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Multiattribute Risk Analysis in Nuclear Emergency Management

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Radiation protection authorities have seen a potential for applying multiattribute risk analysis in nuclear emergency management and planning to deal with conflicting objectives, different parties involved, and uncertainties. This type of approach is expected to help in the following areas: to ensure that all relevant attributes are considered in decision making; to enhance communication between the concerned parties, including the public; and to provide a method for explicitly including risk analysis in the process. A multiattribute utility theory analysis was used to select a strategy for protecting the population after a simulated nuclear accident. The value-focused approach and the use of a neutral facilitator were identified as being useful.

KEY WORDS: Nuclear emergency management; risk analysis; multiattribute utility theory (MAUT); decision conferences; uncertainty

1. INTRODUCTION

In Europe, the Chernobyl nuclear accident has focused attention on the need for developing better structured and coherent procedures for decision making on protective actions in nuclear emergency management. A nuclear accident develops fast, has major impacts on the environment and society, and is the subject of highly emotional feelings and beliefs among the public.

Decisions on countermeasures are not only driven by the need to avert the radiation dose to the population but are based on complex and multiattribute problems, involving, for example, monetary costs and sociopsychological factors, such as stress and anxiety. These decisions have far-reaching consequences, yet they often have to be made under severe time-pressure constraints and conditions of uncertainty. Moral and ethical values held by decision makers and stakeholders are as important as the technical issues about the consequences of radiation. Even some of the underlying assumptions in neutral risk assessments may contain value judgments. This complex situation thus places high demands on the decision-making processes. It is important to be able to identify and process both factual issues and value issues; see for example the Values in Decisions On Risk (VALDOR) Symposium[(1)] for a discussion.

In Finland, the radiation protection authorities have therefore seen a potential for applying multiattribute risk analysis in nuclear emergency management, especially in the training and planning processes, to deal with the conflicting objectives, different parties, and uncertainties that are inherent in such complex situations. This type of an approach is expected to be of assistance in at least the following three areas: to ensure that all the relevant attributes are considered in decision making; to enhance communication between the concerned parties, including the general population; and to provide a method for explicitly including risk analysis in the process. This article discusses some recent research that has been done on this subject in Finland.

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This study was part of RODOS (Real-time On-line DecisiOn Support), an ongoing European Union (EU) project on developing a support system for nuclear emergency management. The study builds on previous work done in this field,[2–7] from which the following conclusions have been drawn:

1. Decision conferencing is a promising way to support the process.
2. The structured approach offered by multi-attribute risk analysis is useful.
3. Good communication and understandable presentations of the data and options are essential.
4. The use of utility theory for risk handling is difficult, as the participants are not familiar or comfortable enough with the techniques.

An important goal of these exercises was thus to familiarize the decision makers with multiattribute risk analysis techniques, as well as to build a way of thinking that could be used in the improbable event of a real accident. The approach used was the spontaneous decision conferencing technique.[8] That is, a fast type of decision conferencing was used to ensure that the analysis could be conducted in the limited amount of time available. Hämäläinen *et al.*[7] discuss how this type of decision conferencing was applied.

Another possible approach is the decision analysis interview technique.[9] In a decision analysis interview, the analysts work individually with each decision maker to build the model and to elicit preferences. By focusing separately on each decision maker, analysts can ensure that all issues are clarified and that no misunderstandings arise; that is to say a better understanding of the complexities involved in the decision situation is achieved. This type of approach has been tested in another project with a similar nuclear-emergency setting.[10]

Decision analysis techniques have also been used in similar risk analysis approaches to environmental decisions and energy policies.[11–15]

This article presents a short description of nuclear emergency management in Finland and the RODOS project, followed by a general discussion of using decision analysis in nuclear emergency management and a case study. Main results are described and the needs for further research are clarified.

2. NUCLEAR EMERGENCY MANAGEMENT IN FINLAND

The basic principle in emergency management of nuclear accidents in Finland is that each administrative branch is responsible for emergency responses and preparedness arrangements in their own sector of authority. Hence, each ministry decides on countermeasures in their jurisdiction and presents matters to the State Council of Finland that require political commitment. The Ministry of the Interior is responsible for the overall coordination of actions within the central government, especially in the early phase of an accident.

The Radiation Act (592/1991) and Radiation Decree (1512/1991) on radiological protection determines the general principles taken into account in the protection of people against ionizing radiation. In exceptional radiation situations, the Ministry of the Interior is responsible for the planning, coordination, and overall leadership of urgent protective measures. The central legislation covering emergencies is the Act on Rescue Services (561/1999; which includes fire protection, rescue services, and civil protection). In the acute phase of an accident, this act delineates the rights and responsibilities of each administrative body involved, and the urgent protective measures to be implemented, such as sheltering of people and cattle, evacuation, decontamination, and other actions described in the contingency plans.

In domestic accidents, these operations are led by the regional fire chief (regional cooperation for rescue purposes is arranged between several municipalities). All relevant local authorities are represented in the steering group assisting the fire chief. At the province level, the province administration board—with all relevant sectors represented—and at the national level, the Ministry of the Interior, have the right to give orders related to rescue operations.

For decision making, all other relevant laws are also valid, and the corresponding authorities are responsible for decisions in those sectors. The distribution of responsibilities is as follows:

1. The Ministry of Social Affairs and Health is responsible for the health protection of the population (advice on iodine prophylaxis, control of drinking water, psychological aid, medical treatment, etc.), and for providing logistics for evacuated people.
2. The Ministry of Trade and Industry is responsible for food and trade restrictions. Reporting to the ministry are the National Food Administration Authority, which is responsible for food sold in retail stores, and the National Emergency Supply Agency (HVK), which is responsible for preparedness and planning of food supply for exceptional conditions.

3. The Ministry of Agriculture and Forestry is responsible for issues related to agriculture, forestry, and fisheries, and for the implementation of the agricultural and fishing policy of the EU.
4. The Ministry of the Environment is responsible for housing relocated population groups and reclamation of contaminated land (waste from decontamination).

Other relevant ministries and agencies in accident situations include the Cabinet Information Unit, which coordinates information provided to the public; the Ministry of Foreign Affairs, responsible for information provided to the foreign media on Finnish accidents; and the Ministry of Transport and Communication, responsible for communications (through the Finnish Broadcasting Company) and transportation-related issues.

The cases studied in this report were conducted in cooperation with the Radiation and Nuclear Safety Authority (STUK)—a regulatory body for radiological practices and nuclear safety, subordinate to the Ministry of Social Affairs and Health. The general duties of STUK regarding off-site management include

- assessing the radiation situation;
- predicting and assessing radiation-related health consequences;
- providing recommendations on countermeasures to other authorities; and
- performing radionuclide analyses.

The participants in these exercises are thus experts responsible for giving advice on appropriate countermeasures to political decision makers.

3. RODOS

Partly due to the varied response to the Chernobyl accident, both in and beyond the former Soviet Union, the European Commission proposed the development of RODOS, which aims to provide consistent and comprehensive support for off-site nuclear emergency management. It is designed to assess, present, and predict the consequences of an accident, and support the decision makers in choosing appropriate countermeasures. Ehrhardt and Weis[16] and the RODOS Web site[17] provide an in-depth description of the project.

The RODOS software is designed to be a decision support system for off-site nuclear emergency management. This implies that RODOS must be able to support a wide variety of decision makers at several different stages of an accident. The decision support provided is divided into four levels (as shown in Table I).

Table I. Decision Support Levels in Real-Time, On-Line Decision Support (RODOS)

Level 0	Acquisition and checking of radiological data, and their presentation (directly or with minimal analysis) to decision makers, along with geographical and demographic information available in a geographical information system
Level 1	Analysis and prediction of the current and future radiological situation (i.e., the distribution over space and time in the absence of protective actions) based upon monitoring and meteorological data and models
Level 2	Simulation of potential protective actions (e.g., provision of shelter, evacuation, issue of iodine tablets, food bans, and relocation), in particular, determination of their feasibility and quantification of benefits and disadvantages
Level 3	Evaluation and ranking of alternative protective action strategies in the face of uncertainty by balancing their respective benefits and disadvantages (e.g., costs, averted dose, stress reduction, social and political acceptability) taking in account societal value judgments as perceived by decision makers

Note: From Ahlbrecht *et al.*[2]

On the first level, RODOS merely organizes the incoming data and presents it to the decision makers. Increasing levels of support follow, ending at Level 3, where RODOS interacts with the decision makers, helping them to explore and develop their judgments and evaluations. In a sense, RODOS provides decision-making support only at Level 3; on the first three levels it mainly organizes and presents information.[2] The present study focuses on how Level 3 support could or should be implemented.

4. MULTIATTRIBUTE RISK ANALYSIS IN NUCLEAR EMERGENCY MANAGEMENT

Multiattribute risk analysis is a structured approach to decision making that employs systematic analyses to give decision makers a better understanding of the problem, and thus facilitates a better informed choice. The methodology of decision analysis can be implemented in a number of different ways. Keeney[18] divides the process into four steps: (1) structure the decision problem; (2) assess possible impacts of each alternative; (3) identify the decision makers' preferences and values, and (4) evaluate and compare alternatives. Other reviewers provide a more thorough description of fundamental decision analysis theory.[19–22]

The structured and systematic approach of multiattribute risk analysis helps decision makers go through each phase of the process in a logical and efficient manner. The methods include techniques for finding suitable alternatives among the various possible countermeasure strategies. Value trees help decision makers consider all factors that have an impact on the decision, including averted dose and cost, as well as sociopsychological and other factors.

Perhaps the greatest advantage of using multiattribute risk analysis is that it explicitly conceptualizes the underlying values in the decision-making process. When constructing the value tree, decision makers must think about which factors are important when deciding on countermeasures. At a later stage, they are asked to consider the necessary trade-offs and choose between them. The given-preference statements show how important each factor is relative to the others. The whole decision process thus follows a value-based approach.[23]

Decisions on countermeasures after a nuclear accident are plagued with uncertainties; for example, how severe the accident really is, what the weather will be, how the population will react, etc. It is necessary to consider these risks distinctly, and multiattribute risk analysis is a valuable tool in this process. Without such a tool, there is a danger that decision makers will implicitly add "safety margins" at any or each stage of the process, thus creating a safety "overkill." This is especially likely if there are several layers in the decision-making organization (e.g., experts, managers, and policy makers) with each group giving advice to the nexy level. This scenario is typical in nuclear emergency management.

Risk attitudes determine the acceptable risk levels, and sensitivity analyses reveal to decision makers how small changes in assumptions or data will affect the end result. Both give transparent results that can be assessed or modified at later levels.

A generic value tree can be shown to decision makers in the beginning of the process. This can help them choose the relevant factors and construct a value tree for that particular case. After a nuclear accident, there is often little time to make the far-reaching decisions on what countermeasures to employ. Using prestructured value trees is a way to save valuable time. By having a list of predefined attributes, the decision maker can quickly choose the relevant ones for that particular accident scenario and continue from there, confident that all important factors are included. Other parts of the process can also be preanalyzed. For example, sets of suitable risk attitudes can be presented to provide the decision maker with a starting point from which to proceed by making the necessary modifications to the suggested models.

The use of a neutral facilitator from outside the expert organization, as in decision conferencing, can also be beneficial to the decision-making process in nuclear emergency management. An outside facilitator familiar with decision analysis techniques can help decision makers in many ways. His or her experience with complex decision-making situations can steer the group to the relevant aspects and help them avoid typical pitfalls in the process—for example, "groupthink"[24] and biases caused by homogeneity in the group makeup. The facilitator's help might be needed especially in explaining mathematical concepts to nontechnical participants. A facilitator can ensure that all phases of the decision-making process are thoroughly examined, all relevant factors are included, and a well-founded decision is reached in the limited time available. For credibility reasons, the fact that there is an impartial facilitator involved, who does not belong to the organization making the decision, can also be important.

Depending on the goals of the process, the emphasis can be on different phases. Often, the "structuring" phase is very important in decision conferences involving multiple stakeholders. Facilitators successfully practice different approaches in the structuring phase, but the merits of these different approaches have not yet received much comparative analysis.[25]

Decisions on nuclear emergency management affect large population groups, and thus have important social and political impacts. The decisions taken must be explained and justified, and will be subject to critical evaluation long afterwards. Using decision analysis techniques will aid this process by providing a transparent and reconstructable process of decision making. The basis for the decisions can be found from the alternative countermeasures considered, the value trees used, and the preference statements given. Weighing the positive and negative consequences of each alternative provides a way to explain actions taken and actions omitted after the fact.

Decisions on countermeasures after a nuclear accident are almost always prepared by a group. The issues are complex, and participants from different areas of expertise must come together to find the right countermeasure strategy. Effective and clear models for communication are thus needed. The structured approach of multiattribute risk analysis can provide the group with a common framework from which to approach the issues. By defining each factor in the analysis and following a logical analytical sequence, multiattribute risk analysis enhances the communication between the concerned parties, and minimizes the risk of misunderstandings and confusion.

Multiattribute risk analysis provides a structured process of decision making. The method ensures that decision makers consider all aspects of the problem and explicitly bring forward their values and preferences. It is often the structuring and prioritization processes that bring the greatest gain from using a decision analysis approach.

5. CASE STUDY: EARLY-PHASE PROTECTIVE ACTION AFTER A NUCLEAR ACCIDENT

A series of decision conferences on nuclear emergency management were organized in Finland in the autumn of 1997 as part of the RODOS project. For a full report on these conferences see Hämäläinen *et al.*[7]

The decision conferences were held on the development of an early-phase countermeasure strategy for protecting the population after a simulated nuclear accident. Two simulated nuclear accident cases were used, and a total of four meetings were organized. The meetings were attended by national nuclear safety authorities and technical experts in the role of decision makers. In the case of a real accident, their job would be to assess the situation and give advice to higher level political decision makers (see Section 2).

The meetings were half a day long each and chaired by a facilitator, who was one of the authors (Hämäläinen). The facilitator guided the group through the multiattribute risk analysis techniques, and an assistant generated the model and performed the analysis on-line. The results were displayed on a wide screen. The software used put some restrictions on which analyses could be conducted and how the inputs could be given—for example, which elicitation techniques could be used, how uncertainties could be modeled, and how the results could be presented and analyzed. These limitations could be eliminated by using other software. It is important to note that the choice of software will influence the analysis, although the main issue is, of course, that the facilitator and analyst must be well familiar with the software and its capabilities.

In the first accident scenario, no uncertainties were assumed; however, in the second case uncertainty about the release was included. The 5%, 50%, and 95% release fractiles were calculated and presented to the participants.

These conferences focused on urgent protective actions, that is, iodine prophylaxis, providing shelter, and evacuation. The primary goals were to test the RODOS system and to study and extend the applicability of decision support systems for different situations. In the early hours of an accident, there is hardly time to model the decision to be taken; rather, the decision must be based on intervention levels developed and considered beforehand, and on guidance given by a decision support system. The conferences were designed to analyze how this modeling should be done and which factors are important. Whether to use prestructured value trees or other types of shortcuts is another issue that was studied. In the later phase of an accident, by contrast, there is usually both the time and the need to perform more extensive analyses.

International organizations have published their recommendations for generic intervention levels,[26] and in addition there are also suggested values for the trade-off between costs and averted dose. An important aim of the present work was to probe deeper into the recommendations, and to explicitly introduce the values and beliefs held by the decision makers in the decision-making process: the factors that need to be considered, the necessary value trade-offs, and how the uncertainties should be modeled and accounted for.

In the first session, a generic value tree (see Fig. 1) was constructed using a brainstorming approach. The value tree was designed to contain all factors that should be considered in deciding on countermeasures after a nuclear accident. At this phase of the analysis, no thought was given to the relative importance of the factors, which is why the first tree is rather large. Although a smaller value tree was later used in the actual analysis, this type of generic tree helps in ensuring that no significant factor might be inadvertently omitted. It can also be used afterward to show that all factors were initially considered in the process, including those that were later eliminated as having no significant impact on the decision. In the second accident case, the value tree in Fig. 2 was used in the final analysis. As can be seen, in the second scenario only six attributes were included.

The majority of the participants felt that this type of approach helped them to consider more aspects of the problem than they would otherwise have done. (Hämäläinen *et al.*[7] provide a detailed description of the participants' opinions and thoughts.) The use of a generic value tree from which the significant factors were developed especially helped to raise confidence in the analysis. The participants also felt that prestruc-

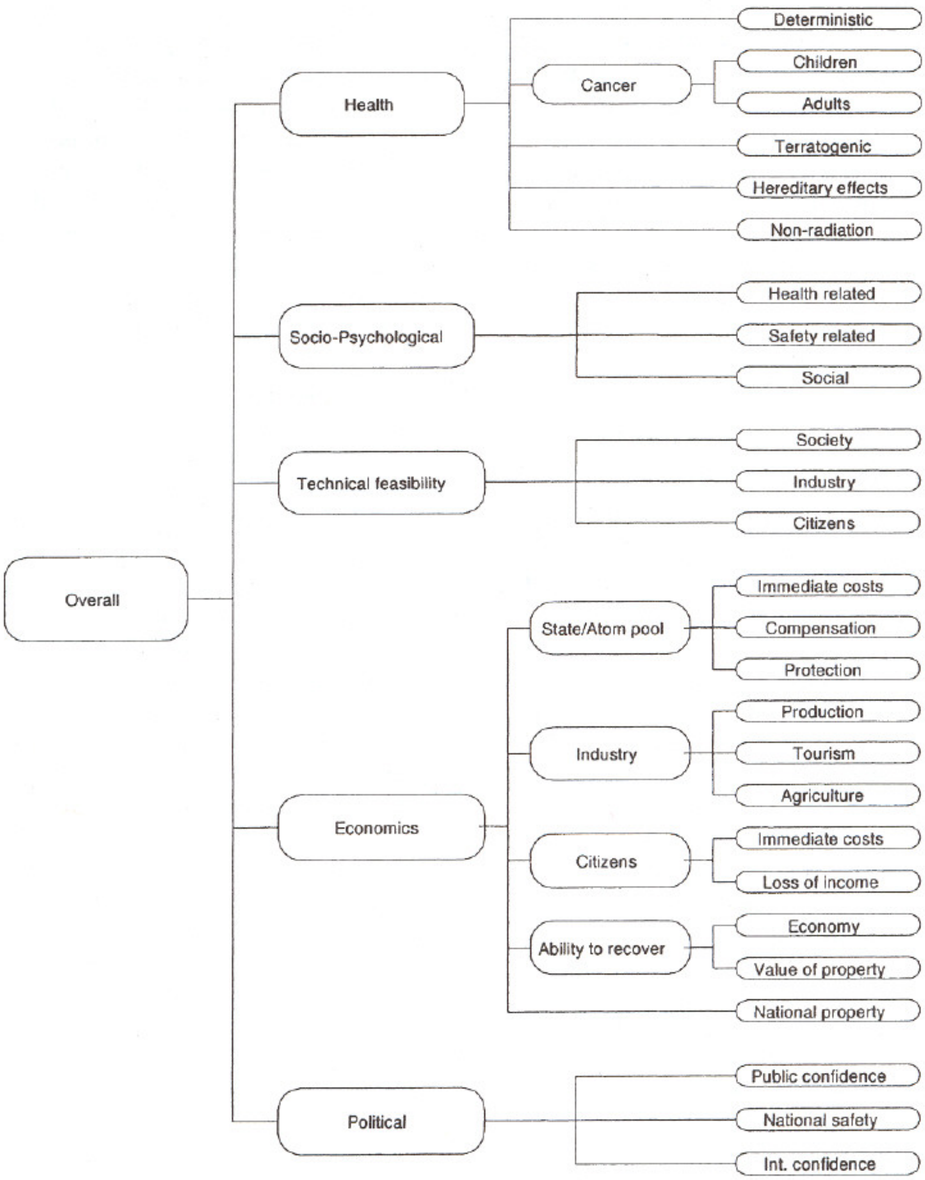

Fig. 1. Preliminary value tree constructed in a brainstorming session. It includes all possible factors that might need to be considered.

tured accident scenarios could be used to save time and help focus on the important issues. Predefined preference sets were, however, seen as more problematic.

In the conference, five different countermeasure strategies were constructed and analyzed. The impacts of each strategy are shown in Table II. Uncertainties regarding the magnitudes of the impacts are presented for three fractiles—5%, 50%, and 95%—corresponding to three different scenarios: optimistic, realistic, and pessimistic.

A three-stage system for constructing suitable strategies has been envisaged for RODOS.[16] This model would compute all possible combinations of actions and the areas where they would be used, and then apply certain decision rules to eliminate infeasible or clearly inferior strategies. The remaining options would be further analyzed, and a shortlist of suitable options would be generated. This model is not yet ready, however, so a different approach was followed. In particular, a group of experts created a set of alternative strategies, with the goal of covering a wide area of possible alternatives. The group con-

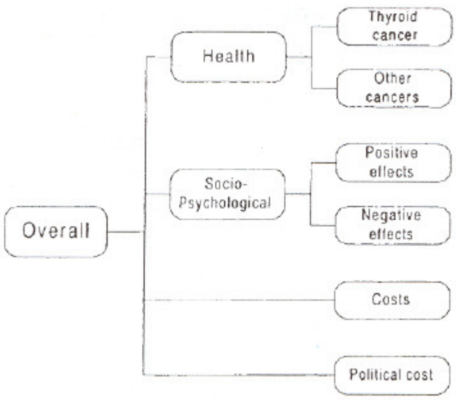

Fig. 2. Final value tree used in the second decision conference.

sisted of nuclear emergncy experts in planning of protective actions and who are in charge of preparing recommendations to the governmental decision makers. The strategies therefore ranged from doing nothing to evacuating a large area. It was pointed out to the participants that these options were only preliminary, and that the best course of action could probably be found by examining and combining a subset of the presented strategies. As the goal of this study, however, was to examine the use of multiattribute risk analysis techniques, the following set of optional strategies was seen as sufficient for this purpose:

Strategy 0: No additional countermeasures taken.

Strategy 1: Distributing iodine tablets and providing shelter in Rauma, a city of 30,000 inhabitants and 12 km south of the NPP. The number of people affected by sheltering and taking iodine is 40,600.

Strategy 2: Implementation of providing shelter in the city of Rauma and the closest areas around that city and distributing iodine tablets within an area almost to the city of Turku (i.e., 100 km away from the site). The number of people affected by sheltering is 56,200, and taking iodine is 88,500.

Strategy 3: Implementation of providing shelter in the same areas as in Strategy 2, but distributing iodine tablets in all areas affected by the accident (including both the cities of Turku and Tampere, for example). The number of people affected by sheltering is 56,200, and taking iodine is 1,023,200.

Strategy 4: Evacuation of Rauma after the cloud has passed the area, with provision of shelter and distribution of iodine tablets dur-

Table II. The Impacts of Each Strategy on the Different Attributes in the Second Phase of the Decision Conferences

Attribute	Unit	Fractile	Strategy 0	Strategy 1	Strategy 2	Strategy 3	Strategy 4
Health							
Thyroid cancer	Number of	5%	0	0	0	0	0
	cancer	50%	20	5	2	2	4
	incidents	95%	240	50	20	20	40
Other cancers	Number of	5%	0	0	0	0	0
	cancer	50%	22	20	20	20	12
	incidents	95%	320	286	288	286	204
Sociopsychological							
Positive effects	No change,	5%	0	100	10	10	0
	very positive	50%	0	75	50	45	40
	(0–100)	95%	0	50	90	80	80
Negative effects	No change,	5%	40	0	90	80	50
	very negative	50%	70	40	50	45	35
	(0–100)	95%	100	80	10	10	20
Costs	MECU[a]	5%	0.0	1.6	2.2	2.2	160.3
	MECU	50%	2.0	3.1	3.8	3.8	160.8
	MECU	95%	27.7	23.9	24.3	24.1	176.3
Political cost	No change—	5%	30	0	0	20	80
	very negative	50%	65	40	40	30	50
	(0–100)	95%	100	80	80	40	20

[a] MECU = million ECU, currently called EURO.

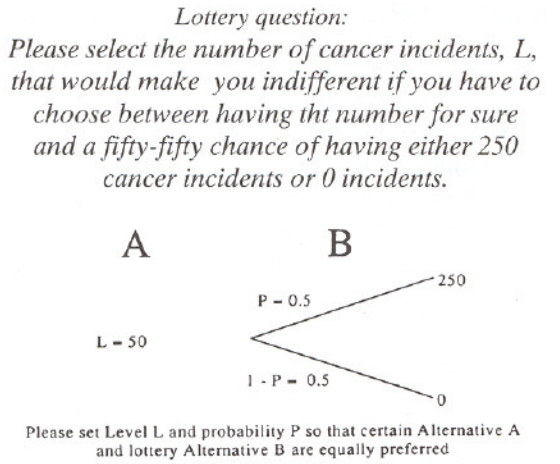

Fig. 3. Lottery question used in the second phase of the decision conferences.

ing the plume passage. The number of people affected by these actions is 40,600.

Because uncertainties were included, and the SMART (Simple MultiAttribute Rating Technique) and trade-off techniques were to be used for weighting, the shapes of the utility functions for the different attributes needed to be assessed.[19] The participants were asked to answer "lottery" questions of the type shown in Fig. 3. Resulting answers were tabulated individually rather than on the group level. The elicitation was done openly, and the whole group discussed the individual responses, so the resulting utility functions were used as the group's opinion. It was pointed out that the purpose of this exercise was not to produce a decision, but rather to help develop new insights into such a situation.

Only the utility functions for the two cancer attributes and the cost attribute resulted in nonlinear forms; the rest were linear. Figure 4 presents the shapes of the utility functions. The utility function for the costs attribute shows that the participants did not give much concern to money. It is only after the costs exceed about 130 million ECU that there is any significant decrease in the utility. When it comes to cancer, the participants seemed to be "risk seeking"; that is, they would rather take a risky option with the possibility of avoiding cancer totally, than the sure option of having some cancer incidents. This result might be partially due to the way in which questions were posed, and partially due to the fact that "zero incidents" was included. There is often a discontinuity point at zero, with the utility of reaching zero incidents being much higher than that of one incident.[27]

It is also important to consider the time frames involved. For example, thyroid cancer develops shortly after the accident. Leukemia, however, can appear decades later, and by then it can be difficult to identify the original cause of the disease. Should all of these effects be taken into account equally, or should some be discounted, and if so, which ones? How should the sociopsychological factors be assessed—the first reactions, or the feelings years after the accident, or a combination of both? These issues need to be analyzed in depth in future research.

The weights for the attributes were elicited both with the SMART technique[22] and with the trade-off method.[21] The nontechnical participants especially felt that SMART was easier to understand. The trade-off method was considered more difficult, and some participants had real problems understanding the underlying logic behind it. The resulting weights from both methods are given in Table III. The table also includes a case where only the 95% fractile (i.e., the pessimistic-case scenario) was used. That is, it was assumed that the 95% scenario would occur for sure, thus eliminating all uncertainties. This was done because it was noted that the decision makers had a tendency to concentrate on the worst-case scenario at the expense of the more likely ones. Therefore, it was seen as fruitful to examine what types of decisions such an approach would produce.

The resulting ranking when using the SMART method is presented in Fig. 5. The ranking for the pessimistic-case scenario is shown in Fig. 6. As can be seen from these figures, considering only the pessimistic-case scenario leads to a much higher level of intervention.

A linear additive utility model was used in the analyses. Keeney and von Winterfeldt[28] and Clemen[19] provide a more in-depth discussion on this model's validity and limitations.

Looking at the results, an observation can be made. The impact on cancer and costs in Table I is in many cases the same regardless of what strategy is chosen; Strategy 0 is worst in terms of thyroid cancer and Strategy 4 in terms of costs, but the remaining strategies score about the same on the cost and cancer attributes. Consequently, their ranking will be solely based on how well they score on the other attributes, for example, political costs. Nevertheless, most of the discussion emphasized the cancer attribute, and it also received a high weight in the analyses. How is it that the cost and cancer attributes cannot discriminate between Strategies 1, 2, and 3? One reason for this finding is the sparse population density and hence small number of cancer cases in the

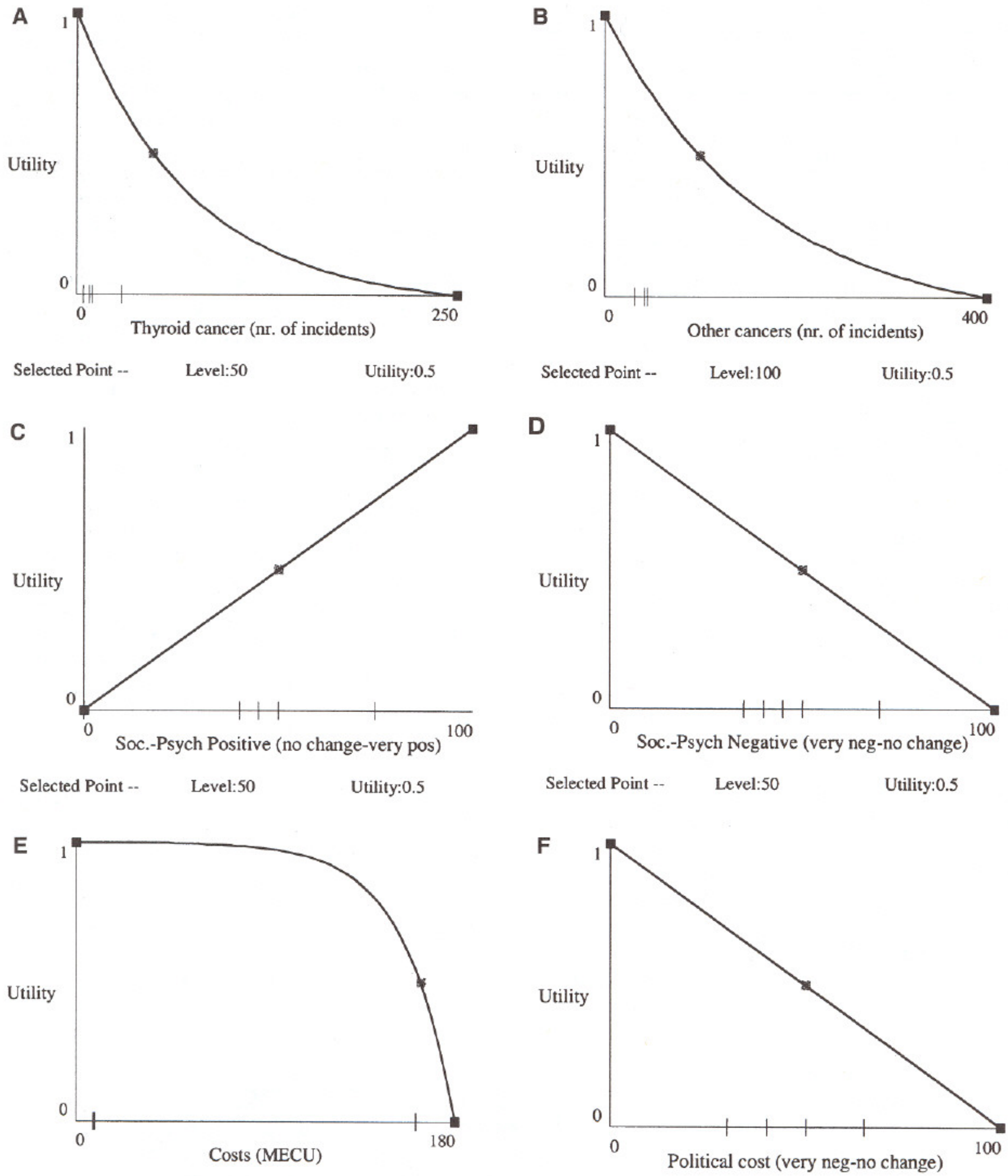

Fig. 4. Utility functions for the different attributes in the second phase of the decision conferences. (A) Thyroid cancer, (B) other cancers, (C) positive effects, (D) negative effects, (E) costs, and (F) political cost.

area where the plume hits after passing the city of Rauma. In addition, iodine prophylaxis is very cheap; no additional costs occur in the model when iodine is administered to over 1 million people (Strategy 3), instead of only 40,000 (Strategy 1).

This type of situation might easily occur when the range of possible countermeasure strategies is wide. Then the worst options will be screened out, but the analysis will have difficulties in discriminating between the remaining choices. One solution could

Table III. The Weights Given in the Second Decision Conference

Attribute	Worst level	Best level	SMART	Trade-off	SMART 95%
Thyroid cancer	240	0 (20)	0.33	0.21	0.40
Other cancers	320	0 (204)	0.26	0.10	0.12
Positive effects	0	100	0.03	0.03	0.04
Negative effects	100	0	0.10	0.10	0.08
Costs	180	0 (30)	0.03	0.05	0.04
Political cost	100	0	0.26	0.50	0.32

Note: The values given in parenthesis and in the last column refer to an elicitation where only the pessimistic scenario was considered.

be to use an iterative process. That is, a rough analysis first screens out the worst alternatives, and then a refined analysis looks more closely at the remaining strategy candidates. This idea will be adopted in future versions of RODOS.[2]

6. DISCUSSION

As previously mentioned, this case study showed that multiattribute risk analysis can improve decision making in nuclear emergency management. However, this approach was novel to many of the participants, and more training is needed to familiarize the decision makers with these tools. One of the conclusions is that, when using multiattribute risk analysis in nuclear emergency management, there must be sufficient understanding of the decision-modeling literature to avoid behavioral and procedural biases.

Decision conferencing is certainly useful in the later phases of an accident, when there is time to model the situation.[5,6,29] Then, the possibility for all stakeholders to learn and take part in the decision process is higher. By contrast, the specific decision conferencing approach evaluated in this study is meant to be adopted in the early phases of an accident. Since time is limited at that point, a common understanding and acceptance of the decision analysis procedures is a prerequisite. All in all, the results from this study are promising. However, further practice meetings must be organized to deepen insight into the features of the decision-making process in the early phases of an accident, and to familiarize decision makers with decision analysis techniques. The positive results obtained in the present study encourage continued research on how to implement decision conferencing in nuclear emergency management.

A current trend in decision support is to make more extensive use of the Internet. In the RODOS project, discussions have been held about using the web to transmit data, and to connect geographically isolated experts and decision makers. In a similar way, decision analysis could be performed using certain software[30,31] and the Internet. The Web could also be used to provide decision makers with other types of support: access to data banks, video footage of the accident, etc. As an example, real-time images from the affected population centers could show how the populace is reacting to the crisis. This information could then be used when deciding on countermeasures, and thus help to ensure a more appropriate response. The information could also be linked to the web-based decision analysis software and utilized online in the decision conference.

It should also be mentioned that this type of setting assumes a single decision stage. In reality, as was pointed out during the conferences, decisions could often be made in a sequential manner: first, warn the public; wait to discover how serious the accident is; and then, if necessary, employ stricter countermeasures. This type of approach was not followed here, but should be considered and tested in the future.

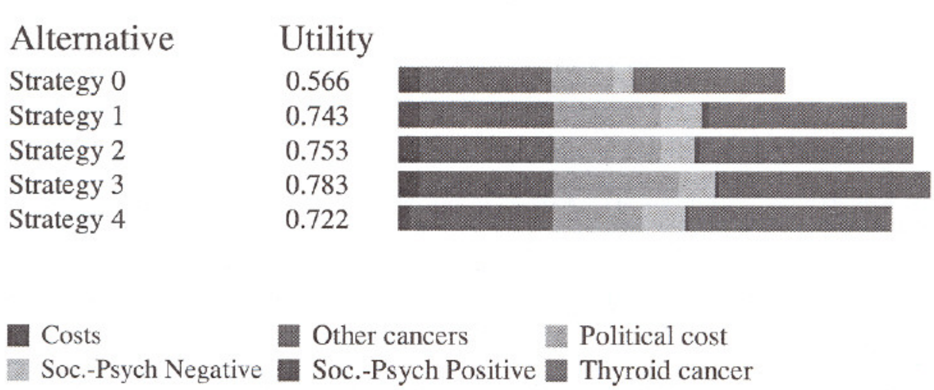

Fig. 5. Ranking of strategies with SMART.

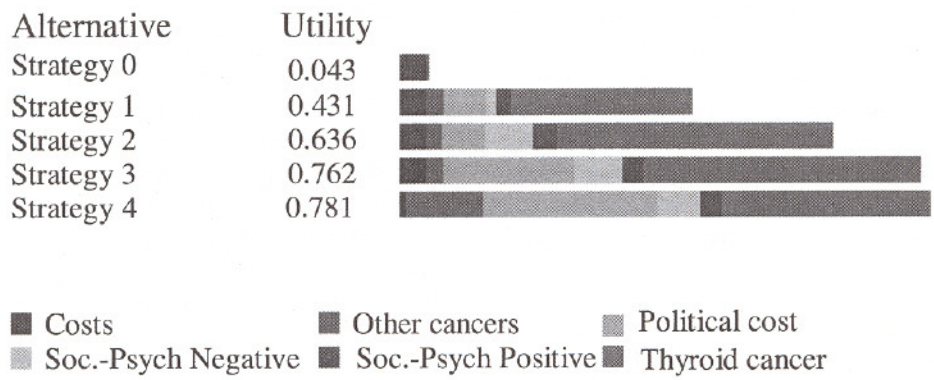

Fig. 6. Ranking of strategies for the 95% fractile case.

The participants unanimously felt that being able to explain and justify decisions afterward is important. The majority of the participants said that multiattribute risk analysis provides a transparent decision-making process that can be used for this purpose.

All in all, the findings in this study concur with previous research.[2–7] It can thus be said that decision conferencing, when applied in a customized manner suitable to the case at hand, is a promising approach. (In emergency situations, however, the format cannot be a day-long meeting, which was the original format suggested by Phillips.[29])

6.1. Process of Analysis

The participants felt that having a neutral facilitator was beneficial, both to keep the discussions focused and to ensure that the appropriate steps were taken in the right order to reach a well-founded decision. As not all of the participants were familiar with multiattribute risk analysis, it was also necessary to have an expert facilitator lead the conferences and assist in using the techniques.

The role of decision analysis software is also important. Software can help decision makers visualize the analysis, and can provide graphical sensitivity analyses, e.g., on the effects of changing the attribute weights. An easy-to-use software package can help the decision maker through the decision analysis phases, but it also limits flexibility and imposes assumptions and simplifications that can lead to nonoptimal decisions. Thus, it is important to understand the methodology used by the software as well as its limitations. At several times in the conferences, the software used was not able to provide the type of approach or output requested. The possibility to quickly conduct what-if analyses would have been especially valuable.

In the early phases of an accident, decisions must be taken quickly. This means that the procedures for making the decision must be fast and focused. Especially when there is so little time available, the procedures must be closely adapted to the intended user. Unfamiliar or nonrelevant procedures are not likely to be followed under times of stress. No matter what features are designed into a system, the users will either adapt the system to their needs, or else resist or even refuse to use the system if it does not meet their expectations and demands.[32–34]

In addition, there are also official regulations and procedures that must be followed (see section 2). Certain adjustments will therefore have to be made to standard multiattribute risk analysis methodology in order to customize it to the requirements of nuclear emergency management. As in previous studies,[6–7] it was noted that a thorough understanding of the decision-making process and the parties involved is essential, and more research is needed in this area.

6.2. Modeling the Decision Problem

Throughout the conferences, a great deal of time was spent on defining factors and terminology. There is a clear need to define the attributes in advance, so that the persons involved understand their correct and intended meanings. Some of the attributes used in this analysis were too vague. For example, the distinction between the sociopsychological attribute and the political cost attribute was not clear. This became even more evident when the impacts were to be evaluated.

There should also be a clear understanding of the appropriate countermeasures to be implemented. Issuing iodine tablets was a component in the strategy, but to whom should they be given? Should the tablets be taken only by children, and will adults comply this with recommendation? In Finland, larger residential dwellings are obliged to store iodine tablets, and small households are encouraged to purchase them. In a real situation, however, not all people may find them, and the effectiveness of iodine prophylaxis could therefore turn out to be quite low. Further examination is needed of other countermeasures and their feasibility.

All in all, the conferences showed how vital it is to have a clear and common framework for discussing the societal aspects of the problem. Explicitly defining the attributes, alternatives, and other factors reveals where there might be problems in understanding, and what is still missing. The participants felt that the multiattibute risk analysis approach helped them to communicate with one another and to include all opinions in the process.

Reality checks should be performed to see whether the results make sense. In nuclear emergency management, there are internationally accepted generic intervention levels to which possible countermeasures can be compared.[26] In addition, there are also suggested values for the relationship between costs and averted population dose.

The utility functions constructed in this exercise are problematic. The participants did not seem to fully understand the elicitation process, and it is not clear how well the functions capture their true risk attitudes. Overall, the handling of uncertainties is still an open issue. Should utility functions, scenario analyses, or some other approach be used? If fractiles are considered, which ones should be included? The concept of probability is also not straightforward. Presenting and handling uncertainties is thus an issue that needs more research, a conclusion also reached in previous studies.[2,6] Ongoing and future research[10] in the RODOS project will address this issue in more detail.

In the second phase of the decision conferences, uncertainties were included and studied. The general finding was that evaluating uncertainties is difficult, and that the incorporation of probabilities is problematic. In the conference, there was a tendency to ignore the other scenarios and concentrate only on the 95% fractile, which was probably due to the fact that the participants were not able to assess all the fractiles simultaneously. The participants were not familiar with utility theory, and were thus not able to use it with confidence. These findings are similar to those of earlier conferences.[2] However, the participants did feel that it is important to consider the risks explicitly, and that the multiattribute risk analysis approach provides a useful framework in this context.

The value tree was fairly easily constructed. An agreement was quickly reached on the factors to be included and those to be eliminated. One can argue that this was partially due to the relatively strong leadership of the experienced facilitator. The preliminary value tree acted as a guide for finding a suitable final version. However, when comparing the value trees used in the different exercises, it can be seen that they changed from exercise to exercise. This is only partly due to the fact that different value trees were needed for different scenarios, it is also an indication that the choice of attributes was not always obvious. More research is needed to determine which attributes to include in the initial tree, and how a generic tree can be constructed. At this point, it should be remembered that the format of the value tree can have an effect on the weights. In studies where an evaluation of nuclear waste disposal sites was conducted,[35–37] varying the value tree affected the weights.

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