriate for decision making as the original was. The effect of the transformation is to put all of the scaling information into the W'_i at least as it applies to the set of alternatives at hand.

An appropriate elicitation procedure would find out whether the transformed weight factors W'_i are satisfactory. If they still are, either the values U'_j or U_j can be used. If not, the decision-makers can revise the ratios until they are again satisfied.

The formulas demonstrate clearly weight's dependency on the range of the attribute:

$$W'_i = W_i \cdot R_i \;/\; \sum_i W_i \cdot R_i$$

Expanding the scale: $R_i \to \infty$ then $W'_i \to 1$
Shrinking the scale: $R_i \to 0$ then $W'_i \to 0$

So, if the actual range of the attribute is small, changes in the corresponding effect score will have minor influence on the overall valuation of the alternatives, despite a high importance of that attribute.

<u>Example</u>:

Natural scale E_1: $0 \to 10.000$ Weight: $W_1 = 0.4$
Plausible scale E_2: $0 \to 100$ Weight: $W_2 = 0.6$

Range E_1 alternatives at hand: $5500 - 6000 \to V_1$: $0.4 - 0.5$
Range E_2 alternatives at hand: $20 - 95 \to V_2$: $0.5 - 0.8$

Transformed weights:

$$W'_1 := \frac{0.4 \cdot (0.5 - 0.4)}{0.4 \cdot (0.5 - 0.4) + 0.6 \cdot (0.8 - 0.5)}$$

$$= 0.18 \to W'_2 := 0.82.$$

ANNEX F

AGGREGATION OF HIERARCHICAL ATTRIBUTES

When using the linear additive mode, the aggregation of hierarchically constructed attributes goes step-wise. First the values of the lowest intermediates are calculated, then the next higher intermediates, until finally reaching the top intermediate: "goal". Referring to the hierarchy in Figure III.3:

$$V(\vec{E}) \equiv V(\text{goal}) = W_6 \cdot V(I_1) + W_7 \cdot V(I_2)$$

$$V(I_1) = W_1 \cdot V(E_1) + W_2 \cdot V(E_2) + W_3 \cdot V(E_3)$$
$$V(I_2) = W_4 \cdot V(E_4) + W_5 \cdot V(E_5)$$

$$1 = W_1 + W_2$$
$$1 = W_3 + W_4 + W_5$$
$$1 = W_6 + W_7$$

(NB: These weight factors correspond to childs of one parent: "local" weight factors.)

The construction of a hierarchy of attributes is a very helpful instrument, and furthermore it does not affect the linear additive aggregation model. The final outcome is not dependent on the way the hierarchy is structured. After a normal substitution of "intermediary" equations, the result is:

$$V(\vec{E}) = W_6 \cdot W_1 \cdot V(E_1) + W_6 \cdot W_2 \cdot V(E_2) + W_6 \cdot W_3 \cdot V(E_3) + W_7 \cdot W_4 \cdot V(E_4) + W_7 \cdot W_5 \cdot V(E_5)$$

$$= W_1' \cdot V(E_1) + W_2' \cdot V(E_2) + W_3' \cdot V(E_3) + W_4' \cdot V(E_4) + W_5' \cdot V(E_5)$$

$$= \sum_{i=1}^{5} W_i' \cdot V(E_i)$$

(NB: The weight factors W_i' are called "global" weight factors; they relate the endpoints to the overall valuation (goal).)

ANNEX G

DETAILED DESCRIPTION OF THE FUNCTIONS PRESENTLY IMPLEMENTED IN RADE-AID

G.1 Options for Presentation of an Accident Scenario

For the presentation of an accident scenario involving food contamination, the following major options are available:

- presentation of general data on the area involved;
- presentation of data on the area, dependent on countermeasures;
- presentation of data on costs;
- presentation of general data on health effects;
- presentation of data on health effects, dependent on countermeasures.

The presentation of general data on the area involved includes the presentation of:

- the maximum distance for food bans;
- the potential area with a ban duration between point of time T_i and T_{i+1};
- the potential area with a ban duration greater than or equal to a point of of time T_i;
- the time-integral from 0 to T_i of the potential area;
- the production area with a ban duration between point of time T_i and - T_{i+1};
- the production area with a ban duration greater than or equal to a point - of time T_i;
- the time-integral from 0 to T_i of the production area;
- the yield with a ban duration between point of time T_i and T_{i+1};
- the yield with a ban duration greater than or equal to a point of time T_i; - the time-integral from 0 to T_i of the yield.

The presentation of data on the area (dependent on the countermeasure) includes the presentation of:

- the amount of yield to be stored;
- the size of the production area with a ban time greater than or equal to one year not submitted to the removal of the top soil layer;
- the amount subject to the countermeasure.

The presentation of data on costs involves the presentation of several categories of costs (for instance disposal of the soil, cost of labour, and others).

The presentation of general data on health effects includes the presentation of:

- theoretical maximum dose from ingestion;
- the area with a potential dose;
- the reference collective dose.

The presentation of data on health effects (dependent on a countermeasure) includes the presentation of:

- effective doses saved;
- thyroid saved.

For a detailed description of the data used for presentation refer to Annex I (Table I.8).

G.2 Options for File Manipulation

For the manipulation of files and the use of functions related to the operating system, the following options are available:

- loading of a file;
- definition of a new file;
- saving of a file;
- changing of a directory;
- returning temporarily to the operating system;
- leaving RADE-AID.

G.2.1 Loading a file

If the user wants to use (a part of) an existing file, this option allows for the definition of such a file. The user is asked to supply RADE-AID with the name of the file.

G.2.2 Defining a file

The definition of a new file (the file contained no data yet) is equal to loading an empty file.

G.2.3 Saving a file

This option allows the user to save a file after the definition of a new file or the alteration of an existing file.

G.2.4 Changing a directory

This option allows the user to change his/her directory without leaving RADE-AID. In this way it is possible to search for specific files. The option is not yet implemented in RADE-AID.

G.2.5 Returning to the operating system

This option allows the user to leave RADE-AID temporarily to perform actions outside RADE-AID. Upon return to RADE-AID the status of the program will be completely restored. This option is not yet implemented in RADE-AID/D.

G.2.6 Leaving RADE-AID

This option leaves the RADE-AID system.

G.3 Options for Manipulation of Attributes

For the manipulation of attributes the following options are available:

- display of attributes;
- addition of attributes;
- modification of attributes;
- deletion of attributes;
- movement of attributes.

G.3.1 Display

This option allows the user to check the current hierarchy of attributes; the picture was shown in Figure IV.7. Modification of the hierarchy is not allowed.

G.3.2 Addition

This option the user to add attributes at any point in the hierarchy (as well as intermediate endpoints). By pointing to the proper point, it is selected. A name for the attribute will be asked and the hierarchy will be re-arranged accordingly.

G.3.3 Modification

This option allows the user to modify the hierarchy of attributes. Modification may be considered as first deleting and then adding an attribute (refer to Sections A.3.4 and A.3.2).

G.3.4 Deletion

This option allows the user to delete an attribute. An attribute in the hierarchy is selected by cursor movements. Endpoints are deleted immediately; when immediate points are deleted, all points below it in the hierarchy are also deleted.

G.3.5 Movement

Moving a point (or several points) in the hierarchy allows the user to re-arrange the hierarchy.

ANNEX H

THE PREDICTION OF EFFECT SCORES FOR THE EXTERNAL EXPOSURE COUNTERMEASURES APPLICATIONS

The levels of ground contamination predicted to occur as a result of the two accidents, were determined using the recommendations of a UK Working Group on Atmospheric Dispersion[1]. The atmospheric dispersion model used was a straightline gaussian model, modified to take account of the dry deposition of radionuclides, using a deposition velocity. Constant Pasquill Category D atmospheric conditions, without rain, were assumed. The assumptions used are summarised in Table H.1. No allowance was made for site specific factors which might have resulted in different patterns of contamination around the two sites.

The external doses which would result from these levels of ground contamination were predicted using the model described in reference[2], assuming individuals to be permanently outdoors. This assumption clearly gives an overestimate of the external dose, but the authors considered it likely that relocation criteria would incorporate such an assumption.

The collective dose received by decontamination workers was calculated based on estimates of the man-hours required to undertake the decontamination of an area[3]. It was assumed that workers completed their decontamination of one area before commencing work in a new one. Therefore they can be assumed always to be exposed at the dose-rate existing in an area prior to the decontamination being carried out. For the purposes of the (highly stylised) illustrative applications, the simplifying assumption was made that the decontamination work was initiated immediately after the people were relocated from the area, and was completed within the first year. The collective dose to the workers was therefore calculated by multiplying the dose rates integrated over the first year for each area, by the man-hours required for the decontamination of that area, and then summing over the total area.

The model used for calculating the monetary costs resulting from the implementation of countermeasures has been developed under the MARIA programme[4]. The monetary costs were divided into two categories, intervention costs and indirect costs. The intervention costs comprise the costs of transporting the individuals away from (and back to) the area and the costs of decontamination. The indirect costs considered were those for production losses, costs associated with lost services and capital stock, loss of consumer durables, and empty housing. The monetary costs which would be saved, resulting from the reduced population health risk, were subtracted from the total indirect monetary costs. This model is described in detail in reference 4. The values of the parameters used in the illustrative applications are listed in Table H.2.

References

1 Clarke, R H, The first report of a Working Group on Atmospheric Dispersion. A model for short and medium range dispersion of radionuclides released to the atmosphere. Harwell, NRPB-R91 (1979). (London, HMSO).

2 Crick, M J and Dimbylow, P J, GRINDS - a computer program for evaluating the shielding provided by buildings from gamma radiation emitted from radionuclides deposited on ground and urban surfaces. Chilton, NRPB-M119 (1985).

3 Tawil, J J, Bold, F C, Harrer, B J, and Currie, J W, Off-site consequences of radiological accidents: methods costs and schedules for decontamination. NUREG-CR-3413, PNL-4790, Pacific Northwest Laboratory (1985).

4 Haywood, S M, Robinson, C A, Heady, C, COCO-1: A model for assessing the cost of off-site consequences of accidental releases of radioactivity, NRPB report, to be published.

Table H.1

Dispersion and Release Parameters Assumed for Control of External Exposure Applications

Pasquill Category D
Windspeed 5 m/s
Mixing Layer Depth 800 m
Rainfall 0

Release Height 10 m
Release Duration 30 mins

Deposition Velocity 10^{-2} m/s
for isotopes of iodine

Deposition Velocity 10^{-3} m/s
for other radionuclides

	amount released (Bq)
I-131	$3.4\ 10^{16}$
I-132	$5.0\ 10^{16}$
I-133	$6.8\ 10^{16}$
I-134	$7.8\ 10^{16}$
I-135	$6.4\ 10^{16}$
Kr-88	$2.3\ 10^{16}$
Cs-134	$3.9\ 10^{15}$
Cs-137	$2.3\ 10^{15}$

Table H.2

Economics Data used for Control of External Exposure Applications

1) Site B

Transport	£3.0 / Person-Journey
Capital Value of Stock	£9,500 / Person
Consumer Durables	£1,708 / Person
Production Loss	£5,389 / Person
Dwellings	£11,118 / Person
Land	£3.0 x 10^5 / km^2

2) Site A

Transport	£3.0 / Person-Journey
Capital Value of Stock	£8,600 / Person
Consumer Durables	£1,151 / Person
Production Loss	£4,991 / Person
Dwellings	£11,917 / Person
Land	£3.0 x 10^5 / km^2

For Both Locations

Stock Depreciation Rate	0.06 y^{-1}
Consumer Durables Depreciation Rate	0.1 y^{-1}
Dwellings Depreciation Rate	0.02 y^{-1}
Real Interest Rate	0.05 y^{-1}

Decontamination Cost

Urban Land	£2.4 x 10^6 / km^2
Rural Land	£3.0 x 10^6 / km^2

ANNEX I

THE PREDICTION OF EFFECT SCORES FOR THE GRAIN COUNTERMEASURES APPLICATIONS

This annex describes the modelling used to predict the effect scores for the illustrative applications of RADE-AID for countermeasures against contamination in grain. It begins with a general discussion of the factors involved in determining that concentrations in grain exceed certain levels, and then it describes in detail how the relevant effect scores were calculated.

The models and data used are based mainly on the information given in references 8 and 9.

I.1 Model for the Decisions About Foodbans

For a given foodstuff, the total activity per unit amount of the foodstuff[1] which comes from radionuclides belonging to some nuclide ban group, is calculated in a given grid element under the assumption, that the foodstuff is produced in the grid element. The ratio between this activity sum and the intervention level for the foodstuff and nuclide group under consideration determines the decision about foodbans:

(Equ. I.01)

$$R(f,g,N,t) = \frac{AF(f;g,N,t)}{IL(f,N)} \begin{cases} \geq 1 \text{ for any N: foodban = yes} \\ < 1 \text{ for all N: foodban = no} \end{cases}$$

with

$$AF(f,g,N,t) = \sum_{n \epsilon N} AF(f,g,n,t)$$

and $AF(f,g,n,t) = AFG(f,n,t) \bullet AG(g,n)$

where f foodstuff
g grid element
N nuclide group for banning
n radionuclide belonging to group N
t time

AF activity per unit amount of foodstuff $[Bq\ [\text{unit amount}]^{-1}$
AFG activity per unit amount and deposit $[(Bq\ [\text{unit amount}]^{-1}/(Bq\ m^{-2})]$
AG activity initially deposited on ground $[Bqa\ m^{-2}]$
IL intervention level $[Bq\ [\text{unit amount}]^{-1}]$

---

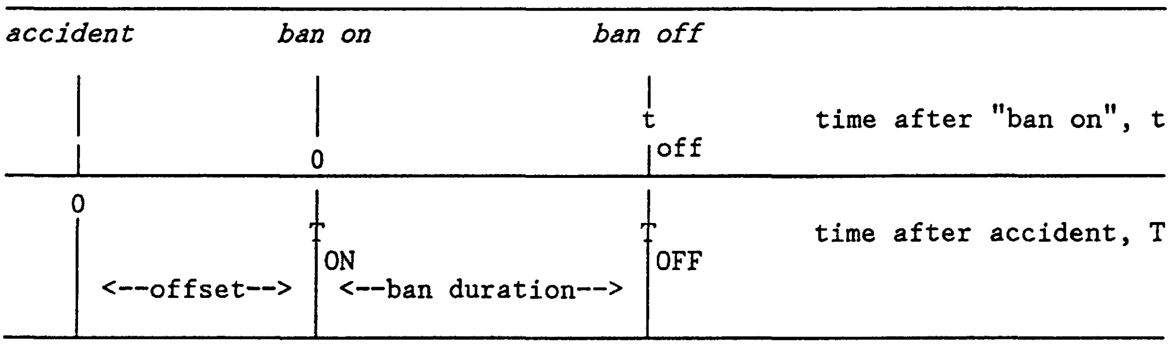
[1] Also referred to as "activity (level) in the foodstuff", "activity concentration" (for amount=volume) or "specific activity" (for amount=mass).

A foodban is assumed to be introduced at the first time where $R \geq 1$ for <u>any</u> N ("ban on"). Dependent on the date of the accident and the foodstuff, there may be a delay between the introduction of a ban and the time of the accident (see Fig. I.01). *The time zero for the introduction of grain bans is always the time of the 1st harvest after the accident.*

To estimate the duration of a foodban, for 10 discrete times after the introduction of the ban it is asked if $R < 1$ for <u>all</u> N ("ban off"). If this is so, the ban is assumed to be withdrawn and the ban duration is taken to be the timespan between the introduction and the withdrawal of the ban[2].

All results referring to the ban duration are given parameterized with respect to the ban duration as defined above together with the offset.

Figure I.01:
Times scales in the foodban-model



The 11 time points (including t=0), the resulting ban durations and the end of foodbans are given below. No decision can be made between two time points; it is conservatively assumed that the ban is withdrawn at the upper end of the corresponding time interval. If the intervention level is exceeded for the last time point, it is assumed that the ban is never withdrawn.

---

[2] If the condition "ban on" is again encountered afterwards (this can happen e.g. for milk), the bantime is taken to be the timespan between the *first* "ban-on"-time and the *last* "ban-off"-time found.

Table I.01:
Basic foodban time matrix

time after introduction of bans											duration of bans	end of bans
0 d	7d	30d	90d	180d	1a	2a	5a	10a	20a	50a		
N	N	N	N	N	N	N	N	N	N	N	-	0 a
Y	N	N	N	N	N	N	N	N	N	N	≥ 0d < 7d	7 d
Y	Y	N	N	N	N	N	N	N	N	N	≥ 7d < 30d	30 d
Y	Y	Y	N	N	N	N	N	N	N	N	≥ 30d < 90d	90 d
Y	Y	Y	Y	N	N	N	N	N	N	N	≥ 90d < 180d	180 d
Y	Y	Y	Y	Y	N	N	N	N	N	N	≥ 180d < 1a	1 a
Y	Y	Y	Y	Y	Y	N	N	N	N	N	≥ 1a < 2a	2 a
Y	Y	Y	Y	Y	Y	Y	N	N	N	N	≥ 2a < 5a	5 a
Y	Y	Y	Y	Y	Y	Y	Y	N	N	N	≥ 5a < 10a	10 a
Y	Y	Y	Y	Y	Y	Y	Y	Y	N	N	≥ 10a < 20a	20 a
Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	N	≥ 20a < 50a	50 a
Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	≥ 50a	∞

I.2 Production Model for Grain

In our climate, grain is sown in late autumn (winter seed) or early spring. After germination, the plants remain in an idle state up to some time late in spring, when they start to grow rapidly. After reaching their full height they sease to grow, and the corn ripens. Finally, at the end of summer, the grain is harvested and the agricultural production cycle begins anew[(1)].

The specific activities at different time points were estimated with precalculated activities per unit mass and deposit (see Equ. I.01) obtained from a dynamic foodchain transport (FCT) model. The data used were derived from data calculated with the German FCT-model ECOSYS[(2)] provided from the GSF for the German Risk Study - Phase B (see also Section I.5).

In the FCT-model it is assumed, that for the first two years after the accident the grain is produced once per year and that each crop is consumed up to the next harvest. During this time span, the contamination level decreases only by radioactive decay. For later times, continuous production and consumption is assumed. Allowance is made for processing losses, mainly for removing the chaff from the corn.

The times assumed in illustrative examples for the production of grain are shown in Table I.02. The time for the introduction of grain bans, i.e. the time of the 1st harvest after the accident, is taken to be on August 15.

Table I.02: Production cycle for grain	
no plants on field:	1.09. - 1.10.
seed on field:	1.10. - 31.03.
begin of growth:	1.04.
harvest period:	1.08. - 31.08.

The predicted time dependence of the activity levels per unit deposit of I-131 and Cs-134 (radioactive half lives of ≈ 8 d and 2 a, respectively) in grain after a release on July 1st can be seen in Figure I.02. The curve for I-131 falls off steeply because its radioactive half life is short in comparison to the time scales involved. For Cs-134 one observes an abrupt decrease of the curve after the first harvest. This is so because the accident was assumed to occur during the growing season of grain, so that the contamination of the first year's crop is mainly caused by direct deposition, which is a much more efficient means to transfer the activity to the plants than root uptake, which dominates in the following years.

I.3 Models used for Action Alternatives

NOACT - No action

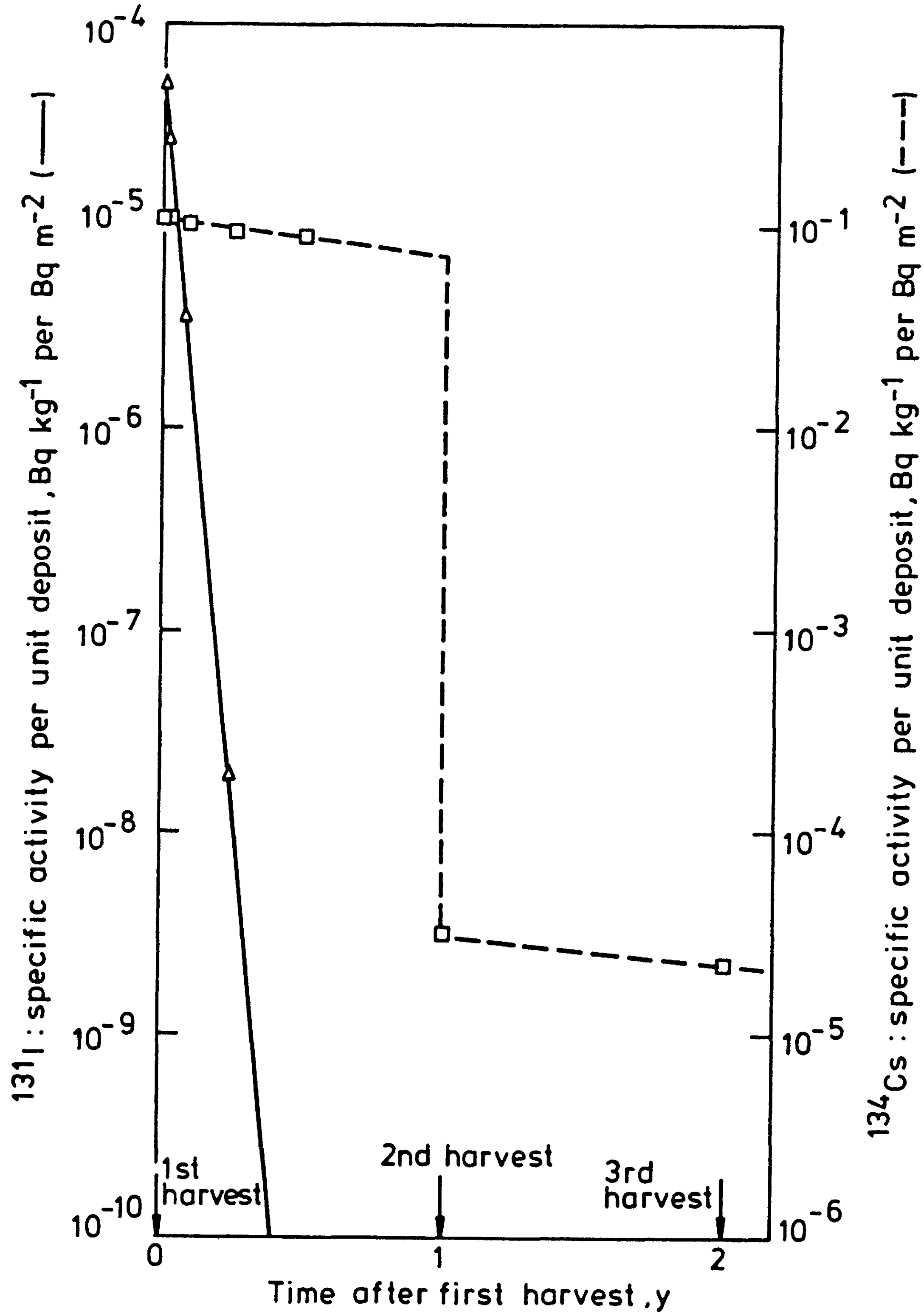
Description Grain is produced and distributed for human consumption regardless of the accident.

By definition, this is a global action, i.e. it holds for all grid elements.

UPLOU - Plough under

Description Grain plants present on the field are ploughed conventional farm ploughs. Since conventional ploughing is part of the standard agricultural practice and can be carried out by local agricultural

Figure I.02:
Example for the estimated time dependence of the activity levels in grain per unit deposit of I-131 and Cs-134 for a release on July 1st



workers, the effort and costs associated with carrying out the action are relatively low.

Assumptions

1. The first crop is always lost in the affected grid elements.
2. It is likely that the action cannot be carried out when the plants are fully grown, because then much biomass is left on the field. A suggestion for a time interval during which the action is assumed not to be possible is given in Table I.3.

DISPO - Disposal

Description In the areas with foodbans, the plants will be removed from the fields and then treated as low level radioactive waste.

STORE - Storage

Description The grain from areas affected by foodbans is harvested and subsequently stored with the aim to reduce the contamination level by radioactive decay to such a degree, that the intervention level is not exceeded for any nuclide group N.

From practical considerations, two methods of carrying out the action are conceivable:

(1) Grain from grid elements with foodbans and about the same estimated storage time (and thus about the same specific activity) is stored together for the corresponding time period.

The storage times ts are then simply the ban times determined for each grid element:

(Equ. I.2-1)

$$IL(N) < AF/g,N,ts(g)) \quad \text{for all } N$$

(2) Grain from all grid elements with foodbans is stored together for the time ts' determined by the average specific activity of the resulting "grain mix":

(Equ. I.2-2)

$$IL(N) < \frac{\sum_{g} AF(g,N,ts') \cdot P(g)}{\sum_{g} P(g)} \qquad \text{for all } N$$

where g represents the grid elements with foodbans, AF the specific activities in grain as defined in Equ. I.1, and P the amount of grain produced in a grid element per harvest; the index f for the foodstuff "grain products" has been omitted.

Method (2) is probably easier to be carried out. However, if a significant fraction of the harvest would be affected by grain bans, method (1) may have the advantage that parts of the harvest could be reused more quickly.

Assumptions

1. The possible storage times are evaluated for the same discrete time points as the bantimes (see Table I.1).
2. If the objective cannot be achieved within some time period, grain will not be stored. The assumed upper limit for the storage time is given in Table I.3.

DILUT - Dilution

Description Grain with a specific activity above the IL is mixed with uncontaminated or less contaminated grain until the specific activity of the mixture does not exceed the IL (bringing a benefit only to individuals, no collective dose is saved).

For a given nuclide group N, the amount P' of uncontaminated grain required to dilute the amount P of grain with a specific activity AF at harvest time down to to the intervention level can be calculated by:

(Equ. I.3)

$$AF'(n'0) = IL(N) \qquad \text{(from Equ. 1.01 with } R = 1)$$

with

$$AR'(N,0) = \frac{AF(N,0) \cdot P(N)}{P(N) + P'(N)}$$

then

$$P'(N) = (R(N,0) - 1) \cdot P(N) \qquad \text{(with } R(N,0) \text{ from Equ. 1.1)}$$

The amount required is the maximum found for any nuclide group N:

$$Pd = \max(P'(N))$$

The indices representing the foodstuff "grain products" and the grid element, f and g, respectively, were omitted in Equ. I.3.

As it was the case for the action STORE, two methods of carrying out the action are conceivable:

1. Grain from all grid elements with foodbans and about the same activity levels is diluted with the amount of uncontaminated grain determined by the corresponding specific activity.
2. Grain from all grid elements with foodbans is diluted with the amount Pd determined by the average specific activity of the resulting "grain mix".

The total amount required for dilution is the same for both methods.:ehpl. However, if this amount is large, it might be desirable to dilute only the less contaminated fractions of the crops, and dispose of the rest.

Assumptions

1. Only uncontaminated grain is used for dilution.
2. In practice, dilution will possibly only be carried out if the contamination of the harvested grain stays "about constant" with time. Therefore, this action type is eliminated in KFKGRA when the ban times in all grid elements are shorter than 90 d. If this is not so, dilution will be taken into account for all grid elements, independent of the ban times.

NADEC - Natural decontamination of the soil

Description Areas affected by bans are left fallow for the estimated ban duration.

Any existing grain may be left on the fields to rot or to be and harvested and subject to other actions.

Assumptions

1. Time-dependence of specific activity in grain from second harvest onwards is always calculated under the assumption that the first crop was harvested.

ROTSL - Removal of the top soil layer

Description Removal of top soil layer and disposal of removed soil. About 90% or more of the the activity is removed.

Action does not need to be carried out very fast on most soils; a time span of one year after the accident can be considered as an upper limit.

Land is immediately usable for agriculture after treatment. However, especially for poor soils, loss of nutrients can reduce the productivity or require the application of fertilizers.

Impossible or doubtful results for shallow, stony soils, for wet, peaty soils, for clay soils (when wet: material sticks to the blade; when dry: soil becomes very hard); when crops are cultivated in ridges (e.g. potatoes); when firm plants are present on the fields (e.g. sugar beets, maize stubble etc.).

Standing crops must not be removed from the field before carrying out the action.

Required equipment: scrapers, road graders, bulldozers etc.

Assumptions

1. If in a grid element the activity remaining after the action is such that the IL is still exceeded for grain at the time of the second harvest, i.e. if (f * AF(g,N,1)) &ge. IL(N) for any N, the action

will not be carried out in the grid element (f is the fraction of the initial deposited activity remaining after the action, see Table I.3).

2. Action is always physically possible for areas where grain is grown.
3. Operation time for (human operator + machine) is 8 h/d and 5 d/w. This, together with the theoretical rate per piece of equipment gives the effective decontamination rate for one single pass (machine + human operator) given in Table I.3.
4. The first crop is always lost in the affected grid element.

Table I.3:
Data used in grain action models

	UPLOU - Plough under	
action not possible	01.07.-31.08	"switch"
	STORE - storage	
max. allowed storage time	1 a	"switch"
	DILUT - dilution	
AF about constant over	90 d in all grid elements	"switch"
	ROTSL - removal of top soil layer	
theoretical rate per equipment	5-10 10^{-4} km^2/h	
operation hours per year	2080 h/a	
effective rate per equipment	1-2 km^2/a	
fraction of initial activity remaining (fr)	0.1	"switch"
removed soil per cm depth	10^{+4} $m^3/(km^2cm)$	
average depth	5 cm	

(rate and efficiency for single pass)

I.4 Calculation of Results

In this Section, g stands for any grid element *with foodbans*, λ for the radioactive decay constant ($[a^{-1}]$), i for the i'th position in the ban-array with ti being the corresponding time from Table I.1 (all converted to [a]), N for a nuclide ban group, and n for an individual radionuclide; if not explicitely referring to a given N, n means any radionuclide.

I.4.1 Grid element data

In each grid element, the following grid-dependent data are known:

- the total area of the grid element, [km^2]
- the production rate PR of grain in the grid element [$kg\ a^{-1}$]
- the activity in grain per unit mass, AF(g,n,t) and AF(g,N,t), calculated with Equ. 1.01 for the times t=ti under the assumption that grain is produced in the grid element, [$Bq\ kg^{-1}$]
- the ratio R(g,N,t) for the times t=ti calculated with Equ. I.1 under the assumption that grain is produced in the grid element
- the end of foodbans tb calculated under the assumption that grain is produced in the grid element, [a]

For the production rate of grain, at present the 100 km &times. 100 km CEC-grid from reference 3 is used. The spatial resolution of this grid is inadequate for RADE-AID/D, but no other data were available. The total annual production in a given grid element, PR, is equal to PR. times 1 a. The corresponding production area, PA, is obtained by dividing PR by an average production yield of 5.0 E+5 [$kg\ km^{-2}$], which was derived from German agricultural statistics data[(1)].

I.4.2 General information about the situation (independent of AAs)

In this Chapter, Q stands symbolically for any of the quantities "potential area", "production area" or "produce".

Potential area [km^2] / production area [km^2] / produce [kg] with bans for $tb \geq ti$ for given IL

(Equ. I.4)

$$QC(tb \geq t_i) = \sum_{g(tb \geq t_i)} Q(g)$$

$QC(tb \geq 0)$ under the condition that foodbans = yes for t = 0 is the initial quantity.

Time integral from 0 to ti of production area [km² a] / produce [kg a] for given IL

(Equ. I.5)

$$TIQ(0) = 0 \text{ for } i = 1$$

$$TIQ(t_i) = TIQ(t_{i-1}) + QC(tb \geq t_{i-1}) \times (t_{i-1}) \times (t_i - t_{i-1}) \text{ for } \geq 2$$

I.4.3 Public health

In the following, G(a,n,o) stands for the dose-per-unit-intake factor for an individual belonging to some age group a, for radionuclide n and for organ/tissue (or effective dose) o.

I.4.3.1 Collective dose saved

The collective dose saved by an action alternative is calculated by multiplication of the collective intake saved with a dose-per-unit-intake factor ("production method"). The collective intake saved is taken to be the total activity contained in the grain produced in the affected area, which was not distributed for consumption for the duration of the bans.

As an approximation, the collective dose saved is calculated with committed-dose-per-unit-intake factors for adults; the values used were derived from data provided by the GSF for the German Risk Study - Phase[4,5].

Table I.4 summarizes the collective dose saved for the different action alternatives. In the table, C1, CF, C1SM1 and C1SM2 stand for one of the following expressions:

Collective dose saved by not distributing the total first crop

(Equ. I.6-1)

$$C1(o) = \sum_g \sum \left(G(n,o) \times PR(g) \times \int_0^1 dt \; AF(g,n,t) \right)$$

Collective dose saved by not distributing the first crop for a given time period ts(g)=tb(g) - STORE Method 1

(Equ. I.6-2)

$$C1SM1(o) = \sum_g \sum \left(G(n,o) \times PR(g) \times (1 - e^{(-\lambda(n)tb(g))}) \times \int_0^1 dt \; AF(g,n,t) \right)$$

<u>Collective dose saved by not distributing the first crop for a given time period</u>

<u>ts' - STORE Method 2 (not yet realized)</u>

(Equ. I.6-3)

$$C1SM1(o) = \sum_g \sum \left(G(n,o) \times PR(g) \times (1 - e^{(-\lambda(n)tb(g))}) \times \int_0^1 dt \; AF(g,n,t) \right)$$

with ts' from Equ. A.01-2.

<u>Collective dose saved by not distributing all crops from second harvest onwards</u>

<u>up to time tb:</u>

(Equ. I.6-4)

$$CF(o) = \sum_g \sum \left(Gn(o) \times PR(g) \times \int_1^{tb} dt \; AF(g,n,t) \right)$$

Table I.4:
Contributions to the collective dose saved by action alternatives

AA	Ban duration $\geq 0 < 1a$	$\geq 1a$
NOACT	0	0
NADEC/NADEC	C1	C1 + CF
NADEC/ROTSL	C1	R1 (R<fi) | C1+CF (R≥fi) 1)
UPLOU/NADEC	C1	C1 + CF
UPLOU/ROTSL	C1	R1 (R<fi) | C1+CF (R≥fi) 1)
DISPO/NADEC	C1	C1 + CF
DISPO/ROTSL	C1	R1 (R<fi) | C1+CF (R≥fi) 1)
STORE/NADEC	C1SM1|M2	C1 + CF 2)
STORE/ROTSL	C1SM1|M2	R1 (R<fi) | C1+CF (R≥fi) 1)
DILUT/NADEC	0	CF
DILUT/ROTSL	0	R1 (R<fi) | C1+CF (>fi) 1)

Notes

1) For R < fi, it is assumed that the area will be re-used for grain production after the first year: R1 = C1 + (1-fr) CF, with fr being the fraction of the initial deposited activity remaining after ROTSL with the default value given in Tab. 3.02, and fi = 1 / fr. - For R ≥ fi, NADEC is assumed (see note (3) in Chapter 4).

2) DISPO is assumed instead of STORE here - see Section I.3.

I.4.3.2 Reference collective dose

The collective dose in areas affected by foodbans for a given IL calculated under the assumption that the foodban is ignored for the bantime, is the maximum value of collective dose which can be saved up to the end of the foodbans by any AA. This quantity is therefore used as a reference value for the collective dose saved by an action alternative to provide a measure for the efficiency of the AA:

(Equ. I.7)

$$CDR(o) = \sum_{g} \sum \left(G(n.o) \times PR(g) \times \int_{0}^{tb} dt \; AF(g,n,t) \right)$$

The total reference collective dose can be split up into different components with respect to the time of ingestion, e.g. a part coming from ingestion in the first year (integrating to tb for grid elements with $tb < 1$ and to 1 for grid elements with $tb \geq 1$) and a part coming from ingestion in the following years (integrating from 1 to tb for all grid elements with $tb \geq 1$).

I.4.3.2 Individual dose

By definition of the intervention level, for a given IL the maximum committed dose which an average member of a critical group in the population could receive from ingestion of a foodstuff in any one year during the bantime, is the dose he or she would receive when consuming the food with an activity level just about equal to the intervention level for each of the nuclide ban groups. In the following, this quantity is called TMID (theoretical maximum individual dose).

Since the ILs are defined for groups of nuclides, which may consist of nuclides with a different radioactive half life, the value of TMID may change with time, when the composition of the nuclide group changes. By the same reason, TMID can depend on the distance to the site. However, this effect is rather small for the radionuclides and distances considered in RADE-AID/D and is neglected, i.e. in KFKGRA TMID is calculated only in one grid element near to the site. The possible variation with time is accounted for by calculating the values in the first, second and eleventh year in the following way:

for the first year

(Equ. I.8-1)

$$TMID(a,o,1) = CR(a) \times \sum_{N} \sum_{m \in N} \sum_{i} \left(G(a,n,o) \times f(N, t)_i \times \int_{t_i}^{t_{i+1}} AF(g,n,t) \, dt \right)$$

for any of the following years:

(Equ. I.8-2)

$$TMID(a,o,t_i) = CR(a) \times \sum_N \sum_{n \in N} \left(G(a,n,o) \times f(N, t_i) \times \int_{t_i}^{t_i+1} Af(g,n,t) \, dt \right)$$

with

$$f(N,t_i) = \frac{IL}{AF(g,N,t_i)} \qquad \text{with } AF(g,N,ti) \text{ from Equ. I.1}$$

CR are the age dependent consumption rates, the values currently used are ([kg a^{-1}]): 15 (0 a), 53 (1-4 a), 83 (5-9 a), 98 (10-14 a), 120 (15-19 a), 143 (≥20 a). These values were derived from the average values for the FRG given in[5] by multiplying each value with 1.5 to account for a higher than average consumption.

TMID is calculated for all six different age groups, the critical group is then, by definition, the group receiving the highest dose. - For the action alternative "No Action", TMID is infinity by definition.

Another useful quantity may be the maximum committed individual dose saved found in any of the grid elements, i.e. the highest dose which is calculated for an average member of a critical group in the population consuming a foodstuff over the given ban duration. This quantity is given for for the six age groups above using activity-dose-coefficients, which take into account that an individual ages as time goes on after the accident[10].

I.4.4 Practicability

Areas subject to AA

For all AAs which do not contain ROTSL (AAY): The initial area from Equ. B.01 calculated under the condition that the primary action types are possible. - *For AAs containing the ROTSL component (RAY)*: The initial area from Equ. B.01 calculated under the condition that ROTSL is possible, i.e.

(Equ. I.9-1)

$$RAY = \sum_{g(tb \geq 1a \wedge R < fi)} PA(g)$$

In addition, for ROTSL the part of the area A1, for which the primary action type foreseen for the first year is possible (RAYA1), and the parts of the areas A2 for which ROTSL is not possible (RANA2) is calculated as a function of time, i.e.

(Equ. I.9-2)

$$RAYA1 = \sum_{g(tb<1a \wedge AT1=yes)} PA(g)$$

(Equ. I.9-3)

$$RANA2(tb \geq t_i) = \sum_{g(tb \geq 1a \wedge R \geq fi)} PA(g)$$

Amount of soil to be disposed (for AAs containing ROTSL):

(Equ. I.10)

$$DS = RAY \times rspd \times ad$$

where rspd = removed soil per cm depth and ad = average deptgh with the default values given in Tab. 3.02.

Operation time for ROTSL (for AAs containing ROTSL)

(Equ. I.11)

$$OT - \frac{RAY}{r\ speed}$$

where the default value for rspeed is taken to be 0.001 km/h in accordance with the value range given in Table 3.02 for the theoretical operation rate per equipment.

Amount of produce to be disposed for all grid elements where disposal applies as either the primary or the secondary action type:

(Equ. I.12)

$$DP = \sum_{g(DISPO=yes)} PR(g)$$

Amount of produce [kg] to be stored for $T \geq Ti$ (for AAs containing STORE only) As in Equ. B.01, but under the conditon $0 \leq tb < 1a$.

Amounts under the condition that the primary action type is not possible (for AAs not containing ROTSL only)

Area The initial area from Equ. B.01 under the condition that the primary action types are not possible.

Produce For all AAs for which it is assumed that then DISPO has to be carried out instead, the corresponding amount adds up to the amount which has to be disposed.

I.4.5 Costs

All numerical values given here use values of 1.5 and 0.15 to convert £ and FFr to ECU respectively.

I.4.5.1 Gross output, gross product, capital costs

In the calculations of the above costs the following assumptions are made(6): In the first year, the gross output (GO) represents the costs from the loss of foodstuffs, which consists of the losses resulting from the purchases from other producers, from the income of farmers and workers, and from the depriciation of capital. If the duration of the bans is estimated to exceed 1 year, it is assumed that grain is not produced in the affected areas after the first year for the estimated ban time, so that purchases from other producers need not to be made and only the income and capital losses expressed by the gross domestic product (GP) remain. If the ban duration is estimated to exceed 3 years, it is assumed that people who receive their income from agriculture in the affected areas are re-integrated elsewhere in the national economy, leading the income losses to vanish and only the capital costs (CA) to remain.

Table I.5 gives the current values for the unit costs for GO, GP and CA(7). Table I.6 shows the contributions of the three cost types for the different action alternatives (both Tables are at the end of this Section).

The formulae and data currently used in the cost calculations are given below(6). In the formula, Uxx represents the corresponding unit cost, j the j'th year after the accident, and AREA the production area affected in this year or during some time interval starting with year j.

The areas affected depend on the AAs and are explained after the formulae. It should be remembered here, that the assumption is made that, independent of what is actually going on, the production in the first year is either completely lost or not at all.

Gross output (GO)

(Equ. I.13-1)

$$GO = UGO \times AREA(j) \times DISCNT(j) \times \Delta T \qquad \text{for } j = 1 \text{ only}$$

The discount factor for the first year is assumed to be 1.

Time: Due to the underlying assumption mentioned above, &Delta.T is always 1 a.

AREA *For all AAs without STORE*: AREA is the initial production area QC(tb≥0) from Equ. I.4. - *For AAs with STORE:* AREA is the area QC(t≥1a) from Equ. I.4.

Gross product (GP)

(Equ. I.13-2)

$$GP = UGP \times \sum_{j=2}^{3} AREA(j) \times DISCNT(j) \times \Delta T$$

with

(Equ. I.14)

$$DISCNT(j) = \frac{1}{(1 + r)^{j-1}}$$

The current value for r is 0.05 (corresponding to 5 %).
Time: GP is calculated for years 2 and 3, so ΔT is 1 a for each of the two time periods.
AREA: *For all AAs without ROTSL*: AREA(2) = QC(tb≥1a) and AREA(3) = QC(tb≥2a) with QC being the production area from Equ. I.4. - *For all AAs with ROTSL:* AREA(2) = RANA2(tb≥1a) and AREA(3) = RANA2(tb≥2a) with RANA2 being the part of A2 for which ROTSL is not possible from Equ. I.9-3.

Capital costs (CA)

(Equ. I.13-3)

$$CA = UCA \times \begin{array}{l} AREA(3) \sum_{j=4}^{5} (1 - A)^{(j-1)}(A+RR)DISCNT(j) \\ + \sum_{i=8}^{10} AREA(t_i) \sum_{j=j(i)}^{j(i+1)} (1 - A)^{(j-1)}(A+RR)DISCNT(j) \end{array}$$

where i is the i'th position in the ban-array, ti the corresponding time and j the corresponding year (i.e. j(i) = ti + 1). The current values for A and RR are 0.01 (corresponding to 10%) and 0.05 (corresponding to 5%). - The formula for the discount factor is the same as for the gross product.

The separation of the contributions from years 4 and 5 from the rest is necessary, because the ban- array does not contain the 4th and 5th year as times on their own.

AREA AREA(3) is the same as for the gross product. - *For all AAs without ROTSL:* AREA(ti) = QC(tb≥ti) with QC from Equ. I.4. - *For all AAs with ROTSL:* AREA(ti) = RANA2(tb≥ti) with RANA2 from Equ. I.9-3.

Table I.5:
Default values for unit gross output-, gross product-, capital costs

gross output:	8.9 E+4	[£ km^{-2} a^{-1}]	first year
gross product:	3.5 E+4	[£ km^{-2} a^{-1}]	years 2 and 3
capital costs:	3.0 E+4	[£ km^{-2}]	≥ year 4

Table I.6
Contributions from gross output-, gross product-, capital costs for the action alternatives

AA	Ban duration ≥0 < 1a	≥ 1a
NOACT	0	0
NADEC/NADEC	GO	GO + GP + CA
NADEC/ROTSL	GO	GO (R<fi) | GO+GP+CA (R≥fi) 1)
UPLOU/NADEC	GO	GO + GP + CA
UPLOU/ROTSL	GO	GO (R<fi) | GO+GP+CA (R≥ffi 1)
DISPO/NADEC	GO	GO + GP + CA
DISPO/ROTSL	GO	GO (R<fi) | GO+GP+CA (R≥fi) 1)
STORE/NADEC	0 2)	GO + GP + CA 3)
STORE/ROTSL	0 2)	GO (R<fi) | GO+GP+CA (R≥10) 1)
DILUT/NADEC	0 2)	GP + CA
DILUT/ROTSL	0 2)	GO (R<fi) | GO+GP+CA (R≥10) 1)

Notes

1) For R < fi, it is assumed that the area will be re-used for grain production after the first year (fi = 1 / fr, with fr being the fraction of the initial deposited activity remaining after ROTSL with the default value given in Table I.3). - For R≥fi, NADEC is assumed (see Section V.2.2).

2) Some costs will arise from not being able to use the grain immediately after the harvest. These costs are not accounted for at present.

3) DISPO is assumed instead of STORE here - see Section I.3.

I.4.5.2 Costs for carrying out the actions

The unit costs for the different costs types are shown in Table I.7, the sources of the numerical values are given in the following chapters.

Table I.7:
Default values for unit costs for carrying out the actions

storage	1.5 E-2 [ECU kg^{-1} a^{-1}]				
disposa	1 (grain) 5.2 [FFr kg^{-1}]				
disposa	1 (soil) 5.2 E+3 [FFr m^{-3}]				
ploughing under	1.0 E+3 [£ km^{-2}]	(Labour)	2.0 E+ 3 [£ km^{-2}]	(Equipment)	
removal of t.s.	1.0 E+5 [£ km^{-2}]	(Labour)	1.4 E+ 5 [£ km^{-2}]	(Equipment)	

Storage

The value in Table I.7 corresponds to 0.04 ECU per ton and day[(8)]. The actual costs are calculated by:

(Equ. I.15)

$$\text{costs} = \text{USTOR} \times \sum_{1=1}^{i=4} QC(t_i) \times (t_{i+1} - t_i)$$

with USTOR being the unit costs, i the i'th position in the ban-array, ti the corresponding time, and QC the amount of grain stored for t ≥ ti calculated from Equ. I.4 under the condition 0 ≤ tb < 1 a.

Disposal of grain and soil

The values in Table I.7 are derived from a value of 1180 FFr given by[(8)] for the storage of low level radioactive waste packed in metallic 225 l containers. For grain, the mass to be disposed is calculated and not the volume; a density of 1 was assumed in the conversion for the disposal of soil.

The amounts of soil / grain to be disposed calculated using Equ. I.10 and I.12, respectively, were used to obtain the actual costs. However, for grain, probably not the corn alone but the complete plant would be disposed, increasing the volume and hence the costs, but this was not taken into account.

Labour and Equipment

The numerical values in Table I.7 for the unit costs for labour and equipment for the action types UPLOU and ROTSL were taken from reference 9; corresponding data for other action types were not available.

For the illustrative examples, the sum of both cost categories was calculated. The areas with which the unit costs were multiplied to obtain the actual costs were:

UPLOU/NADEC (UPLOU-component): the area subject to UPLOU (AAY from Equ. I.9-1). - UPLOU/ROTSL (UPLOU-component): the area A1 (RAYA1 from Equ. I.9-2). - ROTSL-component of all action types: the area subject to ROTSL (RAY from Equ. I.9-1).

Monitoring costs

These were not included, since little relevant information was available.

I.5 Data for the Specific Activities Per Unit Deposit

In this Section, AFG represents the activity per unit mass and deposit, ti stands for one of the times of the ban-array, and λ for the radioactive decay constant; all indices referring to the radionuclide were omitted.

The original ECOSYS-data for the activity per unit mass and deposit provided by the GSF were in the form of annual integrals for the times 0 a, 1 a, 2 a, ..., 199 a, the time zero for the integration being the time of the accident. For the German Risk Study - Phase B these data were modified to represent annual integrals with time zero being the first harvest; from these values, the time integrals from 0 to ti and from ti to 200 a were calculated[5]. For the illustrative applications, however, not only time points between 0 and 1 a were required, but also the activities themselves, and had to be derived from the available (modified) data.

Under the assumption, that radioactive decay is the only means to decrease the activity level in grain after harvest, the time dependence of AFG is given by:

(Equ. I.15)

$$AFG(t) = AFG(0)\ e^{-\lambda t}$$

With this equation, the activity level at the time tj of the j'th harvest, AFG(tj), can be calculated from the known annual integrals:

$$\int^{t_j+1} dt\ AFG(t) = AFG(t_j) \int_0^1 dt'e^{-\lambda t'}$$

$$= \frac{AFG(t_j)\ [1 - e^{-\lambda}]}{\lambda}$$

giving

(Equ. I.16)

$$AFG(t_j) = \frac{\lambda \int_{t_j+1}^{t_i} dt\ AFG(t)}{1 - e^{-\lambda}}$$

The annual integrals and the integrals from 0 to ti and ti to 200 a for ti = 0 and ti ≥ 1a were taken over from(C10).

For times 0 < ti < 1, AFG(ti) is calculated from Equ. I.15 using AFG(0) from Equ. I.16. - The time integrals from 0 to ti are obtained by integration of Equ. I.15. - The annual integrals are calculated by integration of Equ. I.15, taking account of the fact that part of the integral comes from the first and part from the second harvest:

$$\int_{ti}^{t_i+1} dt\ AFG(t) = \int_{ti}^{1} dt\ AFG(0)\ e^{-\lambda t} + \int_{0}^{ti} dt\ AFG(1)\ e^{-\lambda t}$$

The time integrals from ti to 200 a for times 0 < ti < 1a are then obtained by adding the value calculated from above for the part of the first harvest to the integral from 1 to 200 a.

I.6 Additional Data used for Direct Valuation of Socio-Political Attributes

In order to provide direct valuations for the socio-political attributes, supplementary information was calculated. The nature of this information is listed in Table I.8.

Table I.8:
Additional data for Direct Valuation

General information about the situation (independend of AA)

- Specific activity [Bq/kg] in each grid element for given nuclide group
- Ratio R in each grid element for each nuclide group and IL
- Max. distance [km] for bans as a function of time for each IL
- Potential area [km^2] / production area [km^2] / produce [kg] with ban durations of Ti ≤ Tb < Ti+1 for each IL
- Potential area [km^2] / production area [km^2] / produce [kg] with bans for Tb ≥ Ti for each IL
- Time integral from 0 to Ti of / production area [km^2 a] / produce [kg a] for each IL

Public health (for each IL and organ/tissue)

- Theoretical maximum individual effective committed dose equivalent [mSv] from intake of a given foodstuff in / first / second / eleventh year as a function of age
- Committed dose equivalent [mSv], which a member of a critical group would receive if he consumes the contaminated food from the time of the accident to the end of the foodbans, as a function of age
- Reference collective dose [man Sv] from intake of a given foodstuff (total, contributions from ingestion in 1st year and from following years up to the end of the bans)
- Contributions (%) of radionuclides to reference collective dose from ingestion in 1st year and over following years
- Collective dose [man Sv] saved by AA and fraction of reference collective dose

Practicability (for each IL)

- Amounts subject to AA (area affected [km^2], soil to be disposed [m^3], produce to be disposed [kg], operation time for ROTSL [h])
- Produce [kg] to be stored for T ≥ Ti
- The area [km^2] for which the primary action type is not possible (required for the calculation of costs)
- The parts of area A2 for which ROTSL is impossible [km^2] as a function of time (required for the calculation of costs)

Table I.8 (cont'd):
Additional data for Direct Valuation

Costs [ECU] for each AA and IL
• Costs for lost gross output / gross product / capital, and their sum
• Costs for carrying out the actions
• Costs for the amounts of soil / produce to be disposed
• Costs for storage
• Sum of costs for labour and equipment
• Monitoring costs
• Sum of costs for carrying out the actions

References

1 BUNDESMINISTERIUM FÜR ERNÖHRUNG, LANDWIRTSCHAFT UND FORSTEN (ed.). Statistisches Jahrbuch über Ernährung, Landwirtschaft und Forsten der Bundesrepublik Deutschland 1988. Münster-Hiltrup, Landwirtschaftsverlag (1988).

2 M. MATTHIES, K. EISFELD, H. MÜLLER, H.G. PARETZKE, G. PRÖHL, E. WIRTH. Simulation des Transfers von Radionukliden in landwirtschaftlichen Nahrungsketten. Neuherberg, GSF-S-861 (1982).

3 M. BROOMFIELD, J.R. SIMMONDS, T.A. CHAPMAN. POP-MARC and AG-MARC: Population and agricultural distributions for use in the methodology for assessing the radiological consquences of accidental releases. Chilton, NRPB-M75 (1982).

4 J. EHRHARDT et al.. The program system UFOMOD for assessing the consequences of nuclear accidents. Harlsruhe, KfK-4330 (1988).

5 C. STEINHAUER. UFOING: A program for assessing the off-site consequences from ingestion of accidentally released radionuclides. Karlsruhe, KfK-4475 (1988).

6 Faude, D, Haywood, S M, Robinson, C A, The modelling of Economic Consequences in COSYMA. Proceedings of Seminar on Methods for Assessing the Off-site consequences of Nuclear Accidents, Athens, May 7-11th 1990.

7 A, Despres, private communication.

8 J.M. HOWORTH and F.J. SANDALLS. Decontamination and reclamation of agricultural land following a nuclear accident. A literature review. Harwell, AERE-R112666 (1987).

9 F. van DORP, R. ELEVELD, M.J. FRISSEL. Agricultural measures to reduce radiation doses to man caused by severe nuclear accidents. Brussels, Luxembourg, Report EUR 7370 EN (1981).

GLOSSARY

DECISION LOGIC VOCABULARY USED IN THIS REPORT

alternative	=	one item of the possible choices (synonym: option).
anti-ideal alternative	=	hypothetical alternative that performs the least desired effect scores on all attributes.
attribute	=	distinctive (relevant) property of an alternative (common synonyms: criteria, objective).
effect score	=	the outcome of an alternative measured on a certain scale in the dimension of a specific attribute, reflecting the number of units by which that attribute is expressed.
effect score matrix	=	matrix in which for all alternatives every relevant relevant effect score is given.
endpoint	=	attribute at the bottom of the hierarchy, corresponding to an attributes that is not broken down into more detail, and may have a direct relationship with an effect score through a value function.
goal	=	top of the hierarchy, it corresponds to the attribute "overall desirability".
hierarchy	=	scheme expressing the relationship between the attributes (synonym: (value) tree).
ideal alternative	=	hypothetical alternative that performs the most desired effect scores on all attributes.
indifference judgement	=	comparison of two equal (relative) strengths of preference.
intermediate attribute	=	attributes that are aggregates of underlying attributes in the hierarchy.
preference	=	ordinal priority order.
relative strength of preference	=	difference between two different relative values.
trade-off	=	personal judgement about the relative desirability for effect scores on different attributes; the trade-off can be expressed in terms of weight factors and value functions.
utility	=	a transformation on value, intended to take account the decision-maker's attitude towards risk or uncertainty.

value = quantity expressing the (relative) desirability of an object; strength of preference.

value function = an expression relating the effect score corresponding with a single attribute, to the valuation of that effect score.

weight factor = number expressing the trade-offs between the value of attributes, reflecting their relative importance for the overall evaluation; the weight factors are usually normalised.

European Communities — Commission

EUR 12552/2 — Radiological aspects of nuclear accident scenarios
Volume 2 — The RADE-AID system
Post-Chernobyl action

Edited by: *J. Sinnaeve*

Luxembourg: Office for Official Publications of the European Communities

1991 — XXX, 166 pp., num. tab., fig. — 21.0 × 29.7 cm

Radiation protection series

ISBN 92-826-2939-2

Catalogue number: CD-NB-12552-EN-C

Price (excluding VAT) in Luxembourg: ECU 15

In the event of a nuclear accident, there is a need for a rapid assessment of the resulting levels of environmental contamination in order to facilitate decisions on possible countermeasures. Volume 1 of this report covers the development of numerical models, in the form of software packages, to simulate atmospheric transport and deposition over various distances, and techniques for estimation of the resulting doses. Volume 2 describes the RADE-AID project to develop a computer system which can be used to support the formulation of decisions on countermeasures following an accidental release of radionuclides. The system is intended as an aid following an actual accident and a tool for assistance in planning and training.

Venta y suscripciones • Salg og abonnement • Verkauf und Abonnement • Πωλήσεις και συνδρομές
Sales and subscriptions • Vente et abonnements • Vendita e abbonamenti
Verkoop en abonnementen • Venda e assinaturas

BELGIQUE / BELGIË

Moniteur belge / Belgisch Staatsblad
Rue de Louvain 42 / Leuvenseweg 42
1000 Bruxelles / 1000 Brussel
Tél. (02) 512 00 26
Fax 511 01 84
CCP / Postrekening 000-2005502-27

Autres distributeurs / Overige verkooppunten

Librairie européenne/ Europese Boekhandel
Avenue Albert Jonnart 50 / Albert Jonnartlaan 50
1200 Bruxelles / 1200 Brussel
Tél. (02) 734 02 81
Fax 735 08 60

Jean De Lannoy
Avenue du Roi 202 /Koningslaan 202
1060 Bruxelles / 1060 Brussel
Tél. (02) 538 51 69
Télex 63220 UNBOOK B
Fax (02) 538 08 41

CREDOC
Rue de la Montagne 34 / Bergstraat 34
Bte 11 / Bus 11
1000 Bruxelles / 1000 Brussel

DANMARK

J. H. Schultz Information A/S
EF-Publikationer
Ottiliavej 18
2500 Valby
Tlf. 36 44 22 66
Fax 36 44 01 41
Girokonto 6 00 08 86

BR DEUTSCHLAND

Bundesanzeiger Verlag
Breite Straße
Postfach 10 80 06
5000 Köln 1
Tel. (02 21) 20 29-0
Telex ANZEIGER BONN 8 882 595
Fax 20 29 278

GREECE

G.C. Eleftheroudakis SA
International Bookstore
Nikis Street 4
10563 Athens
Tel. (01) 322 63 23
Telex 219410 ELEF
Fax 323 98 21

ESPAÑA

Boletín Oficial del Estado
Trafalgar, 27
28010 Madrid
Tel. (91) 44 82 135

Mundi-Prensa Libros, S.A.
Castelló, 37
28001 Madrid
Tel. (91) 431 33 99 (Libros)
431 32 22 (Suscripciones)
435 36 37 (Dirección)
Télex 49370-MPLI-E
Fax (91) 575 39 98

Sucursal:

Librería Internacional AEDOS
Consejo de Ciento, 391
08009 Barcelona
Tel. (93) 301 86 15
Fax (93) 317 01 41

Llibreria de la Generalitat de Catalunya
Rambla dels Estudis, 118 (Palau Moja)
08002 Barcelona
Tel. (93) 302 68 35
302 64 62
Fax (93) 302 12 99

FRANCE

Journal officiel
Service des publications des Communautés européennes
26, rue Desaix
75727 Paris Cedex 15
Tél. (1) 40 58 75 00
Fax (1) 40 58 75 74

IRELAND

Government Publications Sales Office
Sun Alliance House
Molesworth Street
Dublin 2
Tel. (1) 71 03 09

or by post

Government Stationery Office
EEC Section
6th floor
Bishop Street
Dublin 8
Tel. (1) 78 16 66
Fax (1) 78 06 45

ITALIA

Licosa Spa
Via Benedetto Fortini, 120/10
Casella postale 552
50125 Firenze
Tel. (055) 64 54 15
Fax 64 12 57
Telex 570466 LICOSA I
CCP 343 509

Subagenti:

Libreria scientifica Lucio de Biasio - AEIOU
Via Meravigli, 16
20123 Milano
Tel. (02) 80 76 79

Herder Editrice e Libreria
Piazza Montecitorio, 117-120
00186 Roma
Tel. (06) 679 46 28/679 53 04

Libreria giuridica
Via XII Ottobre, 172/R
16121 Genova
Tel. (010) 59 56 93

GRAND-DUCHÉ DE LUXEMBOURG

Messageries Paul Kraus
11, rue Christophe Plantin
2339 Luxembourg
Tél. 499 88 88
Télex 2515
Fax 499 88 84 44
CCP 49242-63

NEDERLAND

SDU Overheidsinformatie
Externe Fondsen
Postbus 20014
2500 EA 's-Gravenhage
Tel. (070) 37 89 911
Fax (070) 34 75 778

PORTUGAL

Imprensa Nacional
Casa da Moeda, EP
Rua D. Francisco Manuel de Melo, 5
1092 Lisboa Codex
Tel. (01) 69 34 14

Distribuidora de Livros Bertrand, Ld.ª
Grupo Bertrand, SA
Rua das Terras dos Vales, 4-A
Apartado 37
2700 Amadora Codex
Tel. (01) 49 59 050
Telex 15798 BERDIS
Fax 49 60 255

UNITED KINGDOM

HMSO Books (PC 16)
HMSO Publications Centre
51 Nine Elms Lane
London SW8 5DR
Tel. (071) 873 2000
Fax GP3 873 8463
Telex 29 71 138

ÖSTERREICH

Manz'sche Verlags- und Universitätsbuchhandlung
Kohlmarkt 16
1014 Wien
Tel. (0222) 531 61-0
Telex 11 25 00 BOX A
Fax (0222) 531 61-81

SUOMI

Akateeminen Kirjakauppa
Keskuskatu 1
PO Box 128
00101 Helsinki
Tel. (0) 121 41
Fax (0) 121 44 41

NORGE

Narvesen information center
Bertrand Narvesens vei 2
PO Box 6125 Etterstad
0602 Oslo 6
Tel. (2) 57 33 00
Telex 79668 NIC N
Fax (2) 68 19 01

SVERIGE

BTJ
Box 200
22100 Lund
Tel. (046) 18 00 00
Fax (046) 18 01 25

SCHWEIZ / SUISSE / SVIZZERA

OSEC
Stampfenbachstraße 85
8035 Zürich
Tel. (01) 365 54 49
Fax (01) 365 54 11

CESKOSLOVENSKO

NIS
Havelkova 22
13000 Praha 3
Tel. (02) 235 84 46
Fax 42-2-264775

MAGYARORSZÁG

Agroinform
Budapest I. Kir.
Attila út 93
1012 Budapest
Tel. (1) 56 82 11
Telex (22) 4717 AGINF H-61

POLAND

Business Foundation
ul. Krucza 38/42
00-512 Warszawa
Tel. (22) 21 99 93, 628-28-82
International Fax&Phone
(0-39) 12-00-77

YUGOSLAVIA

Privredni Vjesnik
Bulevar Lenjina 171/XIV
11070 Beograd
Tel. (11) 123 23 40

CYPRUS

Cyprus Chamber of Commerce and Industry
Chamber Building
38 Grivas Dhigenis Ave
3 Deligiorgis Street
PO Box 1455
Nicosia
Tel. (2) 449500/462312
Fax (2) 458630

TÜRKIYE

Pres Gazete Kitap Dergi Pazarlama Dağitim Ticaret ve sanayi AŞ
Narlibahçe Sokak N. 15
Istanbul-Cağaloğlu
Tel. (1) 520 92 96 - 528 55 66
Fax 520 64 57
Telex 23822 DSVO-TR

AUTRES PAYS
OTHER COUNTRIES
ANDERE LÄNDER

Office des publications officielles des Communautés européennes
2, rue Mercier
2985 Luxembourg
Tél. 49 92 81
Télex PUBOF LU 1324 b
Fax 48 85 73
CC bancaire BIL 8-109/6003/700

CANADA

Renouf Publishing Co. Ltd
Mail orders — Head Office:
1294 Algoma Road
Ottawa, Ontario K1B 3W8
Tel. (613) 741 43 33
Fax (613) 741 54 39
Telex 0534783

Ottawa Store:
61 Sparks Street
Tel. (613) 238 89 85

Toronto Store:
211 Yonge Street
Tel. (416) 363 31 71

UNITED STATES OF AMERICA

UNIPUB
4611-F Assembly Drive
Lanham, MD 20706-4391
Tel. Toll Free (800) 274 4888
Fax (301) 459 0056

AUSTRALIA

Hunter Publications
58A Gipps Street
Collingwood
Victoria 3066

JAPAN

Kinokuniya Company Ltd
17-7 Shinjuku 3-Chome
Shinjuku-ku
Tokyo 160-91
Tel. (03) 3439-0121

Journal Department
PO Box 55 Chitose
Tokyo 156
Tel. (03) 3439-0124

CD-NB-12552-EN-C

NOTICE TO THE READER

All scientific and technical reports published by the Commission of the European Communities are announced in the monthly periodical **'euro abstracts'**. For subscription (1 year: ECU 92) please write to the address below.

Price (excluding VAT) in Luxembourg: Volume 2: ECU 15
Volumes 1 + 2: ECU 26

ISBN 92-826-2939-2

9 789282 629390

OFFICE FOR OFFICIAL PUBLICATIONS
OF THE EUROPEAN COMMUNITIES

L-2985 Luxembourg