STUK-A173 February 2000

Decision analysis interviews on protective actions in Finland supported by the RODOS system

R. P. Hämäläinen[1], K. Sinkko[2], M. Lindstedt[3],
M. Ammann[4], A. Salo[5]

---

[1] Helsinki University of Technology, System Analysis Laboratory
P.O.Box 110, FIN-02015 TKK, E-mail: raimo@hut.fi
[2] (author for correspondence) STUK – Radiation and Nuclear Safety Authority
P.O.Box 14, FIN-00881 HELSINKI, E-mail: kari.sinkko@stuk.fi
[3] Helsinki University of Technology, System Analysis Laboratory
P.O.Box 110, FIN-02015 TKK, E-mail: mats.lindstedt@hut.fi
[4] STUK – Radiation and Nuclear Safety Authority
P.O.Box 14, FIN-00881 HELSINKI, E-mail: michael.ammann@stuk.fi
[5] Lepolantie 54, FIN-00660 HELSINKI, E-mail: anneli.salo@pp.inet.fi

STUK • SÄTEILYTURVAKESKUS • STRÅLSÄKERHETSCENTRALEN
RADIATION AND NUCLEAR SAFETY AUTHORITY

ISBN 951-712-361-2
ISSN 0781-1705

Oy Edita Ab, Helsinki 2000

Sold by:
STUK • Radiation and Nuclear Safety Authority
P.O. Box 14   FIN-00881 HELSINKI   Finland
Tel. +358 9 759 881

HÄMÄLÄINEN, Raimo P, SINKKO, Kari, LINDSTEDT, Mats, AMMANN, Michael, SALO, Anneli. Decision analysis interviews on protective actions in Finland supported by the RODOS system (STUK-A173). Helsinki 2000, 57 pp.

ISBN 951-712-361-2
ISSN 0781-1705

Keywords nuclear emergency management, multiattribute risk analysis, decision support, decision analysis interviews

ABSTRACT

This work was undertaken in order to study the utilisation of decision analysis interviews and of the RODOS system when planning protective actions in the case of a nuclear accident. Six decision analysis interview meetings were organised. Interviewees were competent national safety authorities and technical level decision-makers, i.e., those who are responsible for drawing up advice or making presentations of matters to decision-makers responsible for the practical implementation of the actions. The theme of the meetings was to study how uncertainties could be included in the decision-making process and whether pre-structured generic attributes and value trees would help this process and save time. The approach was to present a generic value tree, a decision table and a selected information package at the beginning of the interviews. The interviewees then examined the suggested value tree in order to ensure that no important factors have been omitted and they made changes when necessary. Also, the decision table was examined and altered by some participants and some of them asked for further information on some issues. But all in all the selected approach allowed for more time and effort to be allocated to value trade-offs and elicitation of risk attitudes. All information was calculated with the support of the RODOS system.

Predefined value trees were found to ensure that all relevant factors are considered. The participants also felt that RODOS could provide the required information but, as in previous RODOS exercises, they found it more problematic to use decision analysis methods when planning countermeasures in the early phase of a nuclear accident. Furthermore, it was again noted that understanding the actual meaning of 'soft' attributes, such as socio-

psychological impacts, was not a straightforward issue. Consequently, the definition of attributes and training in advance would be beneficial. The incorporation of uncertainties also proved to be difficult and participants felt uneasy about probabilities.

The application of decision analysis in exercises has proven useful. Structuring the problem provided insight and many new issues could be analysed and discussed. Using a decision interview technique forces participants to think about the issue more carefully. Opinions seem to be more coherent and harmonised compared with earlier decision conferencing. Further meetings, however, need to be organised in order to deepen insight into the features of the decision-making process and to familiarise decision-makers with decision analysis techniques. More research is needed on how to implement decision conferencing or interviews in nuclear emergency management.

CONTENTS

page

ABSTRACT 3

1 INTRODUCTION 6

2 NUCLEAR EMERGENCY MANAGEMENT IN FINLAND 10

3 ACCIDENT SCENARIO AND PROTECTIVE ACTIONS 13

4 DECISION ANALYSIS INTERVIEWS 28

5 RESULTS OF INTERVIEWS 36

6 QUESTIONNAIRE 41

7 OBSERVATIONS ON INTERVIEWS 43

8 DECISION TREE 49

9 DISCUSSION 51

10 ACKNOWLEDGEMENT 53

11 REFERENCES 54

Document history 57

1 INTRODUCTION

The varied response to the Chernobyl accident both in and beyond the former Soviet Union above all demonstrated the need for generally accepted procedures and models to ensure an integrated and coherent response to possible future accidents. Therefore the European Commission commissioned the development of RODOS, a Real-time On-line DecisiOn Support system. This is designed to assess, present and predict the consequences of an accident and to support decision-makers in choosing appropriate countermeasures. See Ehrhardt and Weis (1997) or the RODOS homepage at http://resy.fzk.de for a more detailed 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 capable of supporting a wide variety of decisions-makers at several different stages of an accident. The decision support provided is divided into four levels (Table I).

On the first level RODOS merely organises the incoming data and presents it to the decision-makers. Levels that provide an ever-increasing support follow, ending at level 3, where RODOS interacts with the decision-makers, helping them to explore and develop their judgements and evaluations. In a sense RODOS provides decision-making support only at level 3, whereas on the other levels it mostly organises and presents information (Ahlbrecht *et al*, 1997).

As part of the RODOS project STUK arranged a series of decision conferences in 1997. These conferences dealt with decision-making in the early phase of a nuclear accident and were arranged in co-operation between STUK and the System Analysis Laboratory (SAL), Helsinki University of Technology (Hämäläinen et al. 1998). To embrace the decision-making process in the later phases of an accident another series of decision conferences was envisaged. The aim was to continue the work started with the first series of conferences and, in particular, to study and apply decision analysis techniques and the RODOS system in the decision-making of later phase protective actions.

Table I. *Decision support can be provided at various levels (Ahlbrecht et al, 1997).*

Level of decision support	
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., sheltering, evacuation, issue of iodine tablets, food bans, and relocation), in particular determination of their feasibility and quantification of their 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 account of societal value judgements as perceived by decision-makers.

The first series of conferences reached their objectives in structuring the decision problem, in value analysis, in demonstrating the role and value of utility analysis in nuclear emergency management and in familiarising the participants in the conferences with the concepts used in performing this analysis. The primary approach was to use a decision conferencing format to analyse early countermeasures.

The objectives of the first and second series of conferences are given in Hämäläinen et al., 1998. However, given the novelty of the decision conferencing approach in the radiation protection community, some questions remained unresolved. There was also little time to concentrate on the different aspects in this multi-stage process. For this reasons there was a desire to complete the analysis, this time by approaching the problem with an interview technique and by tackling intrinsic uncertainties with other methods than those used in the previous study. The interviews were held at the beginning of 1999 and the results are presented in this report.

Two decision conferences are planned to extend the work commenced with the interviews concerning early protective actions to the later phase of decision-making. Both interviews and these two decision conferences are based on the same accident scenario. All in all, three decision points are envisaged. In the threat of a release or evenduring an ongoing release urgent actions to protect humans, that is iodine prophylaxis, sheltering and evacuation, are of major concern. The interviews documented in the present report are concerned with this decision point. A first conference is meant to deal with urgent measures to protect livestock during the first day following an accident. A second one with follow-up and more extensive countermeasures applicable to milk and dairy products at a time when the fallout pattern and composition are measured.

Decisions on countermeasures are not only driven by the need to avert the radiation dose to the population but are complex and multi-attribute problems involving, for example, monetary costs and socio-psychological factors, such as stress and anxiety. These decisions have far-reaching consequences, but often have to be taken under severe time pressure and conditions of uncertainty. Moral and ethical values held by decision-makers and stakeholders are as important as the technical issues involved in the consequences of an accident. Even some of the underlying assumptions in neutral risk assessments may contain value judgements. This complex situation thus places high demands on a DSS and on the decision-making processes. It is important to be able to identify and process both factual issues and value issues.

International organisations have published their recommendations for generic intervention levels and in addition there are also recommended values for the trade-off between costs and averted dose (EU Radiation Protection 87, IAEA Safety Series No. 109). An important aim of the present work is to explore deeper into the recommendations and to introduce explicitly into the decision-making the values and beliefs held by the decision-makers. What are the factors that need to be considered in the decision-making process, what are the necessary value trade-offs, and how should the uncertainties be modelled and accounted for?

For previous work in the RODOS project, see e.g. Ahlbrecht et al (1997), Bäverstam et al (1997), French (1996), French et al (1993, 1995) or Hämäläinen et al (1998). The main findings from these have been that decision conferencing is a promising way to analyse the problem and to support the decision-making process. The structured approach offered by multi-attribute risk analysis has been found useful. Good communication and comprehensible presentations of the data and options are essential. The use of utility theory for risk handling has been found difficult as the participants have not been sufficiently familiar or comfortable with the techniques used. Decision analysis techniques have also been used in related areas such as environmental decisions and energy policies Apostolakis and Pickett (1998), Hämäläinen (1988, 1990, 1991, 1992), Hämäläinen and Karjalainen (1992) and Keeney (1980) are examples of work in related fields.

In the present work decision analysis interviews were used. A decision analysis interview is a one-to-one interactive process where the analyst works individually with each decision-maker. Decision analysis interviews have previously been used to increase stakeholders' participation in environmental decision-making (Marttunen and Hämäläinen, 1995).

This report is structured as follows. The legal and organisational decision-making structure for nuclear emergency management in Finland is described in Section 2. The RODOS system was used as far as possible to assess the attributes that have to be considered when deciding between different countermeasure strategies, for example, cancer cases and monetary costs. Assessments of these 'hard' attributes were then assembled in decision tables, which constituted the central part of an information package presented to the participants. This is set out in Section 3. The interviews, how they were conducted, the attribute tree, the decision table, preference weighting, sensitivity analysis - all this is described in Section 4. The findings are stated in Section 5. Section 6 reflects on the interviewees' opinions on the usefulness of this particular decision analysis approach and Section 7 gathers observations made throughout the interviews and their analysis. As a pointer for future work, Section 8 outlines a model that would be closer to the sequential nature of the real decision-making process. The report ends with a more general discussion.

2 NUCLEAR EMERGENCY MANAGEMENT IN FINLAND

The basic principle in nuclear emergency management in Finland is that each branch of administration is responsible for emergency responses and preparedness arrangements in their own sector of authority. Hence each ministry decides on countermeasures in their sector of authority and presents matters to the Council of State in issues requiring political commitment. The Ministry of the Interior is responsible for the overall co-ordination of actions within the central government, especially in the early phase of an accident. The information on which decisions are based and organisations participating in decision-making may vary depending on the phase of an accident.

The Act and Decree on radiological protection stipulates the general principles to be taken into account in the protection of people against ionisation radiation. In exceptional radiation situations the Ministry of the Interior is responsible for planning, co-ordination, and overall leadership when deciding on and implementing the urgent protective measures. Such situations normally require measures based on other laws than the Radiological Protection Act. The central Act in emergencies is the Act on Rescue Services (which covers fire protection, rescue services and civil protection).

In the acute phase of an accident the above Act stipulates the rights and responsibilities of those who decide on and implement urgent protective measures, such as sheltering of people, evacuation, decontamination and other urgently needed actions described in the contingency plans.

These operations are led in domestic accidents by the regional fire chief (regional co-operation for rescue purposes is organised between several municipalities). All relevant local authorities are represented in the leading group assisting the fire chief.

At the provincial level the provincial administration board (all relevant sectors represented) and at the national level the Ministry of the Interior can issue orders related to rescue operations, if necessary. A co-ordination group consisting of representatives from all relevant ministries and expert organisations is set up by the Ministry of the Interior for the acute phase.

In the case of nuclear accidents abroad with transboundary contamination the Ministry of the Interior leads the operation. The Ministry of the Interior is also responsible for questions of international assistance and co-ordination of emergency response by all relevant ministries and authorities.

In the acute phase it is the responsibility of the Ministry of Interior to co-ordinate, both vertically and horizontally, the preparation of the decisions. Later, in the aftermath of an emergency normal administrative practice is resumed.

For decision-making all other relevant laws are valid and the corresponding authorities are responsible for decisions in these sectors. Thus the distribution of responsibilities is as follows:

The Ministry of Social Affairs and Health is responsible for the health protection of the population (advice on iodine prophylaxis in the contingency plans, control of drinking water, psychological aid, social support, medical treatment etc.), and for providing logistics for evacuees.

The Ministry of Trade and Industry is responsible for food and trade restrictions. Subordinated to this 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 under exceptional conditions.

The Ministry of Agriculture and Forestry is responsible for measures in agriculture, forestry and fisheries, and for implementation of the agricultural and fishing policy of the EU.

The Ministry of the Environment is responsible for housing of relocated population groups and reclamation of contaminated land (waste from decontamination).

Other relevant bodies and ministries in accident situations include the Cabinet Information Unit, which co-ordinates the information activities. The Ministry of Foreign affairs is responsible for issuing information to foreign media on Finnish accidents and the Ministry of Transport and

Communication is responsible for communications (Finnish Broadcasting Company), transport etc.
The cases studied in this report were conducted in co-operation with the Radiation and Nuclear Safety Authority (STUK), which is the Regulatory Body for radiological practices and nuclear safety and is subordinated to the Ministry of Social Affairs and Health.

The duties of STUK regarding off-site management are inter alia: to assess the radiation situation, to predict and assess radiation-related health consequences and, as a safety authority, to give recommendations on countermeasures to other authorities, and to perform radionuclide analyses.

The participants in the interviews were experts responsible for giving advice to political decision-makers on appropriate countermeasures.

3 ACCIDENT SCENARIO AND PROTECTIVE ACTIONS

For the purpose of analysis it was assumed that a hypothetical core-damaging and containment leak accident had occurred at the Olkiluoto nuclear power plant in Finland, leading to contamination of the environment. The chosen time of the accident was at the end of June, on a working day. The probability of occurrence in real life of such a containment failure accident leading to a significant release is estimated to be less than one in 1,000,000 per reactor-year for this NPP.

There were many uncertainties in the event, but only uncertainties about the release fractions were considered. A release was assumed to have definitely happened and it was assumed that the weather for the next few hours could be predicted[1]. Furthermore, the branch of the containment event tree was identified and therefore the nuclear safety experts were able to give probability distributions for the release. The 5%, 50% and 95% fractiles of the cumulative distribution functions were used to encompass the uncertain situation[2]. Based on these release fractions the probability distributions of the impacts of the accident were calculated. The time of the interviews was set when the release had just started and measurement data were about to come in. Uncertainties in the dispersion calculation were not included in the impact distributions.

The release scenario for the Olkiluoto nuclear power plant was based on a containment failure classification. There were several possible containment event tree branches in each containment failure group and the release fractions given in Table II were due to one possible branch in the early containment failure group. These values were based on an assessment of the NPP's and STUK's nuclear safety experts. The progress of the accident was described as follows:

---

[1] Weather data were actually based on past on-site measurements.

[2] The cumulative distribution gives the probability that a release magnitude is less or equal than the particular magnitude.

'The initiator is loss of external grid due to a minor earthquake at 06:00. The same quake breaks the backup battery cabinets, since the batteries are very heavy and the design of the cabinets did not take earthquakes into account[3]

The automatic overpressure protection of the reactor is successful and the hydraulic SCRAM succeeds. The containment is successfully isolated. The overpressure protection valves close successfully. During the next 45 minutes, the auxiliary feedwater cannot be started and the manual pressure reduction of the reactor fails. Thus the pressure cannot be lowered to the operating range of the low pressure emergency cooling system.

50 minutes after the initiator, the core begins to melt under high pressure. The pressure reduction of the vessel can be recovered before 90 minutes, so the pressure of the vessel can be lowered. The core cooling systems cannot be recovered before the end of the recriticality time window, so there is no recriticality in the core. The flooding of the lowerdrywell (pedestal) is successfully carried out before the vessel breach.

After 2 hours, the vessel breaches into water-filled containment and the containment fails due to a corium spray hitting penetrations above the water level. Thus, there is a direct path from the containment atmosphere to the

Table II. *The Release fractions assumed for the hypothetical accident at Olkiluoto, 'early containment failure'. The release fractions are 5%, 50% and 95% fractiles of the containment failure groups cumulative distribution.*

Nuclide group	**Release fraction**		
	5% fractile	**50% fractile**	**95% fractile**
Noble gases	$4.7 \cdot 10^{-1}$	$4.9 \cdot 10^{-1}$	$5.1 \cdot 10^{-1}$
Iodine total	$2.1 \cdot 10^{-4}$	$1.2 \cdot 10^{-2}$	$1.3 \cdot 10^{-1}$
Alkaline-group (Cs, Rb)	$2.0 \cdot 10^{-4}$	$9.2 \cdot 10^{-3}$	$1.1 \cdot 10^{-1}$
Tellurium-group (Te, Se, Sb)	$2.0 \cdot 10^{-5}$	$6.1 \cdot 10^{-3}$	$9.2 \cdot 10^{-2}$
Alkaline earth-group (Sr, Ba)	$3.4 \cdot 10^{-6}$	$3.1 \cdot 10^{-4}$	$3.1 \cdot 10^{-2}$
Ruthenium-group (Ru, Mo, Tc)	$1.1 \cdot 10^{-7}$	$3.7 \cdot 10^{-6}$	$1.6 \cdot 10^{-3}$
Lanthanide-group La, Nb, Zr, Cm, Ce, Nd, Pm, Sm, Eu, Pu, refr. Ox. Nb, Zr)	$4.6 \cdot 10^{-8}$	$1.2 \cdot 10^{-5}$	$3.1 \cdot 10^{-3}$

---

[3] TVO has modified these cabinets recently.

reactor building, bypassing the filter and stack. The reactor building remains intact, and since it is very large, some deposition also occurs in the reactor building. The corium remains under water.' (Niemelä 1997)

In this accident up to a few tens' percent of the fission products were assumed to have been released into the environment. The release began two hours after shutdown, at 08:00, and lasted for 12 hours. The release rate was not constant, i.e. the initial intense release went down roughly exponentially in 12 hours. The effective release height was 50 m, which corresponded roughly to an initial sensible-heat release rate of a few megawatts (the venting occurs at a height of 10 m).

It was assumed that this was the state of knowledge at about 08:00, when the release had just started. The task of the participants was to decide on countermeasures to protect the inhabitants of threatened municipalities. The first information they needed was the area threatened and the estimated arrival time of the plume in different municipalities (Figure 1). A prediction of the radiological situation was also needed. In our case this meant a forecast of accident consequences for each fractile of the source term distribution. The calculations were made with the atmospheric dispersion and deposition models of RODOS, e.g. PROGNOSE98/ATSTEP[4]. Models within RODOS have a fixed computation grid, currently 40 x 40 grid elements. In order to cover the whole area where urgent protective measures should be considered, the resolution was set to 2 x 2 km^2, corresponding to a computation area of 80 x 80 km^2. Figure 1 gives an impression of this computation area.

Exposure of individual members of the public may be incurred by various pathways. The dispersion and dose model takes into account external irradiation from the passing plume and from ground deposits and internal exposure from the inhalation of radioactive materials[5]. The projected dose accumulated in the first hours or in a day (during the plume passage) was of especial interest since it is the relevant quantity for expressing the risk of deterministic health effects. Furthermore, it allowed the derivation of the

---

[4] PROGNOSE98/ATSTEP is a segmented Gaussian plume model for the atmospheric dispersion within RODOS. It was used within this work to assess both activity concentrations and doses. But it also fed subsequent models, e.g. the early emergency simulation model EMERSIM with time-series of dose-rates.

[5] The ingestion pathway is optionally added by the terrestrial food-chain and dose module FDMT.

avertable dose, which in turn is the relevant quantity for measuring the benefit of countermeasures. For practical reasons we have chosen an integration time of one day. All these doses were calculated under normal living conditions, thus taking into account the shielding effect of houses.

The effective dose that incurs due to exposure to theafore-mentioned pathways and the absorbed thyroid dose in children was computed and included in an information package. Figures 2, 3 and 4 show the thematic maps of the estimated effective doses for the three fractiles 95%, 50% and 5%, respectively.

The first concern for taking decisions on interventions is that all possible efforts should be made to prevent serious deterministic health effects. The projected dose to the highly exposed and radiosensitive groups should be used as a predictor of the likelihood of these effects (Safety Series No. 109). In our

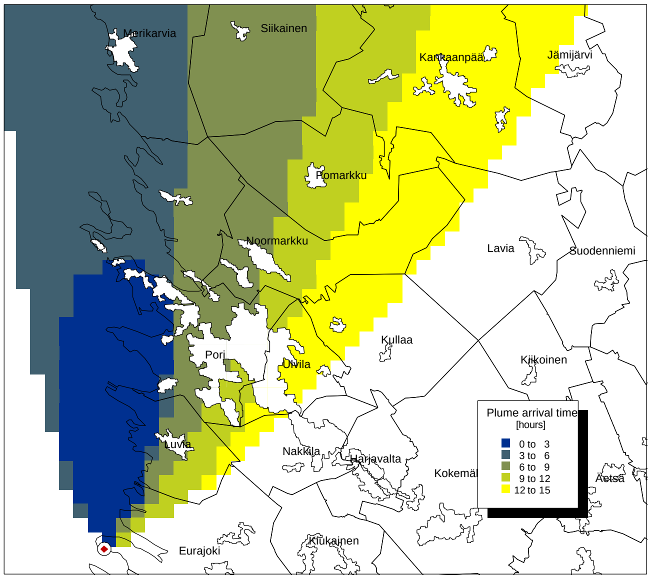


Figure 1. *Elapsed time from the start of the release before the plume reaches different locations.*

scenario the highest doses were expected to occur at the seaside (see Figure 2). In inhabited areas thresholds for deterministic health effects were not likely to be exceeded, not even with a source term corresponding to the 95% fractiles.

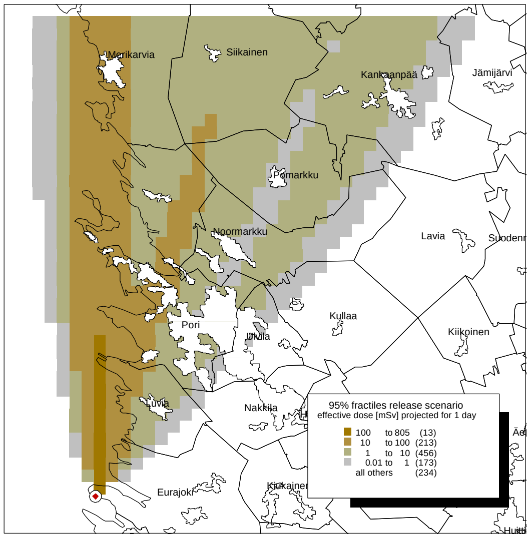


Figure 2. *The spatial effective dose (mSv) distribution due to the 95% fractile release scenario.*

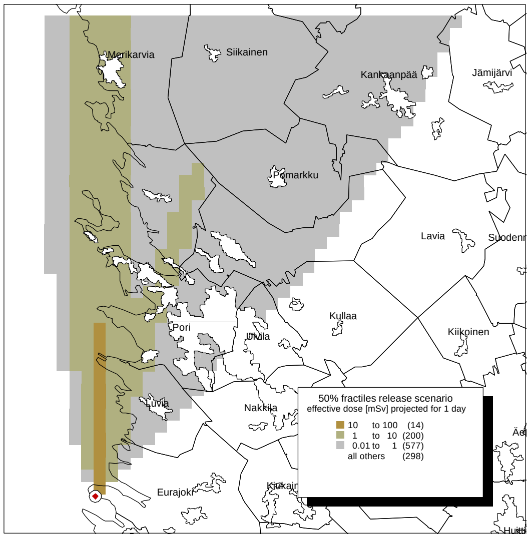


Figure 3. *The spatial effective dose (mSv) distribution due to the 50% fractile release scenario.*

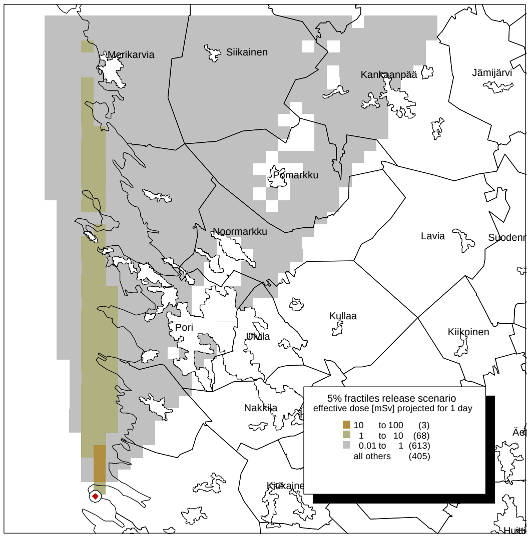


Figure 4. *The spatial effective dose (mSv) distribution due to the 5% fractile release scenario.*

The basic principles for taking decisions on interventions call for justification and optimisation of the actions. Both can be accomplished by a decision analysis, which was approached with the multi-attribute utility theory (MAUT). In practice, protective actions have to be implemented in well-defined areas which very likely correspond to administrative units. Within this report municipalities were regarded as the basic administrative units for intervention. Hence, benefits and harm introduced by protective actions had to be aggregated within municipalities. Strategies were then drawn up by telling which bundle of protective actions may be applied in which municipality. Prerequisite for this procedure was to simulate protective actions with the same time schedule everywhere throughout the computation grid.

The early emergency simulation model EMERSIM of RODOS was used to assess, in terms of doses and costs, the consequences of taking any protective action. This model works primarily with action levels which, when exceeded, mark the area whose population has to be protected. Alternatively, intervention areas can be marked graphically. However, the prototype version of RODOS used did not directly support the concept of municipalities. This is why it was decided to simulate a protective action throughout the computation grid with EMERSIM and aggregate data within municipalities by tools coming with MAPINFO, a commercial GIS.

In each municipality any of the following single actions could be considered:

- no protective action;
- intake of stable iodine tablets before the plume arrival;
- sheltering before the plume arrives and throughout its passage;
- sheltering in combination with intake of stable iodine tablets;
- precautionary evacuation.

A countermeasure strategy could be drawn up by telling which option is taken in each municipality. In the given scenario, within the computation area there are 13 municipalities that are affected by the plume and hence there are 5^{13} possibilities of drawing up a strategy. This vast number had to be drastically reduced in order to provide a manageable set for finding an optimal strategy or to perform a decision analysis. This could be achieved by screening out unfeasible, impractical and clearly mediocre ones, e.g. by applying dose criteria and other constraints.

The following constraints or rules could be applied when forming the countermeasure strategies in this type of accident scenario:

In the threat phase of an accident the decision on protective action or strategies to be implemented close to the site, will be based on plant status since radioactive materials released from nuclear fuel can be quickly spread to the environment. According to the Finnish NPP guide (YVL 7.4) 'if the estimates are that the plant transient leads to severe reactor damage, it is recommendable to carry out evacuation in the plant vicinity in an area with a ca. 5 km radius. In the same way, it is necessary to prepare for the intake of stable iodine by intensifying or supplementing emergency preparedness, if necessary. Gradual evacuation is recommendable at the latest when an accident has reached a phase where a reactor core melt is assumed to have occurred. It is advisable to carry out evacuation according to need in an area extending to a ca. 20 kilometres' distance from the facility'.

Later, farther away from plant when uncertainty is reduced by measurements or if we consider protection against radiation without uncertainties, projected dose i.e. total dose to be expected if no action is taken or intervention levels expressed as avertable dose, which will be averted by a protective action, are radiological attributes in considering actions or to be used as criteria.

According to the intervention levels published by the European Commission in Radiation Protection 87 sheltering is generally recommended when 'a few to a few tens' mSv is avertable and for evacuation the avertable dose should be in the range of 'a few tens to a few hundreds' mSv. The corresponding range for iodine prophylaxis is 'some tens to a few hundred' mGy avertable dose to the thyroid. A straightforward application of internationally recommended intervention levels in our context turned out to be problematic. Looking at Table III it can be seen that, even for such a large release as given by the 95% fractiles, the intervention levels for evacuation are not exceeded in any municipality and those for sheltering only in Merikarvia. The intake of iodine tablets would only be recommended in four municipalities (Table IV). NB, it is assumed in calculations that iodine prophylaxis is fully effective which is not the case in real life. Looking at Figure 2 we gain a different picture. There, the intervention level for sheltering is obviously exceeded in at least parts of

Table III. *Average effective dose (mSv) within municipalities if the options no action, issue of stable iodine tables, sheltering, iodine and sheltering or evacuation were implemented. Values are based on the 95% release scenario.*

Municipality	Normal Living	Iodine	Sheltering	Iodine & Sheltering	Evacuation
Merikarvia	19.61	11.84	11.60	8.03	0.00
Luvia	5,97	3,70	3,56	2,51	0,00
Pori	4,70	2,88	2,80	1,96	0,00
Siikainen	4,64	2,98	2,86	2,11	0,00
Pomarkku	1,27	0,79	0,77	0,55	0,00
Noormarkku	1,16	0,72	0,69	0,49	0,00
Eurajoki	0,89	0,55	0,55	0,39	0,00
Kankaanpää	0,66	0,42	0,40	0,29	0,00
Ulvila	0,37	0,22	0,22	0,15	0,00
Jämijärvi	0,01	0,01	0,01	0,00	0,00
Kullaa	0,00	0,00	0,00	0,00	0,00
Nakkila	0,00	0,00	0,00	0,00	0,00
Lavia	0,00	0,00	0,00	0,00	0,00

Table IV. *Average thyroid dose in adults (mGy) within municipalities if the options no action, issue of stable iodine tables, sheltering, iodine and sheltering or evacuation were implemented. Values are based on the 95% release scenario.*

Municipality	**Normal Living**	**Iodine**	**Shelter**	**Iodine & Shelter**	**Evacuation**
Merikarvia	258.95	0.00	155.37	0.00	0.00
Luvia	75,52	0,00	45,31	0,00	0,00
Pori	60,63	0,00	36,38	0,00	0,00
Siikainen	55,49	0,00	33,29	0,00	0,00
Pomarkku	16,03	0,00	9,62	0,00	0,00
Noormarkku	14,92	0,00	8,95	0,00	0,00
Eurajoki	11,23	0,00	6,74	0,00	0,00
Kankaanpää	7,93	0,00	4,76	0,00	0,00
Ulvila	4,90	0,00	2,94	0,00	0,00
Jämijärvi	0,12	0,00	0,07	0,00	0,00
Kullaa	0,05	0,00	0,03	0,00	0,00
Nakkila	0,01	0,00	0,01	0,00	0,00
Lavia	0,01	0,00	0,00	0,00	0,00

different municipalities. The reason for this discrepancy certainly lies in the averaging process[6] used to aggregate doses within municipalities.

In addition to intervention levels, feasibility of actions screens out a great number of strategies. There were only two hours between SCRAM and the start of the release and hence very little time to plan and implement actions. Large population groups cannot be evacuated within this time. It was assumed that only the relatively small municipalities closest to the site, i.e. Eurajoki and Luvia, have a realistic chance of being evacuated in time. In contrast, intake of stable iodine tables was not thought to pose a problem, since in Finland residential units are obliged to keep iodine tables available and small households are encouraged to purchase tablets. Also, sheltering can be relatively easily implemented, given that the public can be informed in due time before the rush to schools and workplaces starts.

Equality of treatment was also taken into consideration, another constraint. In most circumstances, municipalities closer to the site should receive at least the same level of protection as municipalities farther away.

Within the RODOS project, the course expert system CES has been developed to cope with this constraint satisfaction problem (Papamichail and French, 1997). Nadia Papamichail tailored a stand-alone version of the CES for this elicitation exercise to test its applicability. She adopted the concept of municipalities and assumed that a countermeasure is applied throughout a municipality. By applying the constraints the CES generated a manageable set strategies, i.e. a set of municipalities and the actions taken there.

The effective dose and the thyroid dose for children were calculated as background information for the participants. In Table III are given the average effective doses within affected municipalities when the afore mentioned countermeasures were applied (95% fractile release scenario). Table IV presents similar values for the average thyroid dose[7].

For the purpose of a detailed decision analysis six strategies were defined and they are shown in Figure 5. They were developed by holistically applying the constraints discussed above. Each protective action averts doses, but

---

[6] Collective dose per capita within a municipality.

[7] The thyroid dose for children is believed to be 2.2 times higher.

countermeasures also imply monetary costs, put a burden on the people affected, etc. Aggregating the potential effects of countermeasures within the municipalities that participate in a strategy provides for the main assessment of the 'hard' attributes of the decision table. For example, the collective effective dose averted by a strategy is the sum of dose savings that can be achieved within each of the participating municipalities. A similar claim can be made, at least as a first approximation, for the number of persons directly affected, or even for the costs that incur from implementing the countermeasure. It is worth noting that the number of people directly affected and the costs of implementing a afore mentioned strategy are not dependent on the severity of the accident (see Tables V-VII).

Tables V - VII show for the 95%, 50% and 5% fractiles, respectively, the 'hard' input to the preliminary decision table (Table VIII), which was finally distributed to the interviewee. Collective doses are stated both as projected doses and in terms of averted doses. Strategy 0 provides the baseline when no actions are taken.

Other, non-radiological attributes that influence the decision on urgent protective actions are dealt with in the next section. Also Hämäläinen et al., 1998 gives a wider discussion on attributes and their definitions useful for urgent protective action planning.

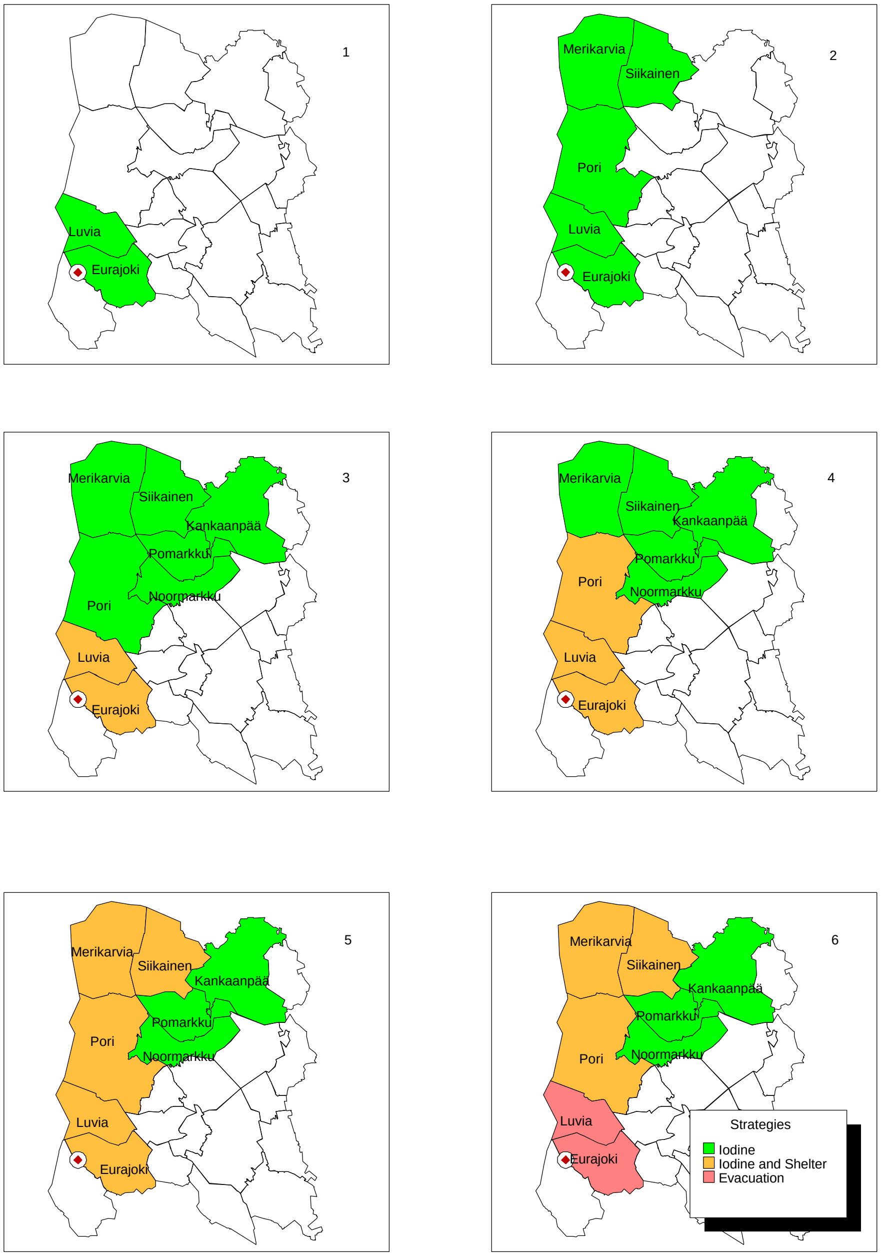


Figure 5. *Strategies for the decision analysis concerning urgent protective actions. They are numbered 1 to 6 from the upper left to lower right.*

***Table V**. The performance of the strategies measured in terms of number of people affected, costs, doses and cancers. Values are based on the 95% release scenario.*

	STRATEGIES						
Attribute	**0**	**1**	**2**	**3**	**4**	**5**	**6**
People in iodine area [No]	0	7740	81060	103401	103401	103401	95661
People in sheltering area [No]	0	0	0	7740	75469	81060	73320
People in evacuation area [No]	0	0	0	0	0	0	7740
Cost due to sheltering [MFIM]	0.0	0.0	0.0	1.9	18.1	19.5	17.6
Cost due to evacuation [MFIM]	0.0	0.0	0.0	0.0	0.0	0.0	13.1
PROJECTED							
Collective thyroid dose [manSv]	5764.9	5460.7	345.0	99.3	99.3	99.3	99.3
Thyroid cancer deaths [No]	4.6	4.4	0.3	0.1	0.1	0.1	0.1
Thyroid cancer incidence in children [No]	47.6	45.1	2.8	0.8	0.8	0.8	0.8
Collective effective dose [manSv]	446.8	437.7	284.2	272.1	209.8	194.9	184.7
Other cancer deaths [No]	13.7	13.7	13.7	13.5	10.3	9.6	9.1
Other cancer incidence [No]	27.4	27.4	27.4	26.9	20.7	19.2	18.2
AVERTED							
Collective thyroid dose [manSv]	0.0	304.2	5419.9	5665.6	5665.6	5665.6	5665.6
Thyroid cancer deaths [No]	0.0	0.2	4.3	4.5	4.5	4.5	4.5
Thyroid cancer incidence in children [No]	0.0	2.5	44.7	46.7	46.7	46.7	46.7
Collective effective dose [manSv]	0.0	9.1	162.6	174.7	237.0	252.0	262.1
Other cancer deaths [No]	0.0	0.0	0.0	0.2	3.4	4.1	4.6
Other cancer incidence [No]	0.0	0.0	0.0	0.5	6.7	8.2	9.2

Table VI. *The performance of the strategies measured in terms of number of people affected, costs, doses and cancers. Values are based on the 50% release scenario.*

	STRATEGIES						
Attribute	**0**	**1**	**2**	**3**	**4**	**5**	**6**
People in iodine area [No]	0	7740	81060	103401	103401	103401	95661
People in sheltering area [No]	0	0	0	7740	75469	81060	73320
People in evacuation area [No]	0	0	0	0	0	0	7740
Cost due to sheltering [MFIM]	0.0	0.0	0.0	1.9	18.1	19.5	17.6
Cost due to evacuation [MFIM]	0.0	0.0	0.0	0.0	0.0	0.0	13.1
PROJECTED							
Collective thyroid dose [manSv]	528.3	500.4	31.6	9.1	9.1	9.1	9.1
Thyroid cancer deaths [No]	0.4	0.4	0.0	0.0	0.0	0.0	0.0
Thyroid cancer incidence in children [No]	4.4	4.1	0.3	0.1	0.1	0.1	0.1
Collective effective dose [manSv]	40.6	39.7	25.7	24.4	16.9	15.1	14.2
Other cancer deaths [No]	1.2	1.2	1.2	1.2	0.8	0.7	0.7
Other cancer incidence [No]	2.5	2.5	2.5	2.4	1.7	1.5	1.4
AVERTED							
Collective thyroid dose [manSv]	0.0	27.9	496.7	519.2	519.2	519.2	519.2
Thyroid cancer deaths [No]	0.0	0.0	0.4	0.4	0.4	0.4	0.4
Thyroid cancer incidence in children [No]	0.0	0.2	4.1	4.3	4.3	4.3	4.3
Collective effective dose [manSv]	0.0	0.8	14.9	16.2	23.6	25.5	26.3
Other cancer deaths [No]	0.0	0.0	0.0	0.0	0.4	0.5	0.5
Other cancer incidence [No]	0.0	0.0	0.0	0.1	0.8	1.0	1.1

Table VII. *The performance of the strategies measured in terms of number of people affected, costs, doses and cancers. Values are based on the 5% release scenario.*

	STRATEGIES						
Attribute	**0**	**1**	**2**	**3**	**4**	**5**	**6**
People in iodine area [No]	0	7740	81060	103401	103401	103401	95661
People in sheltering area [No]	0	0	0	7740	75469	81060	73320
People in evacuation area [No]	0	0	0	0	0	0	7740
Cost due to sheltering [MFIM]	0.0	0.0	0.0	1.9	18.1	19.5	17.6
Cost due to evacuation [MFIM]	0.0	0.0	0.0	0.0	0.0	0.0	13.1
PROJECTED							
Collective thyroid dose [manSv]	9.1	8.7	0.5	0.2	0.2	0.2	0.2
Thyroid cancer deaths [No]	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Thyroid cancer incidence in children [No]	0.1	0.1	0.0	0.0	0.0	0.0	0.0
Collective effective dose [manSv]	5.0	5.0	4.8	4.6	2.5	1.9	1.8
Other cancer deaths [No]	0.2	0.2	0.2	0.2	0.1	0.1	0.1
Other cancer incidence [No]	0.5	0.5	0.5	0.5	0.2	0.2	0.2
AVERTED							
Collective thyroid dose [manSv]	0.0	0.5	8.6	9.0	9.0	9.0	9.0
Thyroid cancer deaths [No]	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Thyroid cancer incidence in children [No]	0.0	0.0	0.1	0.1	0.1	0.1	0.1
Collective effective dose [manSv]	0.0	0.0	0.3	0.5	2.6	3.1	3.3
Other cancer deaths [No]	0.0	0.0	0.0	0.0	0.1	0.1	0.2
Other cancer incidence [No]	0.0	0.0	0.0	0.0	0.2	0.3	0.3

4 DECISION ANALYSIS INTERVIEWS

A decision analysis interview is a one-to-one interactive process where the analyst works individually with each decision-maker. The personal interviews help to ensure that the modelling is correctly done and that the issues are understood correctly. Decision analysis interviews have previously been used to increase stakeholders' participation in environmental decision-making (Marttunen and Hämäläinen, 1995).

The interviews all had a common structure. See Figure 6 for an overview of the process. The participants in this study consisted of six persons, 4 radiation safety experts, 1 psychologist familiar with nuclear emergency management and 1 decision analysis expert. The group of people was selected to represent a variety of viewpoints, but being closely enough involved in nuclear emergency management issues to possess the necessary background information and experience.

The interviews were conducted on a one-to-one basis and computer software was used for the value elicitations and to calculate the results. The interviews lasted on average about two hours. After the elicitation process the ranking was shown and discussed. If anything unexpected was found, it was further examined. Sensitivity analyses were performed and at the end of the interview the participants were asked to fill in a questionnaire.

The accident scenario and countermeasure strategies described in the previous section were prepared in advance by the work group and shown to the participants at the beginning of the interview. In addition to numerical tables (see Tables II – IV), graphical maps (see Figures 1 - 5) were shown to illustrate the issues. An expert group was also available to answer any questions that the participants had about the accident.

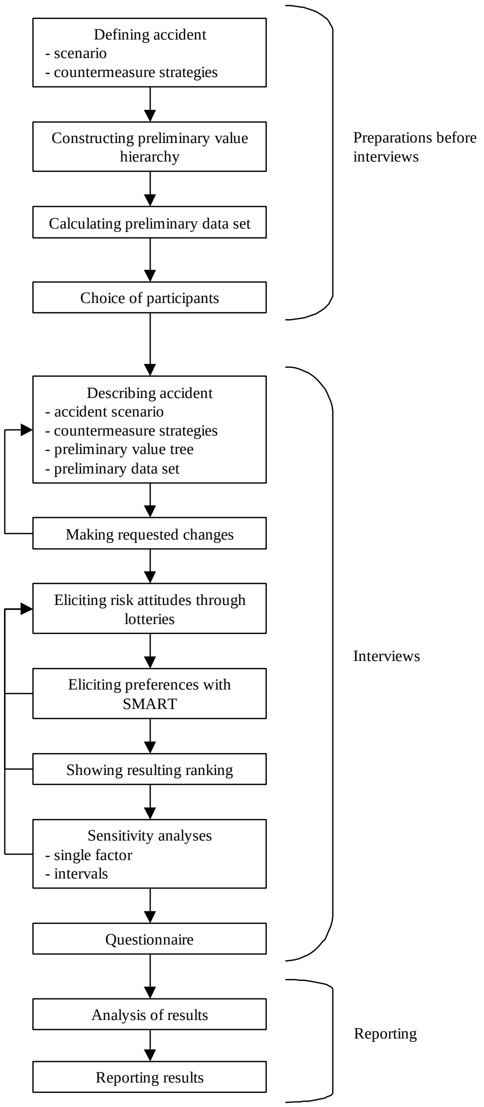


Figure 6*. Stages of decision analysis interviews.*

A preliminary value tree (see Figure 7), constructed using experiences gained in earlier exercises (Hämäläinen et al 1998), was also shown and discussed.

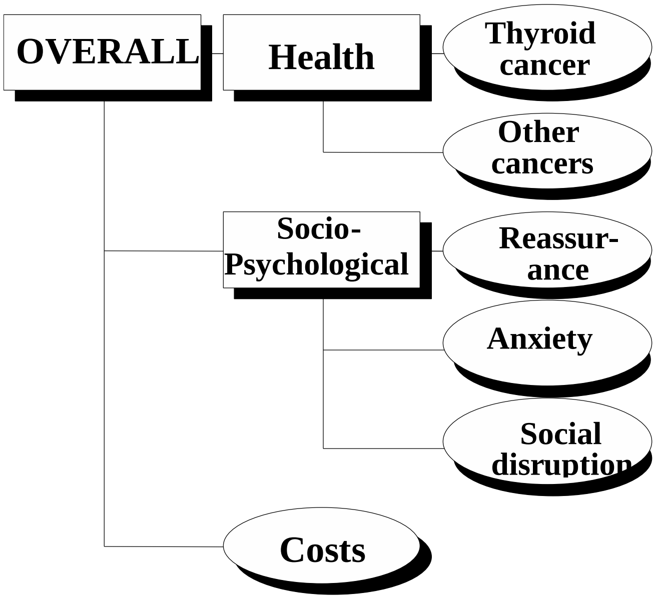


Figure 7*. Preliminary value tree shown to participants.*

The attributes suggested and their definitions are as follows:

Number of *Thyroid cancer incidents in children* and number of *Other cancer incidents***.** Stochastic health effects are likely to occur if large population groups are exposed to radiation, even though the individual doses were quite small. These two attributes could also be measured as projected collective dose to the public (manSv) or as the number of cancer deaths caused by the accident. Mortality is different, though. Whereas it is believed that about 10% of the thyroid cancer incidence result in death this fraction is about 50% for other cancer incidence. Thus depending on the choice of unit, different impressions of the accident are given.

Reassurance of the population (positive effects). In the long run, appropriate and reasonable extensive actions may reassure the people living in the affected area. Especially measures that people can implement themselves are most effective in reducing stress (direct rating).

Anxiety of the population **(***negative effects).* A majority of the persons living in the contaminated area may show varying degrees of stress reactions in response to an accident. But stress may also be introduced by the protective actions. The severity of an accident will also be perceived through the protective measures taken (direct rating).

Social disruption (negative effects). Disruptions in the social network, e.g., when evacuation or relocation is taken (direct rating).

Monetary Costs (EURO). The sum of direct and indirect costs of protective actions. Cancer treatment costs and losses to GDP caused by fatalities should not be included in this attribute in order to avoid double counting, i.e. not to convert cancers into costs.

A list of other possible attributes was also shown; statistical non-radiation fatalities, individual non-radiation fatalities, dose to the workers, anxiety of the workers, feasibility. It was explained that these attributes had been excluded from list as not being of major concern for the decision, already accounted for (all strategies were considered equally feasible), or not possible to incorporate meaningfully into the analysis (individual non-radiation fatalities).

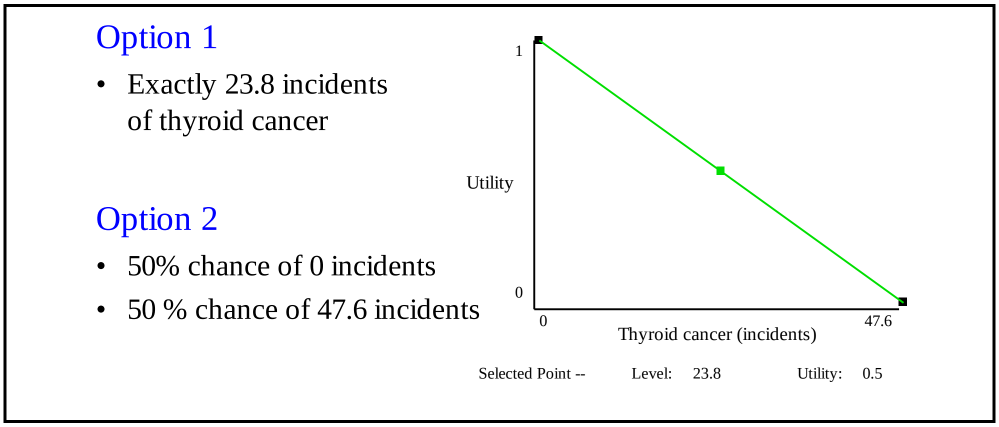
It was, however, also pointed out that this was a preliminary value tree and that changes were possible. In all cases the attributes were discussed and in one case a change was made (see the next section for the results).

Based on the accident scenario and countermeasure strategies the possible outcomes had been estimated. For each strategy the outcome for each of the six attributes was given (see Table VIII). All three fractiles, i.e. 5%, 50% and 95%, were considered. The number of cancer incidents and costs had been assessed with the RODOS software. The preliminary values for 'soft' attributes were assessed by the work group, but the participants were asked to consider if changes were needed to those outcomes assessed by direct rating.

Table VIII. *Decision table.*

			STRATEGIES						
		Unit	**0**	**1**	**2**	**3**	**4**	**5**	**6**
Thyroid cancer incidents	5%	No	0.1	0.1	0	0	0	0	0
	50%	No	4.4	4.1	0.3	0.1	0.1	0.1	0.1
	95%	No	47.6	45.1	2.8	0.8	0.8	0.8	0.8
Other cancer incidents	5%	No	0.5	0.5	0.5	0.5	0.2	0.2	0.2
	50%	No	2.5	2.5	2.5	2.4	1.7	1.5	1.4
	95%	No	27.4	27.4	27.4	26.9	20.7	19.2	18.2
Reassurance	5%	0-100	0	30	40	40	40	40	40
	50%	0-100	0	20	30	40	50	60	60
	95%	0-100	0	40	50	60	80	100	100
Anxiety	5%	-100-0	0	-30	-50	-60	-80	-80	-100
	50%	-100-0	0	-10	-20	-30	-60	-60	-80
	95%	-100-0	0	0	-10	-20	-40	-40	-60
Social disruption	all	-100-0	0	0	0	0	0	0	-100
Costs	all	MFIM	0	0	0	1.9	18.1	19.5	30.7

After requested changes to the value tree and the outcomes had been made, the forms of the utility functions were assessed using lotteries (see Figure 8). Two options were presented, an exact outcome and an option where there was a 50-50 chance of receiving the worst or best level. By iteration the indifference points were established. To provide a further explanation of what was asked, the following example was given. "Imagine that you have two methods of treating the patients. An old and well-known method that you know will help some people, but still result in exactly 23.8 incidents (alternative A). Then there is a new, advanced method (alternative B) which, if it works, will cure all patients. However, the method has not been tested and there is only a fifty-fifty chance that it will work. If it does not work, then you will have 47.6 incidents. Which method do you prefer?"



Option 1

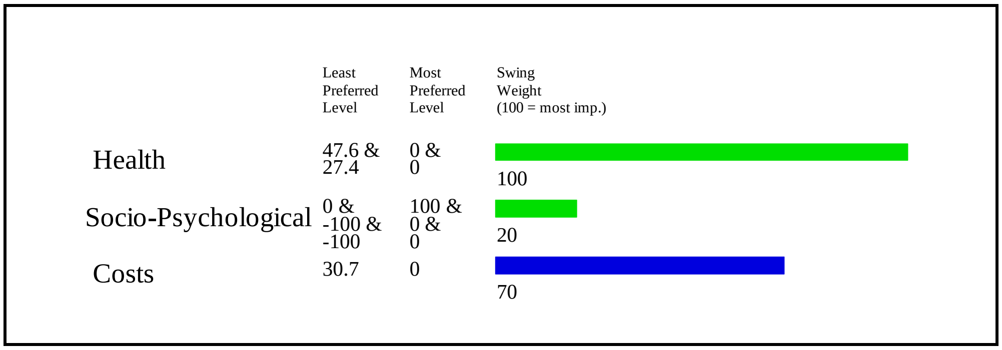
- Exactly 23.8 incidents of thyroid cancer

Option 2

- 50% chance of 0 incidents
- 50 % chance of 47.6 incidents

Figure 8. *Type of lottery question asked to elicit utility functions.*

The preference weights were elicited with the SMART[8] technique (von Winterfeldt and Edwards 1986). It was done in a hierarchical manner with a top-down approach. That is, first the weights for the higher level attributes were elicited (see Figure 9) and then the weights for the lower level attributes. Figure 10 contains an example of ranking.



	Least Preferred Level	Most Preferred Level	Swing Weight (100 = most imp.)
Health	47.6 & 27.4	0 & 0	100
Socio-Psychological	0 & -100 & -100	100 & 0 & 0	20
Costs	30.7	0	70

Figure 9. *Example of value elicitation using* SMART.

---

[8] In the SMART technique the weights are calculated by ranking the importance of the changes in the attributes from the worst attribute level to the best level and then by giving the least important attribute a score of 10 and the rest of the attributes a scoring relative to that.

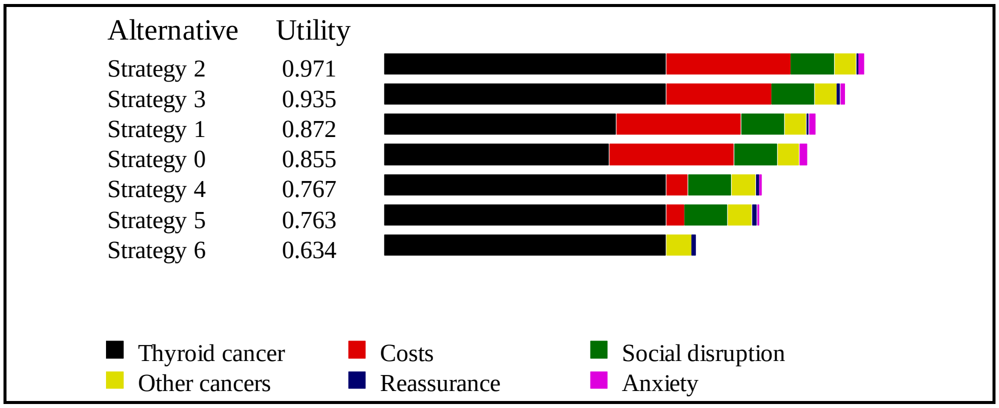


Figure 10. *Example of ranking.*

The sensitivity analyses were performed using two different approaches. First, conventional single factor sensitivity analyses were done to check the robustness of the ranking. See Figure 11 for an example. A new type of sensitivity analysis using intervals was also demonstrated. For this part another software, called WINPRE (downloadable at http://www.hut.fi/Units/SAL/Downloadables/), which allows intervals, was used. The software includes an interval version of the SMART procedure. This is a special case of PAIRS (Preference Assessment by Imprecise Ratio Statements) and can be called simple PAIRS = SPAIRS (Salo and Hämäläinen 1992).

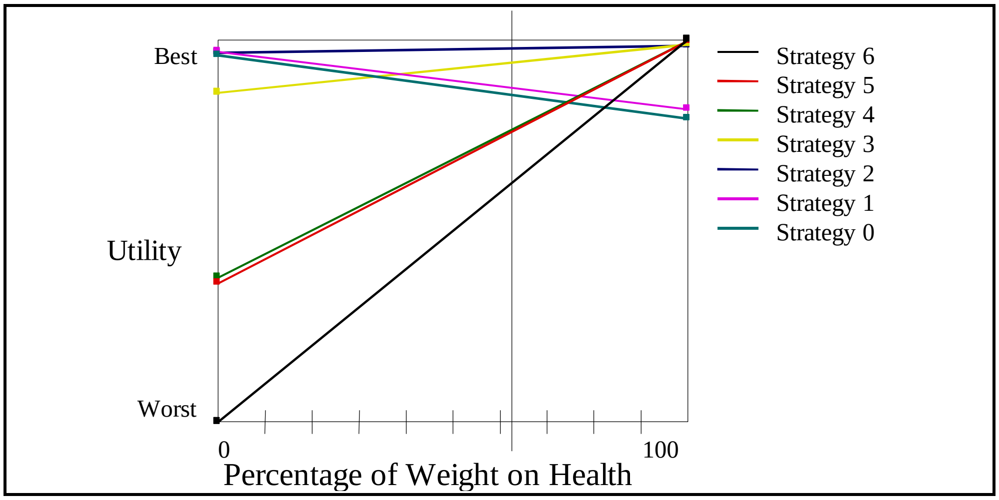
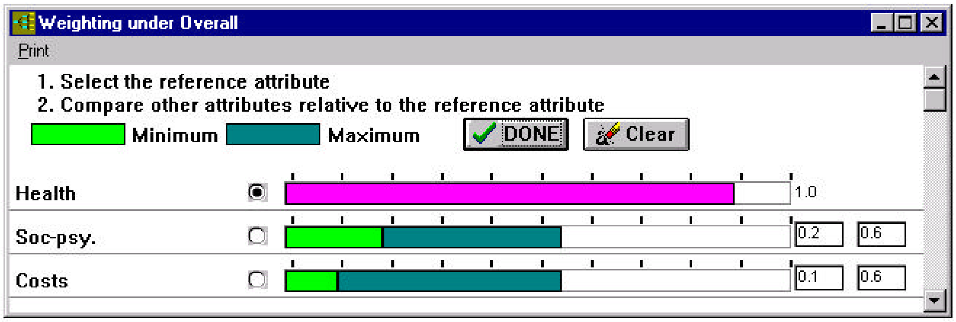


Figure 11. *Example of single factor sensitivity analyses.*

Using intervals in sensitivity analyses allows for applying variance simultaneously to more than one factor. For example, by saying that the score for the attribute *Health* is 100, the score for *Socio-Psychological* is at least 20 but no more than 60, and that the score for *Costs* is at least 10 but no more than 60 (see Figure 12). Such an approach leads to intervals in the weights and the utilities of the alternatives (see Figure 13). If there are dominated alternatives, these can safely be discarded as truly worse alternatives. If there are more than one non-dominated alternative left after such an analysis, these need to be further examined. Using intervals in sensitivity analyses thus reveals how the total sum of the imprecision affects the ranking.



1. Select the reference attribute
2. Compare other attributes relative to the reference attribute

Health ● 1.0
Soc-psy. ○ 0.2 0.6
Costs ○ 0.1 0.6

Figure 12. *Example of using intervals for sensitivity analyses.*

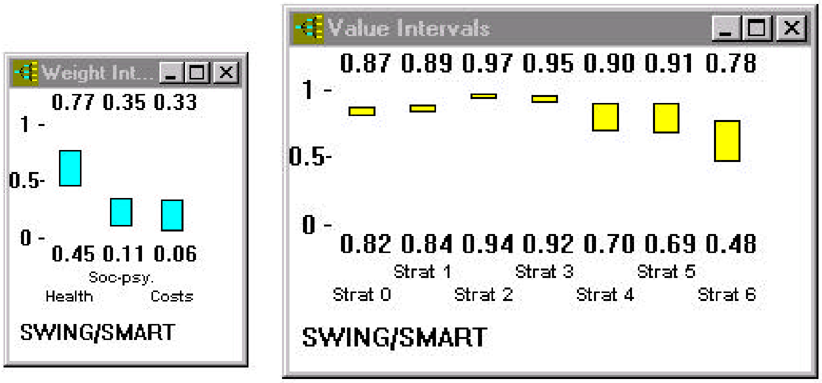


Figure 13. *Example of results from intervals in sensitivity analyses.*

5 RESULTS OF INTERVIEWS

The value tree in Figure 7 was shown to all participants and generally it was considered appropriate in this case. One participant felt that money was not an issue, but this could be taken into account by assigning a weight of zero to the *Costs* attribute. Another participant felt that the attribute *Anxiety* needed to be split into two. This was accomplished by changing the value tree. As hierarchical weighting was used, the splitting of the value tree should not affect the weights of the upper level attributes. But the weights for the other lower level *Socio-Psychological* attributes might be affected, see e.g. Borcherding and von Winterfeldt (1988) and Pöyhönen and Hämäläinen (1998) for more information about the splitting bias.

Some changes in the attribute data were also made. The hard attributes, i.e. the number of cancer incidents and the costs, were kept as they were, but the *Socio-Psychological* attributes were changed in some cases. See Table IX for a list of the changes. Especially the changes in the attribute *Social disruption* show that there was disagreement about how it should be interpreted. It was suggested that *Social disruption* be understood as the disturbance in the social network caused by evacuation. Thus the attribute received –100 when there was evacuation and 0 otherwise. But some participants argued that all strategies cause social disruption and that there are differences between the strategies that need to be considered. The changes that some participants made are shown in Table IX.

As described in Section 4, the risk attitudes were elicited with lotteries (see Figure 8). In Table X are given the risk attitudes of the interviewees. In most cases the shape of the utility function was left linear for both the *Socio-Psychological* attributes and the *Costs* attribute. For the *Health* attributes it was, however, changed. From Table X it can be seen that half the participants were risk averse and half were risk seeking. This is a result that needs to be further examined. A possible explanation might be that some saw the case as an oppoturnity to save lives (a gain situation) and some saw it as a risk of losing lives (a loss situation). People are often risk seeking when it comes to losses and risk averse when it comes to gains (Kahneman and Tversky 1979).

***Table IX**. Changes in the decision table*

						STRATEGIES			
		Unit	**0**	**1**	**2**	**3**	**4**	**5**	**6**
D1:									
Reassurance	all	0-100	0	5	10	20	30	40	100
Anxiety - property	all	-100-0	0	0	0	0	0	0	-100
Anxiety - health	5%	-100-0	-10	0	0	0	0	0	0
	50%	-100-0	-20	-19	-18	-17	-16	-15	-10
	95%	-100-0	-100	-95	-94	-93	-92	-91	-90
Social disruption	all	-100-0	0	0	0	-1	-10	-15	-100
D3:									
Reassurance	5%	0-100	0	30	40	40	40	40	40
	50%	0-100	0	30	40	40	50	60	60
	95%	0-100	0	40	50	60	80	80	100
Social disruption	all	-100-0	0	-5	-10	-30	-40	-50	-100
D6:									
Social disruption	all	-100-0	0	-10	-15	-20	-25	-30	-100

The preferences were elicited with SMART, see Section 4. The scores for the attributes are given in Table XI and the resulting weights in Table XII. As can be seen from the tables, all participants considered the health effects most important. But there were differences of opinion as to whether the *Thyroid cancer* attribute or the *Other cancers* attribute was more important. Three issues might lead to this difference. First, the range of *Thyroid cancer incidents* and *Other cancer incidents* is quite different (see Table VIII). Secondly, there is a difference in risk factors. It was assumed that 10% of the thyroid cancer incidents lead to death, but 50% of other cancers. That is, there is a significant difference whether you consider cancer incidents or cancer deaths. Finally, the time factor is an important issue. Thyroid cancers appear relatively soon after the accident, but other types of cancer occur in many cases decades after the accident. Is a cancer case, say, in 20 years' time as important as a cancer case today? If not, how this can be accounted for?

Table X. *Risk attitudes (utility for midpoint if not linear). A refers to the original value tree, B1 and B2 to the tree where the Anxiety attribute was split into two attributes.*

Upper level	**Lower level**	**D 1**	**D 2**	**D 3**	**D 4**	**D 5**	**D 6**
Health							
	Thyroid cancer	0.6	0.73	0.36	0.40	0.36	0.61
	Other cancers	0.6	0.68	0.34	0.42	linear	0.64
Socio-psycho							
	Reassurance	linear	Linear	linear	linear	linear	linear
A	Anxiety		Linear	linear	0.41	linear	linear
B1	Anxiety-property	linear					
B2	Anxiety-health	linear					
	Social disruption	linear	Linear	linear	linear	linear	linear
Costs		linear	0.37	linear	linear	-	linear

The *Social disruption* attribute received the full score in all cases. But there were differences as to whether the other *Socio-Psychological* attributes were as important or not. From Table XII can also be seen the effect of the splitting bias. D1 and D5 both gave equal scores to all *Socio-Psychological* attributes. But with D1 there were four attributes and with D5 there were only three. For D5 the three original attributes received equal weight. For D1 the splitting of the attribute *Anxiety* into two components led to its receiving twice as much weight as the other two attributes.

In no case does the *Costs* attribute receive much weight. One participant saw it as the second important upper level attribute and one participant gave it zero weight. The reasons for assigning zero weight to it should be examined further. Is it just because the costs are rather small in this particular case, or is there a more fundamental difference of opinion?

Table XI. *Eliciting preferences with* SMART/SWING, *hierarchical weighting. A refers to the original value tree, B1 and B2 to the tree were the Anxiety attribute was split into two attributes.*

Upper level	Lower level	D 1	D 2	D 3	D 4	D 5	D 6
Health		100	100	100	100	100	100
	Thyroid cancer	50	100	100	100	80	35
	Other cancers	100	10	80	100	100	100
Socio-psycho		40	20	70	50	50	60
	Reassurance	100	20	30	30	100	35
A	Anxiety		20	30	60	100	80
B1	Anxiety-property	100					
B2	Anxiety-health	100					
	Social disruption	100	100	100	100	100	100
Costs		10	40	20	30	0	20

Table XII. *The weights of the attributes. A refers to the original value tree, B1 and B2 to the tree where the Anxiety attribute was split into two attributes.*

Upper level	Lower level	D 1	D 2	D 3	D 4	D 5	D 6
Health		0.67	0.62	0.53	0.56	0.67	0.56
	Thyroid cancer	0.22	0.91	0.56	0.50	0.44	0.26
	Other cancers	0.44	0.09	0.44	0.50	0.56	0.74
Socio-psycho		0.27	0.12	0.10	0.28	0.33	0.33
	Reassurance	0.07	0.14	0.19	0.16	0.33	0.16
A	Anxiety		0.14	0.19	0.32	0.33	0.37
B1	Anxiety-property	0.07					
B2	Anxiety-health	0.07					
	Social disruption	0.07	0.71	0.62	0.53	0.33	0.46
Costs		0.07	0.25	0.37	0.17	0	0.11

In Table XIII are given the resulting rankings and utilities of the countermeasure strategies. From the table it can be concluded that occasionally a third decimal is needed to separate strategies. Thus the ranking would seem to be rather sensitive to small changes in the model.

When looking at the table Strategy 2 is the best choice for D2, D3, D4 and D6 and hence a possible choice of the group. Strategies 3 and 5 are possible alternatives. There is, however no full consensus on the best choice of strategy and therefore it would be useful to discuss in a brief meeting whether Strategy 2 is truly the more preferred choice, or whether the group would like to make small changes in the model, making e.g. Strategy 3 more preferred.

Table XIII. *Ranking and utility of the countermeasure strategies.*

	D1		**D2**		**D3**		**D4**		**D5**		**D6**	
Strategy 0	6	0.76	4	0.86	4	0.78	4	0.80	7	0.69	2	0.71
Strategy 1	5	0.77	3	0.87	3	0.78	3	0.81	5	0.72	3	0.70
Strategy 2	4	0.82	1	0.97	1	0.87	1	0.87	4	0.80	1	0.71
Strategy 3	2	0.82	2	0.93	2	0.84	2	0.86	3	0.81	4	0.70
Strategy 4	3	0.82	5	0.77	5	0.65	5	0.77	2	0.81	6	0.69
Strategy 5	1	0.83	6	0.76	6	0.63	6	0.77	1	0.83	5	0.70
Strategy 6	7	0.73	7	0.63	7	0.46	7	0.55	6	0.70	7	0.57

6 QUESTIONNAIRE

Immediately after the interview the participants were given a questionnaire. The questions and answers are set out in Table XIV. From the table it can be seen that there was general agreement on the importance of considering many factors in the process and of explicitly considering uncertainties. However, the appropriateness of using decision analysis techniques was not that clear.

The main software used in the interviews received a slightly positive verdict. There were some questions about whether the software assumes too much and limits the options.

A very interesting question is the time factor, i.e. that thyroid and other cancers occur at different times. From the table it can be seen that D1, D5, and D6 did not consider this fact at all, while the others considered it at least to some extent. These three are also the same three that gave more weight to the *Other cancers* attribute (see Table XI). That is, there is a clear correlation between assigning weight to the cancer attributes and whether the time factor was considered or not.

Sensitivity analyses were seen as somewhat useful and intervals as slightly better than single factor analyses. The fact that sensitivity analyses are not seen as very important and as not increasing the credibility raises a number of questions. Do the participants feel that the results are robust and that sensitivity analyses are not needed, or do they feel that the ranking is anyway only indicative and other methods should be used to decide on the final decision?

Including uncertainties is a very difficult issue. In this exercise three fractiles were given and the participants seemed to like this approach. Other possible approaches in the Table divided opinions rather equally, with the approach mean-value-only gaining more negative response. A little worrisome is the fact that everybody agreed on the importance of considering risks explicitly, but still some participants did not see any problems with using only mean values. Perhaps this is an indication that the theory behind the approaches is not that clear to the participants.

Table XIV. *Questionnaire, the numbers in the answer cells refer to the decision-makers, e.g. a 1 means that D1 chose this answer.*

Decision Analysis Interviews	**1** ☹☹	**2** ☹	**3** 😐	**4** ☺	**5** ☺☺
How appropriate is this type of decision analysis in connection with countermeasure decisions?		26	5	14	3
How important is it to consider other factors also, in addition to costs and cancer incidents?				1245	36
How much did you take into consideration that different impacts happen at different times, for example thyroid cancer vs other cancers?	156	3		24	
How important is it explicitly to consider the uncertainties in the analyses when deciding on countermeasures?			5	2346	1
How much does the approach used by Logical Decision (first software) help you consider the uncertainties?		3	156	4	2
How useful is the type of single factor sensitivity analysis provided by Logical Decision?			2356	14	
How much would the interval approach used by Winpre (second software) increase the credibility of the results?		26	4	15	
How useful is it to do sensitivity analyses, i.e. do they provide more information about the situation?			56	234	1
Which type of sensitivity analysis would you prefer (single factor <- -> intervals)			12	3456	
How appropriate would the following ways be to handle uncertainties?					
- use three equally distributed fractiles, for example 5%, 50% ,95%				13456	2
- use only mean values, i.e. 50% fractile	35	14	6	2	
- use one fractile, but compensate for risk, for example 75% fractile		136	2	45	
- use probability distributions and utility functions to capture risk attitudes		34	56	12	
- use one fractile and intervals around it to incorporate uncertainties		6	124	35	
How well did the ranking of the alternatives from the analysis compare with your own a priori ranking?	6			35	124

In most cases the ranking compared well with the a priori opinion that the participants had about the strategies. For D6 the difference was caused by differences in opinion about the definitions and measuring of the *Socio-Psychological* attributes. From Table XIII it can be seen that small changes in the model were sufficient completely to alter the ranking.

7 OBSERVATIONS ON INTERVIEWS

The first observation that can be made from these interviews is that decision analysis interviews are a suitable approach for training and for planning in advance purposes. The personal interview allows for a deeper understanding of the issues involved and the tools used. It clearly shows where views differ and points out issues for further discussion.

The presentation of data is a very important aspect of the process. The graphical maps used in these exercises are a possible way to communicate the decision situation. Especially the map of the countermeasure strategies was seen as very informative. At a single glance the participants were able to assess the magnitude of the countermeasure strategies. The maps can, however, still be improved. The location of, for example, the city centre of Pori was not really clear from the maps. As found in previous exercises (see e.g. Hämäläinen et al 1998), the chosen colour schemes might also affect the impression gained by the decision-makers concerning the severity of the accident.

The use of fractiles is a problematic matter. Here the 5%, 50% and 95% fractiles were shown to the participants. During the interviews, however, it became, apparent that not all participants were able to grasp the meaning of the fractiles. In addition, the choice of fractiles is not a straightforward matter.

As can be seen from Figures 14 and 15 the increase in cancer incidence is not a linear function of fractiles. Thus it becomes important to know at which point the curve becomes steeper. In the current case it would seem to be around the 70% fractile. The ideal case would be to have the continuous distributions for all attributes. Then graphs such as the one estimated in Figure 16 could be used to show the participants how the uncertainties affect the choices. From the figure it can be seen that Strategies 0 and 1 receive a high utility as long as the scale of the accident remains small, but that the utilities drop rapidly when the accident becomes more severe. The other accidents are much less sensitive to changes in the severity of the accident. This is an important observation to consider when deciding on how much risk one is willing to take. However, as was seen in the answers to the questionnaire (Section 6), the participants were not totally comfortable with continuous distributions. If this is the case, then appropriate fractiles could be picked from the continuous distribution. If continuous distributions are not available, then more than three fractiles need to be calculated, for example 5%, 25%, 50%, 75%, and 95%. Or preferably interactively those fractiles requested by the decision-makers. This places a high demand on the computational abilities of the system, but should perhaps be investigated.

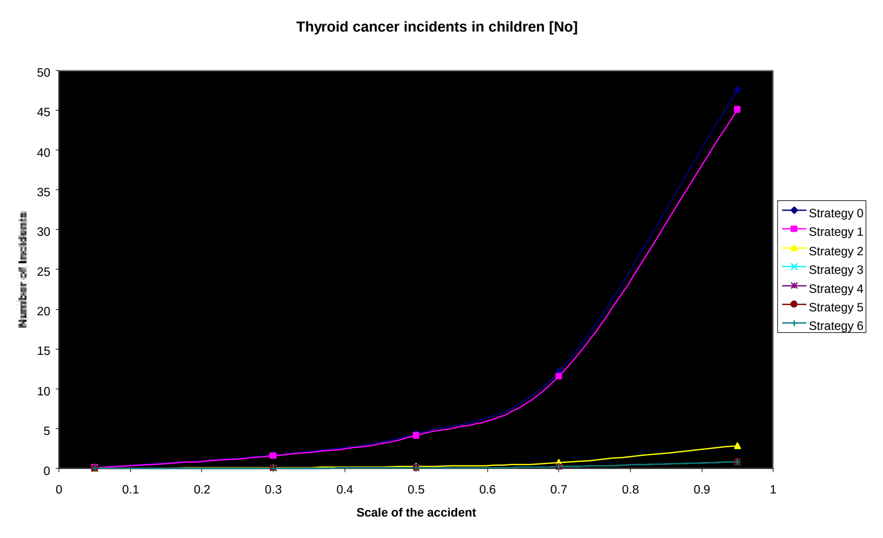


Figure 14. *Cumulative distribution function for the number of thyroid cancer incidents in children for different strategies.*

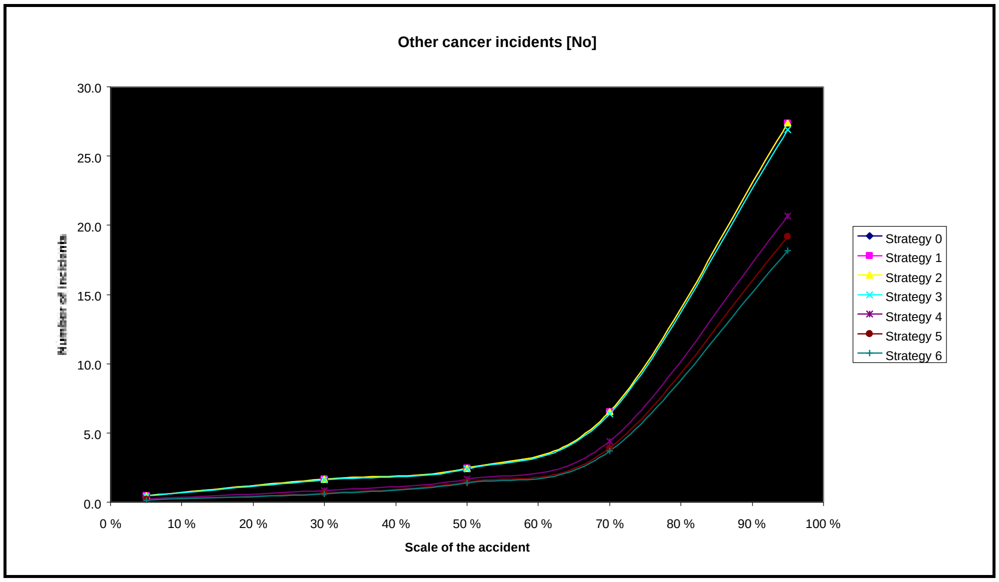


Figure 15. *Cumulative distribution function for the number of other cancers for different strategies.*

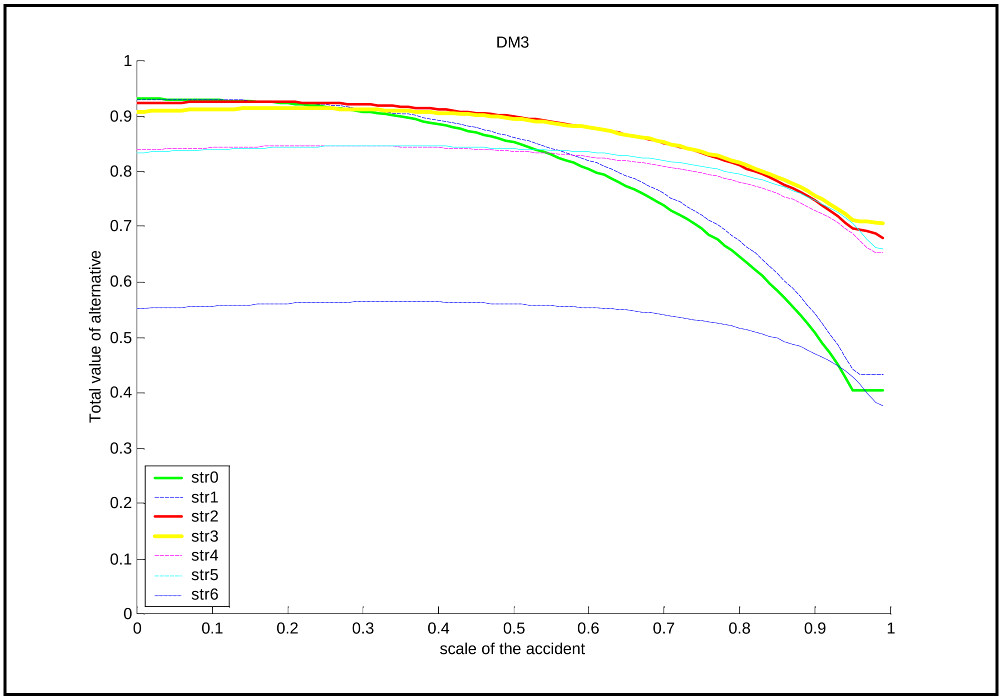


Figure 16. *Estimated effect of the uncertainties on the utilities of the alternative strategies for decision-maker 3.*

Some of the participants also had comments about the actions and attributes chosen since certain important issues were not included in the analysis. For example, the problem of informing the public was not considered. Can the public be informed in time, will people understand and follow the advice, will there be additional sources of false and misleading information, etc? What are the likely reactions of the public, how will they interpret the situation, and what consequences will there be if certain actions are taken? Thus there were uncertainties not only about the magnitude of the accident but also about the feasibility and effectiveness of the countermeasures and about the reactions and actions of the part of population.

Also, the issue of flexibility is an important one, something that was not considered. Can the strategy be altered later? How much later? If a certain countermeasure fails, are there alternative courses of actions open? One participant pointed out that the implementation of countermeasures takes more time than was assumed in the scenario. Evacuating the proximity of the power plant, i.e. the closest 5 km, takes 4 hours. Thus it might be argued that the suggested countermeasure strategies were not 100% feasible, at least not in the eyes of all participants.

Some actions that would be taken, such as access control to the area, were also not included. In addition, one participant stated that the city of Rauma would always be included in any strategy. Another participant felt that deterministic issues such as traffic accidents need to be included in the analysis, although in previous exercises these have been found not to have an impact on the final decision (Hämäläinen et al 1998).

The appropriateness of using a single decision point can thus be questioned. Perhaps a more realistic approach would be to have a series of decisions. At first the immediate actions would be decided upon. Later, when there is more information about the accident, additional countermeasures could be deployed. An example of such an approach is described in Section 8.

Overall, the procedures of value tree analysis were not completely clear to all participants. The format of decision analysis interviews allowed for clarifying the points at issue, but more training in general decision analysis techniques is needed if the decision-makers are fully to understand the process.

The value tree shown to the participants was constructed from the experiences gained in previous exercises. The attributes were defined and the definitions were explained. However, some attributes, such as the socio-psychological factors, still need more clarification. What exactly is meant by them and how are they measured? One suggestion made was that categories could be used instead of numerical values. For example, *very bad – bad – neutral – good - very good*. This does not, however, address the problem of defining the time window. Should only immediate reactions be assessed, or also attitudes long after the accident?

The attributes chosen were also examined. The attribute *Anxiety* was seen as problematic by one participant. The reason was that the accident is sure to happen, so there will be anxiety anyway. No study has been made as to whether there really is any difference in the amount of anxiety between the different strategies. The *Individual dose* attribute was not used in decision analysis. Individual doses were given as the thematic maps to participants (Figures 2 - 4) which might have caused that no participant considered it explicitly or wanted to add it into analysis. As being important in the decision it needs to be considered and studied how the trade-off between individual and collective doses should be done.

In the interviews cancer cases were measured by the number of cancer incidents. As mentioned previously, this is not a straightforward choice. The number of deaths or doses could also be used. A suggestion was made that perhaps separate analyses should be performed with the different units of measurement.

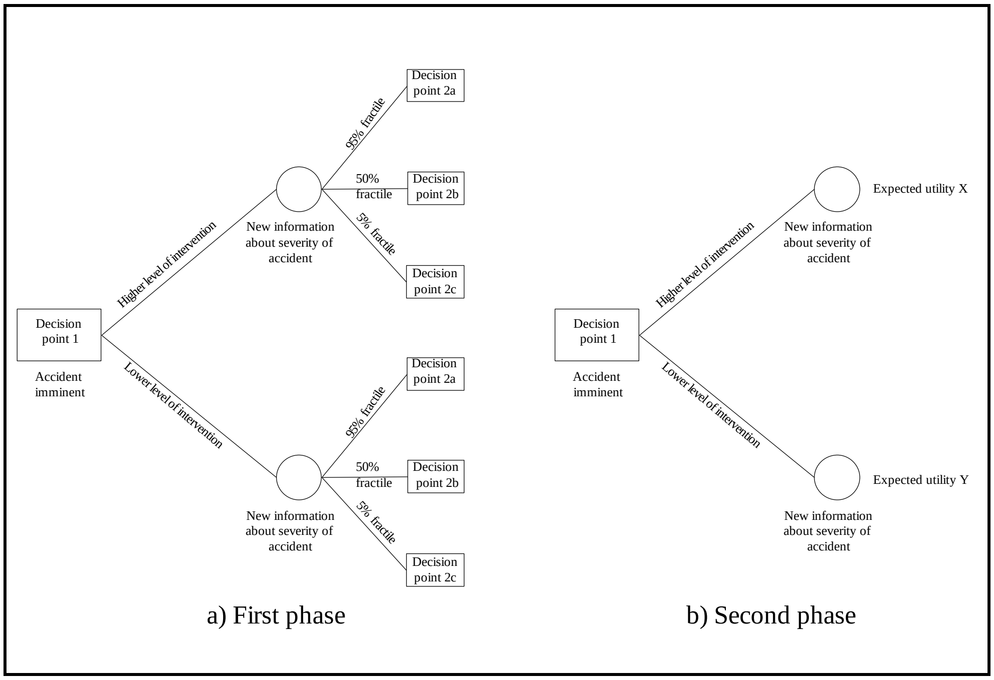
The most difficult part of the analysis was the elicitation of the risk attitudes. In the interviews lottery questions were asked to establish the form of the utility functions. As can be seen from Table X, half of the participants were risk averse and the other half risk seeking. This can partly be attributed to the framing effect, i.e. some participants might have seen the situation as a loss situation and others as a gain situation. But in addition it was clear that most participants had problems grasping the idea of the utility function. Thus the answers might not mirror their true opinions. Using lotteries seems too abstract and the questions seem too difficult for decision-makers to be able to give meaningful answers. Even if the framing effect were be eliminated, it is not clear that this type of approach is appropriate. Thus it would seem that alternative ways of incorporating risks should be examined.

Two types of bias became apparent during the interviews. As described earlier, the splitting bias was evident. This means that care needs to be taken when building the value tree. In addition, this implies that a hierarchical type of weighting might be more suitable, as the upper level weights then stay the same even if a lower level attribute is split. The time factor is also important. The interviews showed that the choice of time frame affected the weights on the cancer attributes. The same effect might also easily occur in other attributes, for example for the socio-psychological attributes. Thus the discounting of attributes should be explicitly brought into the analysis. That is, decision-makers should be explicitly asked how they would like to take the time factor into consideration.

Last, the accident case used revealed an interesting difference in how the uncertainties affect the values of the attributes and thus also the recommended alternative. Figures 14 and 15 show the estimated consequences of the accident for continuous distributions of the two cancer attributes. Figure 16 contains the estimated utilities for D3 for continuous distribution. As can be seen from the first figures, the uncertainties affect the attributes in different way. For the attribute *Other cancers* the uncertainties affect all strategies similarly, i.e. the curves are similar. But for the attribute *Thyroid cancer* there is a difference. The curves for Strategies 0 and 1 have similar shapes as the curves for the attribute *Other cancers*. But the Strategies 2 - 6 curves are more or less linear throughout the range. In the last figure the total utilities of the alternatives are plotted. As can be seen, the utilities for Strategy 0 and 1 drop much more rapidly than the others. Thus it could be argued that although the 50% fractile values are about the same, Strategy 0 and 1 should be discarded as having a much higher variance. This issue is not explicitly considered in the analysis.

8 DECISION TREE

Another type of approach that could be considered is to split the decision into several phases. What the decision points would be would vary depending on the accident scenario. Figure 17 contains an example of how the decision on countermeasures could be split into two decision points. In the example it is assumed that the first decision as to what countermeasures should be deployed would be taken immediately when it becomes evident that an accident is about to happen. At this point actions for the nearest areas would be decided upon and plans made for the areas further away from the power-plant. When more information becomes available about the severity of the accident, i.e. which fractile is relevant, an appropriate countermeasure can be implemented in the outer areas. Thus some of the uncertainties can be eliminated by delaying some of the implementations until more precise information about the accident is available.



a) First phase b) Second phase

***Figure 17**. Example of decision tree.*

For purposes of simplicity the decision tree contains only two decision points with two respectively three twigs. To capture the whole set of possible states a more refined decision tree is needed. However, the same principles apply in both cases.

At the second decision point value tree analyses would be performed for each of the six possible states. Thus each state would be assigned a countermeasure strategy and the utility resulting from that strategy. Then by using the likelihood of each possible state the second decision point can be collapsed to two points, each with an expected utility. Thus at decision point one the branch with the higher expected utility should be chosen.

9 DISCUSSION

The accident scenario used in the interviews was a hypothetical nuclear accident. The setting and description of the accident scenario were as detailed and realistic as possible and the participants were people responsible for planning and in charge that aspect of the decision-making. The whole decision-making situation can be said to have been quite close to a real-life situation. Therefore it can be concluded that the experiences and results obtained from the decision analysis interviews have a high degree of reliability. At the same time it should be remembered that some simplifications had to be made during the simulation of the events, a fact that might reduce the degree of realism.

A general finding from the interviews is that it is very useful to arrange interviews. They are suitable for training and for planning in advance purposes on early phase issues. Personal interviews allow for a deeper understanding of the issues involved and the tools used. It clearly reveals where views differ and points to issues for further discussion.

As in previous studies, predefined value trees were found to be very useful. They help the decision-maker to consider all relevant factors and to focus on the most important ones. Later it is also easier to explain what has been done and why it was done. A generic value tree could thus be pre-programmed into RODOS: the decision-makers could examine the tree, pick the relevant attributes, and then continue from there, thus saving time.

Some issues still need more research. As in earlier decision conferences, it was found that factors and wordings are a source of misunderstandings. There is a clear need to define the attributes in advance so that the persons involved understand their meaning. Also, examples and studies, especially on socio-psychological factors, are needed, e.g. using a 'role playing' method for different types of action.

Practical consideration of protective measures is an important issue. How to define the geographical area where people will be protected or how to apply collective dose and/or individual dose criteria in practice? Sheltering or issuing iodine tablets could be considered, but to whom? Can these actions be implemented only with regard to children and will the adults comply with this? In a real situation people will not or cannot follow the recommendations. All countermeasures need further examination in terms of their feasibility. What are the consequences to individuals, industry and society? What are monetary costs of actions?

A very important question is what the decision-makers want from the software, what type of information and in what form? The decision table given (Table VIII) provides information in compact form and was readily accepted by the participants. This table together with some thematic maps such as individual dose distribution, countermeasure strategies etc., could form an appropriate information package in the early phase. In addition, some further information should be ready if requested, such as plume arrival time, cancer distribution and tabular information as was provided in Tables II - VII. The appropriateness of these information packages should, however, be tested elsewhere, too.

In conclusion, it can be said that the participants seemed to feel that the RODOS software produces a lot of valuable information, e.g., on the effectiveness of countermeasures, but that it is of limited help in the actual decision situation with regard to urgent protective actions. At the moment, the participants seemed to be willing to use RODOS as a data base and as a supplementary calculator, i.e., for level 0, 1, and 2 support. Estimates of health effects and costs were appreciated, but using RODOS in its present form, for the actual decision-making part, was not seen to be appropriate. A change in attitude is needed, which can be gained with good experience or with examples of level 3 support. But as a planning tool the decision analysis supported by the RODOS system has proved to provide much valuable information which would be difficult to elicit using conventional exercises.

10 ACKNOWLEDGEMENT

The authors are grateful to the participants for taking part in the meetings with enthusiasm and for freely giving their advice, value preferences and judgements. We are also thankful to Nadia Papamichail for her efforts to adjust the CES and support our work.

This work has been carried out with the support of the European Commission, Radiation Protection Research Action (DGXII-F-6), Contract FI4P-CT96-0053.

11 REFERENCES

Ahlbrecht M, Borodin R, Borzenko V, Ehrhardt J, French S, Shershakov V, Sohier A, Trakhtengerts E, Verbruggen A. Decision Support Issues in RODOS: The Needs of Decision Makers. Radiation Protection Dosimetry 1997; 1- 4 (Vol. 73): 81-84.

Apostolakis, G. E., Pickett, S. E. Deliberation: Integrating Analytical Results into Environmental Decisions Involving Multiple Stakeholders. Risk Analysis 1998; 5 (Vol 18): 621-634.

Borcherding K, von Winterfeldt D. The Effect of Varying Value Trees on Multiattribute Evaluations. Acta Psychologica 1988; 68: 153-170.

Bäverstam U, Fraser G, Kelly G N. Decision-Making Support for Off-Site Emergency Management. Proceedings of the Fourth International Workshop, Aronsborg, Sweden, October 7-11. Radiation Protection Dosimetry 1997; 1-4 (Vol. 73): 315.

EU Radiation Protection 87. Radiological protection principles for urgent countermeasures to protect the public in the event of accidental releases of radioactive material. European Commission, Luxembourg, 1997.

Ehrhardt J, Weis A (Eds.). Development of RODOS, a Comprehensive Real-Time On-Line Decision Support System for Nuclear Emergency Management in Europe. RODOS R-1-1997 FZKA 5772. Karlsruhe, 1997.

French, S. Multi-Attribute Decision Support in the Event of a Nuclear Accident. Journal of Multi-Criteria Decision Analysis 1996; (Vol. 5): 39-57.

French S, Walmond-Larsen O, Sinkko K. RISO: Decision Conferencing on Countermeasures after a Large Nuclear Accident. RISO-R-676(EN), p. 23, 1993.

French S, Finck R, Hämäläinen R P, Naadland E, Roed J, Salo A, Sinkko K. Nordic Decision Conference: An Exercise on Clean-Up Actions in an Urban Environment after a Nuclear Accident. STUK-A132, 1996.

Hämäläinen RP. Computer Assisted Energy Policy Analysis in the Parliament of Finland. Interfaces 1988; 4 (Vol. 18): 12-23.

Hämäläinen RP. A decision aid in the public debate on nuclear power, European Journal of Operations Research 1990, 1 (Vol. 48): 66-76.

Hämäläinen RP. Facts or values - how do parliamentarians and experts see nuclear power? Energy Policy 1991; 5 (Vol. 19;) 464-472.

Hämäläinen RP. Decision Analysis Makes Its Way Into Environmental Policy in Finland. OR/MS Today 1992; 3 (Vol. 19): 40-43.

Hämäläinen RP, Karjalainen R. Decision Support for Risk Analysis in Energy Policy. European Journal of Operational Research 1992; 56: 172-183.

Hämäläinen RP, Sinkko K, Lindstedt M, Ammann M, Salo A. RODOS and decision conferencing on early phase protective actions in Finland. STUK-A159. Helsinki 1998.

IAEA Safety Series No. 109. Intervention Criteria in a Nuclear or Radiation Emergency. International Atomic Energy Agency, 1994.

IAEA Safety Series No. 115. International Basic Safety Standards for Protection against Ionizing Radiation and for the Safety of Radiation Sources, International Atomic Energy Agency, 1996.

Kahneman, D., Tversky, A. Prospect Theory: An Analysis of Decision Under Risk. Econometrica 1979; 2 (Vol. 47): 263-291.

Marttunen M, Hämäläinen R P. Decision Analysis Interviews in Environmental Impact Assessment. European Journal of Operational Research 1995; 87: 551-563.

Niemelä I. Personal Communication. STUK – Radiation and Nuclear Safety Authority, 1997.

Papamichail, K. N. and French, S. Screening Strategies in Nuclear Emergencies, RODOS(WG5)-TN(97)-01. 1997.

Pöyhönen M, Hämäläinen R P. Notes on the weighting biases in value trees. Journal of Behavioral Decision Making, 1998; (Vol. 11): 139 - 150.

Salo, A., Hämäläinen, R. P. Preference assessment by imprecise ratio statements, Operations Research, 1992; 6 (Vol. 40): 1053-1061.

Winterfeldt von, D., Edwards, W. Decision Analysis and Behavioral Research. Cambridge University Press, New York, 1986.
YVL7.4 Nuclear power plant emergency preparedness, 23 Jan 1997.

LOGICAL DECISION software was used during events. It is available from: Logical Decision, 1014 Wood Lily Drive, Golden, Colorado 80401, 800-35-LOGIC.

Document History

Document Title:	Decision Analysis Interviews on Protective Actions in Finland Supported by the RODOS System
RODOS number:	RODOS(WG7)-TN(99)-04
Version and status:	Version 1.1 (final)
Authors/Editors:	Kari Sinkko
Address:	STUK - Radiation and Nuclear Safety Authority P.O.Box 14 FIN-00881 HELSINKI Email: kari.sinkko@stuk.fi
Issued by:	Kari Sinkko
History:	1st Draft, August 1999
Date of Issue:	January 2000
Circulation:	No constraint
File Name:	Interview RODOS report.doc

STUK-A reports

STUK-A173 Hämäläinen RP, Sinkko K, Lindstedt M, Ammann M, Salo A. Decision analysis interviews on protective actions in Finland supported by the RODOS system. Helsinki 2000.

STUK-A172 Turtiainen T, Kokkonen P, Salonen L. Removal of Radon and Other Natural Radionuclides from Household Water with Domestic Style Granular Activated Carbon Filters. Helsinki 1999.

STUK-A171 Voutilainen A, Mäkeläinen I, Huikuri P, Salonen L, Arvela H. Porakaivoveden radonkartasto/Radonatlas över borrbrunnar/Radon Atlas of wells drilled into bedrock in Finland. Helsinki 1999.

STUK-A170 Saxén R, Koskelainen U, Alatalo M. Transfer of Chernobyl-derived 137Cs into fishes in some Finnish lakes. Helsinki 1999.

STUK-A169 Annanmäki M, Turtiainen T (Eds.). Treatment Techniques for Removing Natural Radionuclides from Drinking Water. Helsinki 1999.

STUK-A168 Suomela M, Bergman R, Bunzl K, Jaakkola T, Rahola T, Steinnes E. Effect of industrial pollution on the distribution dynamics of radionuclides in boreal understorey ecosystems (EPORA). Helsinki 1999.

STUK-A167 Thorring H, Steinnes E, Nikonov V, Rahola T, Rissanen K. A summary of chemical data from the EPORA project. Helsinki 1999.

STUK-A166 Rahola T, Albers B, Bergman R, Bunzl K, Jaakkola T, Nikonov V, Pavlov V, Rissanen K, Schimmack W, Steinnes E, Suomela M, Tillander M, Äyräs M. General characterisation of study area and definition of experminetal protocols. Helsinki 1999.

STUK-A165 Ilus E, Puhakainen M, Saxén R. Strontium-90 in the bottom sediments of some Finnish lakes. Helsinki 1999.

STUK-A164 Kosunen A. Metrology and quality of radiation therapy dosimetry of electron, photon and epithermal neutron beams. Helsinki 1999.

STUK-A163 Servomaa A (toim.). Säteilyturvallisuus ja laadunvarmistus röntgendiagnostiikassa 1999. Helsinki 1999.

STUK-A162 Arvela H, Rissanen R, Kettunen A-V ja Viljanen M. Kerrostalojen radonkorjaukset. Helsinki 1999.

STUK-A161 Jokela K, Leszczynski D, Paile W, Salomaa S, Puranen L, Hyysalo P. Radiation safety of handheld mobile phones and base stations. Helsinki 1998.

STUK-A160 Voutilainen A, Vesterbacka K, Arvela H. Radonturvallinen rakentaminen - Kysely kuntien viranomaisille. Helsinki 1998.

STUK-A159 Hämäläinen RP, Sinkko K, Lindstedt M, Ammann M, Salo A. RODOS and decision conferencing on early phase protective actions in Finland. Helsinki 1998.

STUK-A158 Auvinen A, Rahu M, Veidebaum T, Tekkel M , Hakulinen T, Salomaa S, Boice JD Jr (eds) . Cancer incidence and thyroid disease among Estonian Chernobyl clean-up workers. Helsinki 1998.

STUK-A157 Klemola S, Ilus E, Ikäheimonen TK. Monitoring of radionuclides inthe vicinities of Finnish nuclear power plants in 1993 and 1994. Helsinki 1998.

STUK-A156 Eloranta E, Jokela K (toim.). The Eight National Electromagnetics Meeting, August 27, 1998. Extenced Abstracts. Helsinki 1998.

STUK-A155 Salomaa S, Eloranta E, Heimbürger H, Jokela K, Järvinen H, (toim.). Säteilyturvakeskuksen tutkimushankkeet 1998 – 2000. Helsinki 1998.

STUK-A154 Puhakainen M, Suomela M. Detection of radionuclides originating from a nuclear power plant in sewage sludge. Helsinki 1998.

The full list of publications is available from

STUK- Radiation and Nuclear Safety Authority
P.O. BOX 14
FIN-00881 HELSINKI
Finland
Tel. +358 9 759 881

2 OTSIKKO

2.1 Kakkostason otsikko

Teksti...