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NUCLEAR EMERGENCY RESPONSE PLANNING BASED ON PARTICIPATORY DECISION ANALYTIC APPROACHES

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Academic dissertation

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Nuclear emergency response planning based on participatory decision analytic approaches

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List of publications

The thesis is based on the following research publications which are referred to in the text by their Roman numerals, and a review of relevant literature.

I Sinkko K, Hämäläinen RP, Hänninen R. Experiences in methods to involve key players in planning protective actions in a case of nuclear accident. Radiation Protection Dosimetry 2004; 109 (1 - 2): 127-132.

II Hämäläinen RP, Lindstedt M, Sinkko K. Multi-attribute risk analysis in nuclear emergency management. Risk Analysis 2000; 20 (4): 455-467.

III Bartzis J, Ehrhardt J, French S, Lochard J, Morrey M, Papamichail KN, Sinkko K, Sohier A. RODOS: decision support for nuclear emergencies. Zanakis S. et. al. (eds.). In: Decision making: recent developments and worldwide application. Proceedings of DSI-Conference, Athens, Greece 1999: 381-395.

IV French S, Walmod-Larsen O, Sinkko K. Decision conferencing on countermeasures after a large nuclear accident: report of an exercise by the BER-3 of the NKS BER programme. Riso-R-676 (EN). Roskilde 1993.

V Sinkko K, Ikäheimonen TK, Mustonen R. Decision analysis of protective actions in forest areas. Lehto J. (ed.) In reprint: Cleanup of large radioactive-contaminated areas and disposal of generated waste. Copenhagen: TemaNord 1994; 567: 109-129.

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

VII Ammann M, Sinkko K, Kostiainen E, Salo A, Liskola K, Hämäläinen RP, Mustajoki J. Decision analysis of countermeasures for the milk pathway after an accidental release of radionuclides. STUK-A186. Helsinki: Radiation and Nuclear Safety Authority, 2001.

Contribution of the author to the papers

I Principal author of the paper.

II This work was carried out with the support of the European Commission, Radiation Protection Research Action (DGXII-F-6), Contract FI4P-CT96-0053. The author was the co-ordinator of that project, the case study designer, responsible for consequence assessments, collaborator in the workshop design and co-author.

III Co-author of the paper.

IV This work was carried out with the support of the Nordic Nuclear Safety Research (NKS). The author was the case study designer, responsible for consequence assessments, collaborator in the workshop design and co-author.

V This work was carried out with the support of the Nordic Nuclear Safety Research (NKS). The author was case study designer, responsible for consequence assessments, interviewer and for decision analysis, and principal author.

VI This work was carried out with the support of the European Commission, Radiation Protection Research Action (DGXII-F-6), Contract FI4P-CT96-0053. The author was the co-ordinator of that project, the case study designer, responsible for consequence assessments, collaborator in the workshop design and principal author.

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Keywords nuclear emergency management, countermeasures, decision-making process, decision support, multiattribute risk analysis

Abstract

This work was undertaken in order to develop methods and techniques for evaluating systematically and comprehensively protective action strategies in the case of a nuclear or radiation emergency. This was done in a way that the concerns and issues of all key players related to decisions on protective actions could be aggregated into decision-making transparently and in an equal manner. An approach called facilitated workshop, based on the theory of Decision Analysis, was tailored and tested in the planning of actions to be taken. The work builds on case studies in which it was assumed that a hypothetical accident in a nuclear power plant had led to a release of considerable amounts of radionuclides and therefore different types of protective actions should be considered. Altogether six workshops were organised in which all key players were represented, i.e., the authorities, expert organisations, industry and agricultural producers. The participants were those responsible for preparing advice or presenting matters for those responsible for the formal decision-making. Many preparatory meetings were held with various experts to prepare information for the workshops. It was considered essential that the set-up strictly follow the decision-making process to which the key players are accustomed. Key players or stakeholders comprise responsible administrators and organisations, politicians as well as representatives of the citizens affected and other persons who will and are likely to take part in decision-making in nuclear emergencies.

The realistic nature and the disciplined process of a facilitated workshop and commitment to decision-making yielded up insight in many radiation protection issues. The objectives and attributes which are considered in a decision on protective actions were discussed in many occasions and were defined for different accident scenario to come. In the workshops intervention levels were derived according justification and optimisation principles in radiation protection. Insight was also gained in what information should be collected or subject studied for emergency management. It was proved to be essential that information is in the proper form for decision-making. Therefore, methods and models to assess realistically the radiological and cost implications of different countermeasures

need to be further developed. In the consequent assessments, it is necessary to take production, economic, demographic and geographical information into account. Also, the feasibility and constraints of protective actions, such as logistics, require further investigation. For example, there seems to exist no plans in the EU or Nordic countries to dispose radioactive waste that may result from decontamination.

The experience gained strongly supports the format of a facilitated workshop for tackling a decision problem that concerns many different key players. The participants considered the workshop and the decision analysis very useful in planning actions in advance. They also expected a similar approach to be applicable in a real situation, although its suitability was not rated as highly as for planning. The suitability of the approach in the early phase of an accident was rated the lowest. It is concluded that a facilitated workshop is a valuable instrument for emergency management and in exercises in order to revise emergency plans or identify issues that need to be resolved.

The pros and cons of the facilitated workshop method can be compared with the conventional approaches. The general goal in all methods is that key players would be better prepared for an accident situation. All participatory methods, when practiced in advance, also create a network of key players. Facilitated workshops provide the participants with an forum for structured dialogue to discuss openly the values behind the decision. Stakeholder network can evaluate and augment generic countermeasures but all the possible and feasible protective actions cannot be justified and optimised in depth. The ranking of protective actions depends on weight put on an attribute and is thus dependent on the problem at hand.

Sinkko, Kari. STUK-A-207. Päätösanalyysiin perustuva sidosryhmien yhteinen vastatoimenpiteiden suunnittelu ydinonnettomuustilanteiden varalle. Helsinki 2004, 60 s. + Liitteet 210 s.

Avainsanat ydinonnettomuustilanteiden hallinta, säteilysuojelutoimen-piteet, päätöksentekoprosessi, päätöksenteon tuki, moniattribuutti riskianalyysi

Yhteenveto

Tämän työn tavoite on suunnitella säteilysuojelutoimenpiteitä ja kehittää menetelmiä, joilla voidaan evaluoida systemaattisesti ja kattavasti suojelutoimenpiteitä säteily- tai ydinonnettomuuksissa ja niiden ennakkosuunnittelussa. Toimenpiteiden suunnittelu tehdään siten, että kaikkien päätöksentekoon osallistuvien sidosryhmien näkökohdat otetaan huomioon tasapuolisesti ja avoimesti. Työssä on kehitetty ja testattu päätösanalyysiteoriaan perustuvaa päätösriihimenetelmää. Työ perustuu tapaustutkimusmenetelmään, jossa on oletettu onnettomuus ydinvoimalaitoksella. Sen seurauksena huomattava määrä radionuklideja on levinnyt ympäristöön ja joudutaan pohtimaan erilaisia suojelutoimenpiteitä. Tutkimuksen aikana järjestettiin kuusi päätösriihtä, joihin osallistui viranomaisia, eri alojen asiantuntijoita, teollisuuden ja maatalouden edustajia. Osallistujat olivat siten niitä, joiden tehtävä on valmistella toimenpidesuositus tai niitä, jotka esittelevät suosituksen päätöksentekijöille. Ennen jokaista päätösriihtä pidettiin asiantuntijoiden välisiä kokouksia, joissa valmisteltiin tietopaketti riiheen osallistujille. Tutkimuksessa pidettiin tärkeänä noudattaa samanlaista päätöksentekoprosessia, mihin sidosryhmät ovat tottuneet. Sidosryhmillä tarkoitetaan vastuullisia viranomaisia ja organisaatioita, politiikkoja ja väestön edustajia ja muita henkilöitä, jotka osallistuvat päätöksentekoon ydinonnettomuustilanteessa.

Päätösriihien realistinen perusluonne ja järjestelmällisyys, sekä sitoutuminen päätöksentekoon lisäsivät tietoa toimenpiteiden suunnittelusta. Toimenpiteiden tavoitteista, tekijöistä - attribuuteista - ja toimenpiteiden seurausvaikutuksista keskusteltiin monissa yhteyksissä ja ne määriteltiin mahdollisten uusien tilanteiden varalle. Toimenpidetasot arvotettiin riihessä kansainvälisten säteilysuojeluperiaatteiden mukaisesti (oikeutus- ja optimointiperiaatteet). Riihimenetelmä paljastaa myös mitä tietoa tulee valmistella tai tutkia päätöksiä varten. Ennen kaikkea tiedon tulee olla päätöksentekoon soveltuvassa muodossa, ei tieteellistä keskustelua. Havaittiin lisäksi, että on tarpeellista kehittää edelleen menetelmiä, jotka arvioivat paremmin ja totuudenmukaisemmin eri säteilysuojelutoimenpiteiden annossäästöt ja kustannukset. Seurausvaikutuksia

arvioitaessa on tarpeellista ottaa huomioon alueelliset tiedot kuten väestö-, elinkeino- ja tuotantotiedot. Lisäselvityksiä tarvitaan myös toimenpiteiden toteuttamiskelpoisuudesta. Havaittiin esimerkiksi, ettei ole olemassa tarkkoja suunnitelmia mihin radioaktiivisten jätteet loppusijoitettaan ja miten kuljetetaan joissakin toimenpiteissä tarvittavat suuret tavaramäärät.

Tehty työ vahvistaa näkemystä, että päätösriihimenetelmä soveltuu hyvin sellaisten päätösten valmisteluun, joihin osallistuu eri sidosryhmiä. Riihiin osallistuneet pitivät yleisesti riihtä ja päätösanalyysiä hyvin hyödyllisenä suunniteltaessa suojelutoimenpiteitä etukäteen. He myös arvioivat tämäntyyppisen lähestymistavan soveltuvan todelliseenkin onnettomuustilanteeseen, joskin soveltuvuus ei arvioitu niin hyväksi kuin etukäteissuunnittelussa. Menetelmän soveltuvuus ydinonnettomuuden varhaisvaiheen nopean päätöksenteon tueksi arvioitiin alhaisimmaksi. Voidaan tehdä johtopäätös, että päätösriihi on hyödyllinen menetelmä ydinonnettomuuksien hallinnassa ja varautumisessa. Se auttaa suunnittelua ja tunnistaa kehittämiskohteita.

Päätösriihen valo ja varjopuolet voidaan arvioida vertaamalla sitä muihin sidosryhmien välisessä työskentelyssä käytätettyihin menetelmiin kuten kuuleminen, neuvoa antavat lautakunnat ja suunnitteluryhmät. Kaikki nämä menetelmät, kun niitä harjoitellaan etukäteen, luovat sidosryhmien välisen verkoston. Päätösriihi tarjoaa osallistujille avoimen foorumin, jossa strukturoidun dialogin avulla keskustellaan päätöksen perusteista. Muissa menetelmissä voidaan arvioida ja kartuttaa geneerisiä toimenpiteitä, mutta kaikkia mahdollisia vaihtoehtoja ei voida oikeuttaa ja optimoida syvällisesti kuten riihessä. Toimenpiteiden luokittelu riippuu attribuuteille annettavista painoista ja on tapauksesta riippuva.

Contents

1 Introduction

The consequence spectrum of nuclear and radiological accidents, such as failure of a reactor, medical or industrial sources, has been estimated to be wide. Many accidents have no impacts offsite due to no or negligible release, some have far-reaching environmental consequences and very few might result in early deaths and other health effects off-site, such as increased cancer cases (NRC/CEC 1997; NRC 1975). The consequences of occurred accidents in Windscale (1957), in Kyshtym (1957), in the Three Mile Island (1979) and Chernobyl (1986) have also large variation (UNSCEAR 1988 and 2000). The consequences of an accident and intervention will depend substantially on the event, nuclide composition of the release and on the season (winter vis-a-vis the cultivation season). The choice of intervention measures is also linked to the legislation and living standard of the country potentially affected. Because of this diversity, and the constraints and deficiencies in consequence calculation tools in the past, international organisations have not been able to take into account all potential scenarios and all national circumstances. The recommended intervention levels have been based on reasoning or generic cost-benefit optimisation of protective actions which will most likely protect the population in an appropriate manner. Recommendations cover general and readily available countermeasures. For example, only withdrawal and substitution of contaminated foodstuffs have been considered. Detailed planning was seen as the duty of each individual country and deliberately left to national organisations.

Neither intervention planning nor the decision-making process can be developed from scratch in a nuclear emergency situation. In order to cope with any future accident, planning in advance both possible countermeasures and the decision-making process, developed both for the early and later phases, could ensure rational and transparent decisions. The importance of planning in advance and the need to develop a transparent decision-making process were clearly demonstrated after the Chernobyl (1986) and Coiania (1987) accidents. This study is a response to the international call for national planning in advance and for the development of the decision-making process in nuclear emergency management in order to be better prepared for any future nuclear accident.

Interventions affect various sectors of the society (primary production, industry, trade, population, consumers, clean-up workers etc.). There are different factors (radiological, economic, social, psychological etc.) that have to be taken into account when deciding on countermeasures (Allen et. al. 1996). The decisions are made under high uncertainties (French 1997). For example, the release assessments are very uncertain, the dose and the costs per individual can only be predicted, not be measured at the time of the decision, and wide variations are possible. Protective actions, as concerning society widely, are group decisions. Key players have often different views on the problem and the importance of relevant objectives.

Societal decisions are typically prepared in series of discussions, negotiations and meetings. The key players could be engaged in the decision-making process in various ways and often by the increased cost and complexity of the process (Mumpower 2001). The following citizen participation models are considered the most important to be reckoned with: advisory committees, planning cells, citizen juries, initiatives, negotiated rule making, mediation, compensation and benefit sharing and the Dutch study group (Renn et. al. 1995). The workshop proceedings of OECD/NEA (2001) also give many examples of how key players are involved in radiation protection. Participation is not aimed at replacing modern forms of representative democracy but should be an integrated part of the decision-making process (Renn et.al. 1995). Current practices range from the form where interested parties are only informed of the decision taken, to the form where the public based on a recommendation makes the decision (McDaniels et. al. 1999). Many protective actions in a nuclear emergency would not involve any compulsion and the final decision would be left to the population (French et. al. 1993, IV).

Individual participation methods have apparent advantages but some are also prone to shortcomings that have led to criticism (Gregory et. al. 1993; McDaniels et. al. 1999; Renn et. al. 1995). The decision might not be accountable and long-term planning might be neglected if the participants are not responsible for the implementation of the choice made. The working procedures and efficiency in the use of time in the group meetings have also often been considered to be poor (Hämäläinen and Leikola 1995; Sauri 2002; Susskind and Field 1996). Furthermore, key players might receive more information than they can utilise. Information could be in an unstructured form and not in the form needed in the decision-making process. The reported experience emphasises the importance of having relevant information, and clear procedures and methods for the decision-making process. Not all participatory methods articulate factors and judgement systematically and openly to be viewed by all people concerned.

Openness, transparency and participation by the key players are all important factors for balanced decision-making on public issues. Decisions should be understood, accepted and supported by both the population and decision-makers, not only be made in demographic order (Alho 2004). Those who must bear the harm and/ or benefits should have an opportunity to incorporate their objectives and values into the decision taken. The research in key players' and public involvement in environmental decisions have led to the conclusion that if the relevant parties are not engaged in the decision-making process the policy will fail and the final decision might 'please almost no one and certainly infuriate many' (Dubreuil et. al. 1999; Renn et. al. 1995; Susskind and Field 1996). The international organisations in radiation protection have recognised the importance of prompt, open and transparent decision-making based on scientific facts and social judgement (ICRP 2000; OECD/NEA 2002). They have emphasized that the basis for the decision must be perceived by the public, and all relevant factors concerning the decision should be considered in a rational manner.

The objective of this work in addition to planning countermeasures in advance is to develop methods to include the concerns of all key players openly and equally in the decision taken. The approach applied employs a group process where responsibility is placed on participants to assimilate information and to provide judgements. It has a clear structure based on the Decision Analysis.

Multi-attribute decision analysis provides a suitable framework for dealing with the complexity of the decision problem. It helps to clarify the objectives ('to avoid radiation-induced cancer cases') and to identify the attributes that can be used to measure the success of a strategy in achieving the objective ('the radiation dose'). It provides a reasoning framework that intertwines the beliefs, preferences and value judgements of the key players and achieves a transparent ranking of the various strategies available.

Decision analysis techniques are not a new approach for solving societal problems. It has been applied to solve social and environmental decisions such as wastewater treatment and wilderness preservation problem (McDaniels 1996; McDaniels and Roessler 1998; Renn et. al. 1995). Gregory and Keeney (1994) organised a workshop to elicit stakeholder's values and used them as the basis for creating an improved set of alternatives whether to permit development of a coal mine within an isolated pristine tropical rain forest. Marttunen and Hämäläinen (1995) applied decision analysis as an individual interactive computer supported interview method and involved large number of stakeholders in two river development projects. The papers by Apostolakis and Pickett (1998), Hämäläinen (1988, 1990, 1992) Hämäläinen and Karjalainen (1992), Keeney and von Winterfelt (1993) and Keeney (1980) are examples of studies of problems which deals with clean-up hazardous waste site, energy policy of nuclear power and management of nuclear waste. In the field of nuclear emergency management, decision analysis has been applied and facilitated workshops have been organised in various countries (Albrecht et. al. 1997; Aumonier and French 1992; Bartzis et. al. 1999, III; French et. al. 1996; International Chernobyl Project 1991; Sinkko 1991; Zeevaert et. al. 2001).

At the end of the 1980s the International Commission of Radiological Protection (ICRP) was revising its basic principles in radiation protection, and introduced the terms justification and optimisation. It was also recommended to apply decision-aiding techniques in radiological protection (ICRP 1989). International organisations have demonstrated how justification and optimisation could be applied to the planning of protective actions (OECD/NEA 1990; ICRP 1991; IAEA 1994). Because of their role, international organisations, for example the IAEA, aim to provide a benchmark against which national plans can be compared. A simple cost-benefit analysis approach has been adopted for that purpose.

At the same time, at the end of 1980 the author of this paper made a wide study on decision aiding techniques and its potential in countermeasure planning (Sinkko 1991; Gjörup et. al. 1992; Walmod-Larsen (ed.) 1994). The main issue was how the justification and optimisation could be done in practice. Gradually it becomes evident that multiattribute value or utility analysis of protective actions done by a scientist in emergency management community could not cover all aspects the decision. All relevant parties should come together and aggregate their views and judgements in rational manner in the decision. The format of facilitated workshop (also called decision conferencing) was seen as a promising format to do the planning equally and openly.

Six facilitated workshops were arranged to learn how to improve the decision-making process and plan protective actions in advance. The first workshops followed a two-day decision conferencing approach (French et. al. 1993, IV and 1996). Other forms of decision conferences have also been suggested for example the spontaneous decision conferencing concept, where the whole process can be accomplished in just a few hours and with minimal arrangements (Hämäläinen and Leikola 1995). In problems involving experts and higher level policy makers time is always limited. Therefore, this more concise type of approach was seen to be practical. In planning in advance shorter workshops necessitate extensive background information and preceding preparatory meetings but this kind of process was seen to comply with conventional emergency management. Another approach is the interview technique in order to analyse the decision situation from the perspective of different stakeholders. This approach was also considered useful in this study.

2 Review of literature

2.1 Intervention principles for radiation emergencies

Situations where radioactive materials exist or threaten to spread into the environment, and where protective actions are being considered to reduce the exposure, are called *intervention* situations (ICRP 1991). A nuclear or radiation accident, should it happen, or a prolonged exposure to radioactive materials of natural origin may call for intervention. In most situations, intervention cannot be applied to the source itself as in *practice,* e.g., operating a nuclear power plant where the structure of a source could be planned and the doses predicted. Intervention has to be applied to the environment, as the control of exposure pathways, or to individuals' freedom of action. In intervention protective actions have to be justified and optimised, whereas in practice the activity has to be *justified* and the radiation protection *optimised*.

The system of radiological protection defined by the International Commission on Radiological Protection (ICRP 2000) implies the protection of both individuals and the population. Firstly, the protection of individuals requires that 'deterministic health effects must be prevented and the individual risk of stochastic effects must be restricted'. Secondly, the system requires a wider justification to obtain the maximised health benefit for the greatest number of people by also considering the social and economic circumstances: 'all exposures shall be kept as low as reasonably achievable, economic and social factors being taken into account'. According to the ICRP, these statements could be linked to ethical principles, which link is considered important for societal acceptability of the system of radiological protection. In Operational Research it has also seen necessary to consider all ethical arguments in environmental decisions, and ethical systems to provide a rationale on the value of safety (Rauschmayer, 2001; Schulze 1980). However, the ICRP or any other equivalent international organisation has not explicitly referenced a specific ethical doctrine.

The basic principles for introducing protective actions in an intervention situation, recommended by international organizations (OECD/NEA 1990; IAEA 1994; ICRP 1991, 1993, 2000; IAEA/BSS 1996), are based on the justification and optimization of protective actions. They are intended to be generally applicable irrespective of the time elapsed, the distance from the source or the level of exposure. The basic principles recommended by the ICRP (1991) are as follows:

'The proposed intervention should do more good than harm, i.e., the reduction in detriment resulting from the reduction in dose should be sufficient to justify the harm and the costs, including social costs, of the intervention.'

'The form, scale, and duration of the intervention should be optimized so that the net benefit of the reduction of dose, i.e., the benefit of the reduction in radiation detriment, less the detriment associated with the intervention, should be maximized.'

The dose limits or any other predetermined dose limits are not considered applicable in intervention (ICRP 1991). The use of dose limits as the basis for deciding on intervention could result in marginal dose savings and could do more harm than good. 'The dose limits are intended to be used in practice to apply to the dose received, not to the dose averted, which defines the implementation of intervention.'

The protection strategy for the population affected by a nuclear or radiological accident is, first of all, to do everything possible to avoid deterministic health effects and thereafter to implement protective actions with the aim of averting doses to the population and to avoid stochastic health effects. The deterministic health effect in radiation protection is defined to mean health risks such as death or vomiting and stochastic effects, e.g., cancer cases. If the projected dose from all pathways approaches the thresholds for serious deterministic effects, protective actions are almost always considered justified. In addition, below the thresholds for such effects the exposure of individuals who are the most at risk could be unacceptable because of a high stochastic risk. Protective actions will in general be justified if the existing annual effective dose is rising towards 100 mSv. This value may be used as a generic reference level for establishing protective actions under nearly any conceivable circumstance (ICRP 2000). The recommended reference level for deterministic health effects and high stochastic risks could be used as a constraint in the justification and optimisation process performed by the decision analysis.

Because of the possibility of deterministic effects and high stochastic risks the protection of individuals and hence the individual dose may be a significant factor in the decision-making process (ICRP 1993). If the protective actions taken are not justified from the viewpoint of the individuals concerned, it should be considered if the collective dose of the exposed group could be reduced by protective actions. It might be that the members of the group could not be known by name like in actions affecting the consumption of food.

The implementation of protective action - including no-action - entails harm and benefit to the population, e.g., monetary costs, social disruption, and psychological or physical health risks. If the benefit of a protective action, which includes the *dose averted*, is greater than its associated harm, the action is justified. Justification requires that the relative importance of attributes in different actions has been judged. This assessment is independent of the decision-making process or aid (ICRP 2000). 'These judgements have to be made irrespective of the decision-aiding technique used. Indeed, they are made implicitly even if a decision-aiding technique is not used. (The technique does not create the need for judgements; rather it makes them explicit!).' A simplified example of justification is a cost-benefit analysis in which the avertable collective dose (manSv) is converted into monetary units by α-value, e.g., 20 000 €/manSv (see e.g. IAEA 1994). If the difference, the avertable dose expressed in monetary units minus the costs of action, is positive, the action is justified.

Justification of protective actions in radiation protection is not independent of other choices made by society and particularly not independent of general protection of health (ICRP 1990; IAEA 1994; OECD/NEA 2002). The resources of a society are finite, and if more resources are allocated to radiation protection, it means that less effort and fewer resources are allocated to other aids of health protection. Respectively, more effort and resources allocated to other types of health protection mean less effort for radiation protection. It is seen to be reasonable that the same amount of effort and resources should be expended to avoid serious illness, above all cancers and premature death caused by radiation or other causes.

The revealed assessment of the resource allocation is not straightforward, although made implicitly in many everyday decisions that involve health risk. The IAEA has discussed extensively the value, in monetary terms, of averting the radiation-related health risk and hence the level of resources to be allocated to reducing the dose (IAEA 1994). As a rough estimation, a sum of 20,000 US$ per manSv saved has been given for typical resource allocation. The range given by ICRP is 3,000 - 100,000 US$ per manSv (ICRP 1993).

If it is possible to choose the form, scale and duration of a protective action or if there are several feasible actions, the best action should be chosen, i.e., the action that maximizes the net benefit. The *optimization* of intervention is achieved by ranking all the feasible actions, e.g., applying decision analysis. The protective action with the highest ranking will produce the maximum benefit. The operational research and radiation protection communities interpret the term optimization a bit differently and the OR does not use the term justification. In the discussion part of this thesis there is a proposal how these terms could be understood when applying decision analysis.

In optimization it is thus assumed that all actions and factors are defined at the beginning of the analysis. In practice, however, it is not possible to define all actions before making some preliminary numerical assessments and running through some rough calculations to gain a feeling for what numbers are important and require refined assessment or even new data collection. Although preferences are associated with numbers in the planning of intervention levels, optimization is not a purely mathematical problem.

Realism is sought in consequence assessment both in nuclear emergency management and in risk management text books, not under- or overestimation (IAEA 1994; Wilson and Shlyakhter 1997). The consequences of an action should be assessed for a well-defined group, e.g., for a municipality or children, which could be met by a feasible action. Below the thresholds for deterministic health effects and high stochastic risk, the dose reduced by an action is assessed with the mean dose in the group to be protected, not on the basis of the maximum individual dose received by a group. If there is a definable subgroup within the defined group, that is more at risk (e.g., forest workers, farmers), the feasible actions for this group should be justified and optimized separately. In addition, if the consequences of an action, which might be a benefit or a disadvantage, concern part of the population not belonging to the defined group, the consequence to the group should also be considered in the decision taken.

The international organisations have also given numerical guidance on intervention levels. The recommendations of the ICRP are based on 'objective assessment of the health risks associated with exposure levels and on radiological protection attributes' (ICRP 2000). The Commission has also utilised generic intervention level assessments performed by other international organisations. The advice is expected to serve as an input for the final decision-making process.

The IAEA has provided guidance that could be used as an aid for national authorities in establishing their own intervention levels (IAEA 1994). In order to have a common basis for national decisions the Safety Guide gives generic intervention levels which, prior to accidents, are based on generic accident scenario calculations. Guidance is provided for major protective actions: sheltering, evacuation, relocation, iodine-prophylaxis and food restrictions. Numerical values are derived with cost-benefit analysis.

The expert groups of the World Health Organisation, WHO, has recommended an intervention level of an individual dose of 5 mSv as justified by comparison with variation of natural background radiation (WHO 1988).

The Codex Alimentarius Commission of the Food and Agricultural Organisation, FAO, and WHO have adopted generic intervention exemption levels to control foodstuffs in international trade that have become contaminated with radionuclides in an emergency situation (FAO/WHO 1991). They are intended to be values below which no restrictions are required. The derived intervention exemption levels have been calculated from intervention levels of 5 mSv annual committed effective dose and 50 mSv annual effective thyroid dose (^{131}I), 550 kg of food consumed in one year, all of which is contaminated, taking into account the sensitivity of infants and the food consumption pattern, and dose per unit intake factors for the radionuclides of concern.

The Group of Experts set up under the terms of Article 31 of the Euratom Treaty has recommended that the guidance in the Radiation Protection 87 report should be the basis for setting intervention levels by competent national authorities (CEC 1997). The cost-benefit analysis has been applied to derive recommended ranges of intervention levels. Recommended action levels for foodstuffs are congruent with those of the Codex Alimentarius commission (Council Regulation No. 3954/87).

2.2 The decision-making process

No single agreed structure exits for the emergency management process common to all countries in Europe (Bartzis et. al. 1999, III; Carter and French 2004). There are different persons and organisations that are responsible for decision-making and for implementation of countermeasures at different phases of an accident, and the process vary from country to country. Nonetheless, there are common themes. At the accident site the operator or licensee for the practice is in general responsible for controlling the event. The licensee may also be the first organisation to take the initiative in implementing off-site protective actions close to the site based on emergency plans. In that case a shift of responsibility to the rescue service and/or to the competent authority for implementation and planning of emergency actions will be agreed in the early hours of the incident. In the longer term the decision-making is subject to a country's administrative and legal system.

In minor local accidents the mayor, the head of the local rescue team or the regional fire chief of the municipality concerned leads the operation in domestic accidents. A leading group could be called to assist the regional leader. All relevant local authorities are represented in the group.

At the provincial level the provincial administration board (all pertinent sectors represented) and at the national level, in many countries in Europe, the Ministry of the Interior can issue orders related to rescue operations. The Ministry of the Interior is also generally responsible for the overall co-ordination of actions within the central government, especially in the early phase of an accident or, as in Finland, nuclear accidents abroad with transboundary contamination. The ministry can set up a co-ordination group which is comprised of representatives from all relevant ministries and expert organisations.

The basic principle in nuclear emergency management in central government is that each branch of administration is responsible for preparedness arrangements, emergency responses and information on actions 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 common distribution of responsibilities, which is particularly valid in Finland, is as follows (Sinkko et. al. 2001):

- the Ministry of Health is responsible for the health protection of the population (advice on iodine prophylaxis in contingency plans, psychological aid, social support, medical treatment etc.), and for providing logistics for evacuees;
- the Ministry of Trade is responsible for food and trade restrictions;
- the Ministry of Agriculture is responsible for measures in agriculture, forestry and fisheries and for implementation of the agricultural countermeasures covering primary production, i.e., all foods from field to table;
- the Ministry of Environment is responsible for housing of relocated population and reclamation of contaminated land (waste from decontamination);
- other relevant bodies and ministries in accident situations include the information unit, which co-ordinates information activities. The Ministry of Foreign Affairs is responsible for issuing information to foreign media on national accidents and the Ministry of Transport and Communications is responsible for communications (broadcasting companies), transport etc.

In most countries expert organisation on nuclear and radiation related issues assists all administrative branches. The duties of organisations regarding off-site emergency management are inter alia: to perform radionuclide analyses, to assess the radiation situation, to assess and predict radiation-related health consequences and, as a safety authority, to prepare and give recommendations on countermeasures to other authorities.

Decision-making takes place in groups of various sizes and compositions, ranging from local emergency services through local government to central government bodies. For example, the task of radiation protection and other experts may be to prepare the recommendations or comments which are considered by all relevant parties who have interests in and concerns with protective actions. The formal decision is typically made in the presentation of matters to the President, Governor or maybe, in a less formal way, to the Director General of Rescue Services. For example, later on it may turn out to be necessary that the waste disposal or the coverage of costs requires a new law. A bill is first discussed in a preliminary debate and then sent to the proper committee. After hearing specialists and various parties concerned the committee is to take a statement about the law proposal. It is then sent back to the plenary session for three readings, the last one for passing it. The formal decision is made in the presentation of a bill to the President.

All in all, the power in societal decisions is fragmented, i.e., scattered among many people and many decision-making phases that a single decision-maker cannot exercise much power in a decision. Alho (2004) and Sauri (2002) have observed this fragmentation in the political decision-making process. A precursory activity always has influence on the decision. The sense of power could only be perceived if elected officials, after a reasoned address or report, reconsider their preliminary decision or even change it. Decision-making is often a long process and it is difficult to separate preparatory work and evaluation from each other. It might be difficult to see where and when the actual decision is taken.

In general, a decision has been agreed upon before the formal decision is taken and it is too late to try to affect the decision in the phase of voting or presentation of matters (Sauri 2002). No doubt decisions will be taken outside official meetings, but even in that case, the grounds for a decision should be stated publicly instead of the majority announcing the decision. Sauri (2002) has proposed a way of improving the political culture in which the grounds for a decision or proposals should be announced publicly to be assessed and criticized by all interest groups. The credibility of politics or democracy is always undermined when the grounds are not explained. Susskind and Field (1996) have stressed that in environmental decisions decision-makers and government officials should acknowledge the need for quality information, effective communication and mutually beneficial relationships, not employing techniques such as stonewalling, whitewashing, and blocking and blaming.

Alho (2004) as well as Sauri (2002) has become to the conclusion that the decision-making process should be expanded towards greater openness and transparency. Alho (2004) in studying the exercise the power and the decision-making process in Finland acknowledges the need to broaden opportunities for participation. Participation and rational dialogue are vital for democracy.

An elected official should remain an elected official and not behave as an expert (Sauri 2002; Lackey 1997; Susskind and Field 1996). He or she should control the decision-making process in a way that fixed objectives can be achieved. He or she should speak in such a manner that those who have given the power can understand the issue. Experts should not have the role of an elected official or politician. They make technical calculations and present reports to ensure that elected officials are able to understand the problem and the consequences of decision options. Their role in decision-making process is essential. It has been proven that whoever first writes a reasonable report it will be difficult to change the content of the report during the decision-making process.

2.3 Decision analysis and its application in nuclear emergency management

The ICRP has seen decision analysis as an important practical embodiment of the optimisation concept in radiological protection (ICRP 1989, 2000). The problem could be better clarified if the radiological protection options were properly identified and their performance assessed in terms of risk reduction, costs and other relevant factors. A systematic approach ensures the recognition of the judgements involved.

Operational Research (OR) over the past 40 years has transformed the abstract, mathematical discipline of decision theory into a potentially useful technology known as decision analysis, which may assist key players in handling large and complex problems and the attendant flows of information. Decision theory and its use in decision analysis is a branch of Operational Research, which has links to economics and psychology. Decision analysis is not intended to be used to solve problems automatically. Its purpose is to produce insight and understanding in order to help people to make better choices. It is both an approach and a set of techniques to rank options according to people's preferences. The theory of prescriptive decision analysis is described in detail in the literature (Keeney and Raiffa 1976; Keeney 1992; Winterfeldt and Edwards 1986; French 1988; Goodwin and Wright 1992; Hammond, Keeney and Raiffa 1999). This chapter briefly explains multi-attribute decision analysis and how it could be applied in nuclear emergency planning (Sinkko 1991; Gjörup 1992).

In decision theory it is recognised that people could benefit from the support and guidance of structured decision analysis. Where this is not the case, as e.g. in recurrent, experience-based decisions, it might seem simpler, more efficient and more acceptable to introduce a problem or a complete list of alternatives and their consequences into the decision-making process without recourse to any formal analysis. Nuclear accidents are very rare and their consequences dissimilar. Therefore the decision-making process cannot be based on daily, recurrent experience. An analytical approach could be advantageous in unusual decisions, also helping to focus on pertinent information collection.

Secondly, studies indicate that when left to their own devices people easily create and hold on to many kinds of inconsistent beliefs and preferences (Kahneman and Tversky 1982; Spetzler and Staël von Holstein 1975; Gregory, Lichtenstein and Slovic 1993). This view is supported by research indicating that the correlation between preference rankings derived from holistic judgement and those derived from decision analyses decreases as the number of attributes in the problem increases (Winterfeldt and Edwards 1986). Even in the absence of seriously conflicting objectives, unguided intuitive decision-making is susceptible to many forms of inconsistency. People's preferences may be dictated by the presentation of a problem and not by its underlying structure, which may lead to irrationality.

The essence of decision analysis is to break down complicated decisions into small, manageable pieces that can be dealt with individually and then recombined logically. In this one-step-at-a-time approach many decision problems may be resolved by considering what are the relevant objectives, and alternative actions, what might happen as their consequence and what is the prioritisation among the consequences.

Before any formal or informal analysis is made, it is essential to identify the key players, e.g., the authorities, expert organisations, industry, producers, the public and the formal decision-makers. The decision to be taken and the purpose of the analysis have to be defined as well. The analysis may well serve other purposes rather than lead to prompt decisions. The planning of protective actions in advance is a common example.

Objectives and attributes

Many researchers in the decision theory have proposed that identification of objectives relevant to the decision problem is most important because alternative actions are important only as a means to achieve these objectives (Keeney 1992, 1994). In other words, quoting an old saying, 'if you don't know where you are going, any road would do', fits here. In order to be more useful and understandable, objectives should be measurable. In decision analysis numerical scale are used to evaluate how objectives can be achieved by actions. The related numerical variable is called an attribute.

Objectives and attributes are not always evident, but time and effort is needed to specify them clearly and fully. Incomplete specification will lead to too narrow a focus (Hammond, Keeney and Raiffa 1999). Objective identification could be facilitated by thinking of the pros and cons of potential alternatives. It might also be effective to compare prior attribute definitions in analogous problems.

An attribute hierarchy, also called a value tree, can be useful in defining objectives and attributes (Keeney 1992). The top layer of the tree contains very general and sometimes vague values. The values become more specific the lower one goes down the tree. The building of the objective hierarchy is continued until objectives that are measurable, operational or easy to assess judgementally, are found. Keeney and Raiffa (1976) propose the following criteria for examining the applicability of the attributes: completeness, operationality, decomposability, absence of redundancy and minimum size.

In nuclear emergency management international organisations have listed a generic group or abbreviations of objectives: minimising the radiation dose, physical risks, monetary costs, anxiety and disruption of actions, and maximising the reassurance produced by intervention (ICRP 1991, 2000; IAEA 1994). Certain authors in emergency management community have also written down the definition of fundamental attributes that they have proposed or used in the analysis (French 1992; Hedemann-Jensen et. al. 1996; Morrey and Potter 1994; Atherton and French 1998).

Alternative actions

One essential stage in emergency management and in decision analysis is to identify all feasible alternatives of actions. International organisations have published generic guidance on the primal protective actions considering reduction in dose, especially for the early phase. For planning purposes, protective actions have been listed and categorised into those that restrict people's activities or the use of contaminated food or consumables and into those which prevent radionuclide incorporation in the human environment, food or consumables (ICRP 1991; IAEA 1994).

In planning countermeasures for the event of a nuclear accident generic, protective actions can be developed further by considering the possibility of changing the action's scale, timing and duration. For example, the population group to be protected can be modified. It is useful to iterate between the articulation of attributes and creation of alternatives in order not to end up with too limited set of alternatives. All feasible actions have to be defined - including no action at all - which might be implemented to control a certain exposure pathway. In defining the action, its technical and social feasibility, and national circumstances should be considered; can it be implemented in practice as has been planned?

The aim of radiation protection in nuclear emergency management is to reduce doses by implementing countermeasures. Accidents will cause negative social and psychological impacts. After the Chernobyl accident it was observed that psychological health consequences were the most significant as compared with the economic and radiological ones (Allen et. al. 1996; IAEA 1991). It has been concluded that radiological countermeasures might not withdraw anxiety or stress alone but in addition actions to mitigate social and psychological impacts are needed, for example debriefing where victims by discussions work trough their anxiety (Haukkala and Eränen 1994).

Consequence assessment

Consequences are the values of attributes in various actions, e.g., the assessed doses before and after the actions are taken and the costs of the actions. The measurement of these attributes is easy because we can identify the variables representing them. However, for attributes such as reassurance and anxiety, it will be more difficult to find appropriate statistics or a variable that can be quantified or expressed on a characteristic scale. The technique that can be used to express the preferences over the values of an attribute is grade scales, direct rating of the consequence, which is often used, e.g., in schools and technical magazines.

In direct rating, the most preferred option, for anxiety for instance, is given a value of 100 and the least preferred option the value of zero. The other options are ranked between zero and 100, according to the degree of preference for one option over another in terms of anxiety. The technique seems robust but numbers do not always need to be precise. The availability of relevant information could be more important than its precision.

All in all, rational decision-making requires that the consequences in each action are assessed realistically, without overestimation. Conservatism in assessment may cause overestimation of the benefit of an action, an excess of monetary resources and an increase in unnecessary stress among the population.

There are different consequence assessment tools for nuclear emergency management, for example: ARGOS (http://www.pdc.dk/nucsystems-uk/), COCO-1 (Haywood, Robinson and Heady 1991), OECD/NEA (2000), RODOS (Ehrhardt and Weis 2000) and WSPEEDI (Chino et. al 2000). These softwares are planned to assess, present and predict mainly the radiological consequences of an accident and the monetary costs of actions. However, in the workshops reported here it was not possible to calculate all the consequences needed in the decision-making process. Commercial software can be and were utilised in consequence assessment, for example GIS (Geographic Information Systems) and spreadsheets together with statistical and production information.

Trade-offs

The avertable dose achieved by a countermeasure is probably not of equal importance to its monetary cost. In all decisions - whether explicit or not - the range of attributes has to be balanced, e.g., by assessing the weights on the attributes. They represent the judgement concerning the relative importance of the levels of attributes. For example, how much is society ready to invest to avoid a certain dose? The importance of an attribute not only depends on its conceptual value, such as health, but also on its range of values, such as the number of cancer cases. A thorough assessment of trade-offs is essential for good decision-making but it is not always an easy matter and is prone to mistakes (Keeney 2002).

The trade-off values are subjective, not objective. There are no universal values. The values are related to every specific problem, and in addition, they change according to opinions and are dependent on resources of a society. There are methods and studies which make it possible to estimate trade-off values and shed more light and understanding on the values, for example, studies on willingness to pay and the costs of life-saving interventions (Bengsson and Moberg 1993; Katona et. al. 2003; Ramsberg and Sjöberg 1997, Tengs et. al. 1995). They have reported variations over 11 orders of magnitude in values with the median of 20,000 - 40,000 US$ per statistical life saved per year. Tengs (1995) has concluded that more lives could have been saved by shifting resources between life-saving interventions.

However, methods such as willingness to pay studies and contingent valuation, that are carried out to prevent harm, have been criticised. The problem with contingent valuation techniques is that 'they capture attitudinal intentions rather than behaviour, important information is omitted from questionnaires and their results are susceptible to influence from cognitive and contextual biases' (Gregory, Lichtenstein and Slovic 1993). The results of willingness to pay studies are not any more useful because case studies are usually poorly structured and do not indicate the multidimensional values behind decisions. Values are multidimensional and people have strong feelings and beliefs about these values, which typically are not numerically quantified and are not expressed in monetary terms. Careful structuring of the problem is necessary to identify the underlying multidimensional values, attitudes to risk and trade-offs related to the problem. These are created during the elicitation process in decision analysis. Therefore, it does not seem reasonable to assess trade-off values using problem independent studies. Indeed, a proposal has been made to adopt the multi-attribute value/utility theory in contingent valuation studies (Gregory, Lichtenstein and Slovic 1993).

Uncertainties

Value models, such as MAVT and cost-benefit analysis (CBA) are used in the planning of countermeasures in the event of a nuclear accident (IAEA 1994; Sinkko 1991). They are inappropriate if major uncertainties are connected with the decision, as in nuclear emergency management. In many protective actions the consequences of alternatives cannot be predicted with certainty. For example, depending on the course of the accident, it is possible that much higher or lower doses than estimated will result, or it is not known how successful the action will be. Even if the fallout pattern has been measured, the dose distribution could be substantial. The consequence assessment of other attributes is equally uncertain. Utility analysis (MAUT) is designed to allow both uncertainties and risk to be taken into account. For example, if felt appropriate, it is possible to use the individual dose instead of the collective dose in the calculations by considering the individual dose distribution. There is also software which makes it possible to incorporate distributions into the analysis (Smith 2002). Incorporation of uncertainties into an analysis, however, requires an understanding of probabilities and - if done in an orthodox way - a series of potentially difficult questions for decision-makers.

Should any uncertainty exist, an important issue is to distinguish a good - analytically premeditated - decision from a desired consequence. Because the outcome is uncertain a good decision does not guarantee the realisation of the most desired consequence. A decision cannot be qualified based on its true consequence (Hammond, Keeney and Raiffa 1999).

Group decisions and facilitated workshops

Decision analysis is based on the preference model of a single decision-maker. However, in reality, a decision is rarely taken by a single person, but by a group of key players. It is more complex to develop a mathematical model for rational group decisions than a mathematical preference model for an individual decision-maker (see, for example, French 1988 for more extensive theoretical discussion). Indeed, the well-known Arrow's theorem suggests that for each possible arrangement there is a set of individual preferences such that the group preference constructed from individual preferences breaks at least one of the axioms attached to group behaviour (Arrow 1963, 1984). Nevertheless, it is possible to support key players in a manner that can be characterised as useful and informative. A fair and just solution to a group decision problem can be found only if each member of the group behaves rationally and equitably.

In group decisions as well as in individual decisions decision analysis assists key players towards a greater understanding of the problem and the preferences of the other members of the group. Furthermore, the analysis guides the discussion in a positive and constructive way; there are fewer possibilities to jump from one issue to another without direction or progress in the discussion (French 1988; Phillips and Phillips 1993).

A facilitated workshop (also called a decision conferencing) is an interactive approach to group decision making in order to generate a shared understanding of the problem and to produce a commitment to action. A facilitated workshop combines decision theory, group processes and information technology over an intensive, up to two- or three-day session attended by key players with different fields of expertise. The original arrangement is that a small group of key players is seated in a semicircle to discuss the problem through a facilitator who aids the group's discussion and sharing of knowledge. In the background an analyst, using decision-aiding technology, models the group's views (Phillips and Phillips 1993).

Phillips argued that decision conferencing produces conditions for creative and effective decision-making. Participants are not on home ground (Phillips 1984). Usually sessions take place in hotels, or in an especially designed room on the facilitator's premises. The group is carefully composed of problem owners representing all perspectives of the issue to be resolved. It is recommended that the facilitator should be a professional and neutral outsider (Phillips 1984; Susskind and Field 1996).

Decision analysis techniques

The decision analysis approach in this work is based on multiattribute value (MAVT) and - utility (MAUT) theories (Keeney and Raiffa 1976; French 1988). The selections were made because these theories are well developed and tested for many years and have an axiomatic foundation. These methods are very applicable also in facilitated workshops where the purpose is to guide the thinking of key players, help them to make consistent judgements and to choose rationally. There are other multiattribute evaluation methods such as the analytic hierarchy process, fuzzy decision analysis and multiattribute outranking analysis. All these theories have proponents and opponents (see e.g. French 1988).

The cost benefit analysis (CBA) has also applied in planning of protective actions in advance (IAEA 1994; Gjörup et. al 1992). The costs benefit analysis has its basis in economic theory. Typically analysis is prepared to provide decision-makers with information and do not require decision-makers to express value judgements (French 1988). Therefore, the CBA method is not very applicable in the workshops where the judgements are performed with the key players. The apparent difference is also that in the MAVT the values of attributes are converted into common units, whereas in the CBA values are converted into monetary terms. All effects are translated to financial values regardless of how intangible they might be. This poses problems when human health is the main issue. In the workshops some participants pointed that money is not important in the decision on protective actions.

The quality of any decision analysis will depend on how digestible the problem is structured and how careful consequences of alternatives have been pondered. The decision problems, which are deliberated and judged carefully, the outcome of a decision analysis from all evaluation method could well be the same. The prerequisite is that all pertinent attributes, action alternatives and trade-offs are judged equally. This is not likely to be true if risk attitude of a decision-maker is a major issue. In that case the MAUT analysis offers a reliable method to manage the problem.

3 Objectives of the study

The overall objective of this study is to develop methods and techniques to evaluate systematically protective action strategies in such a way that all key players' concerns and issues could be considered openly and taken equally into account in the decision taken (Hämäläinen et al. 1998, Hämäläinen et al. 2000, VI; Ammann et al. 2001, VII). An important outcome of the work is the creation of preconditions for participatory decision-making in the event of a nuclear accident (Sinkko et. al. 2004, I). The specific objectives are:

- to plan analytically countermeasures with all pertinent key players. International organisations have also recommended analysis of protective actions on a national basis;
- to define the generic attributes that have to be considered when setting intervention levels. Only a few analyses exist where all important attributes and their relative importance for the decision taken have been considered and discussed explicitly (Aumonier and French 1992; French et. al. 1996; International Chernobyl Project 1991; Sinkko 1991; Zeevaert et. al. 2001);
- to study how the area, timing and duration of an action should be defined in order to maximise the reduction in radiation detriment and at the same time to minimise the detriment associated with the intervention;
- to study how single protective actions can be bundled into overall strategies in the affected area. Although protective actions could be optimised independently from each other, in practice the actions are dependent or sequential, e.g., agricultural countermeasures are dependent on evacuation and relocation. The dependence or sequence might influence on value tree or value trade-offs;
- to study and develop 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 has to be based on intervention levels studied and considered beforehand and on guidance given by a decision support system (DSS). In the later phase of an accident, however, there is time and need to perform detailed and more specific analyses;
- to study how uncertainties could be incorporated into nuclear emergency management. In the early hours of an accident uncertainties are dominant, concealing factors which might become apparent in the later hours of the accident. There are also large variations, e.g., in the health consequences for the population.

4 Materials and methods

In this study a series of facilitated workshops have been organised in the Nordic countries to analyse protective actions and to develop methods for key player participation in the event of a nuclear accident. The workshops were jointly arranged by the RISØ National Laboratory, the STUK - Radiation and Nuclear Safety Authority and the University of Leeds (UoL), in Denmark in 1992, and by STUK, RISØ, NRPA (the Norwegian Radiation Protection Authority), SSI (the Swedish Radiation Protection Institute) and UoL in Sweden in 1995, and by STUK and the Helsinki University of Technology in Finland in 1997, 1998, 1999 and 2001. STUK was responsible for the co-ordination, development of the accident scenarios, consequence assessments and for contacts with the key players. The University of Leeds and Helsinki University of Technology were responsible for the decision modelling, the analysis approaches and the implementation of the decision support software as well as for the facilitation of the workshops.

The Nordic co-operation organisation (NKS Nordic Nuclear Safety Research) funded the first two workshops held in Denmark and Sweden (French et. al. 1993, IV and 1996). The members of these workshops were local government officials, emergency planners and members of the radiation protection community from all the Nordic countries. The two subsequent workshops and decision analysis interview were conducted within the fourth Framework Programme of the EU (Hämäläinen et. al., 1998, and 2000, VI). The last workshop was funded by Finnish sources consisting of the Foodstuffs Industry Pool, the National Emergency Supply Agency and Valio Ltd (Ammann et. al. 2001, VII).

Within the NKS the KAN-2-project was performed in 1994, the purpose of which was to provide basic data and methodology to improve the planning of protective actions in the event of nuclear accidents. Special attention was paid to the tail-end topics of the clean-up process; management and disposal of radioactive waste. As part of this project decision analysis was performed in which recovery operations to clean up a forest environment were analysed and discussed to determine appropriate intervention levels in a hypothetical nuclear accident to protect the public, workers and the environment (Sinkko et. al. 1994, V).

The work is based on case studies where the key players were invited to consider a scenario of a hypothetical but realistic nuclear accident. It was assumed that a core-damage and containment leak accident had occurred at a nuclear power plant, leading to contamination of the environment. To increase realisticness, in most cases the accident sequence was taken from probabilistic reactor safety studies (PSA) performed by the NPP and STUK safety experts. It was also considered important that the current emergency management process of the administration was followed closely and that all relevant key players were represented at the meetings. Contacts were made and preparatory meetings held prior to workshops, as would be the case in a real situation.

Several protective actions and the bundle of actions, i.e. strategies, were selected to be considered in the workshops. The workshop held in Denmark considered countermeasures in a situation where early phase protective actions had been taken and decisions on later phase protective actions were to be considered (French et al. 1993, IV). The main issue was to consider whether to relocate people in certain areas. The theme in the second Nordic workshops was the decision on clean-up actions in inhabited areas (French et. al., 1996). The first Finnish workshops focused on early phase countermeasures, i.e. iodine tablets, sheltering and evacuation (Hämäläinen et. al. 1998). The attributes and their definition related to the decision of early phase protective actions were studied in depth. The incorporation of uncertainty into emergency management was studied in these workshops and in the interview analysis (Hämäläinen et. al. 2000, VI). The task of the last workshop was to plan countermeasures to reduce the dose received from consumption of dairy products contaminated by radionuclides (Ammann et. al. 2001, VII).

The simulation of the radiological situation and the generation of countermeasure strategies, together with the assessment of their consequences, were done in advance. The participants were given an information package comprising thematic maps of the radiological situation showing an animation of the dispersion, dose values and assessments of health and economic consequences. The information was also provided in the form of consequence tables. The possible precautionary actions taken to protect the population were mentioned. A list of predefined attributes, the parties involved in decision-making and their duties were attached. All in all, the package was designed to contain all the relevant information necessary for the participants to understand the accident situation and to be able to take an informed decision on the countermeasures to be recommended to formal decision-makers.

At the beginning of the workshops the list of attributes was presented and introduced for discussion. The participants were urged to go through, revise, remove, add and redefine any attribute they wished. During the whole discussion the attribute hierarchy was displayed and suggested changes were incorporated on the fly. Eventually the group agreed on the final set of attributes. The ‘hard’ attributes, i.e. the number of cancer cases and costs were calculated in advance, but the ‘soft’ attributes such as social disruption and anxiety, were directly rated during the workshops. A decision model was constructed and value or utility analyses were performed, including sensitivity analysis with commercially available software. At the end of the workshops the results were discussed.

5 Results and discussion

5.1 Emergency planning

The workshops aimed to elicit justified protective actions or their combination, i.e. strategies of which the scale, timing and duration were optimised in the given situation (optimisation in the sense of radiation protection). Decision analysis has been developed to evaluate and identify the best strategy, i.e. to rank strategies but the term justification is not used in the OR. The justification of actions is conceptually clear but not easily measured. The ranking of countermeasures embodies many value judgements such as the assessment the importance of attributes. If all possible alternatives are considered, the best ranked option should also be justified. Thus the justification is implicitly included in the decision analysis. In traditional vocabulary, the best ranked protective action is justified and optimised. (Sinkko et. al. 2004, I).

International organisations define justification slightly differently. Attributes are most often seen to have either a positive or negative quality; more is better than less (positive) or less is better than more (negative). In nuclear emergency management, avertable dose and reassurance for instance are positive, while anxiety and monetary costs are negative. For the justification process the quality of attributes should be agreed and the relative importance of attributes, i.e. their weights, be judged. Relevant value for weighting is the difference between the value of an attribute in the action under consideration and in the worst action, not its conceptual value. An action which aggregated sum of weighted values is positive is justified. A simplified example of justification is given in figure 1.

The judgement of the relative importance of attributes is not a task of the radiation protection community. It contains the judgement, how much society should invest its resources to health care and, particularly in this context, to avoid radiation risk. The overall justification and optimisation might show that resources are more needed for other health care purposes, and protective actions are not justified. The radiation protection community has a responsibility to be aware of the amount of resources it would be appropriate to allocate to reduce radiation risk, to be comparable to other reductions in the health risk and to hand this information on to formal decision-makers along with transparent recommendation.

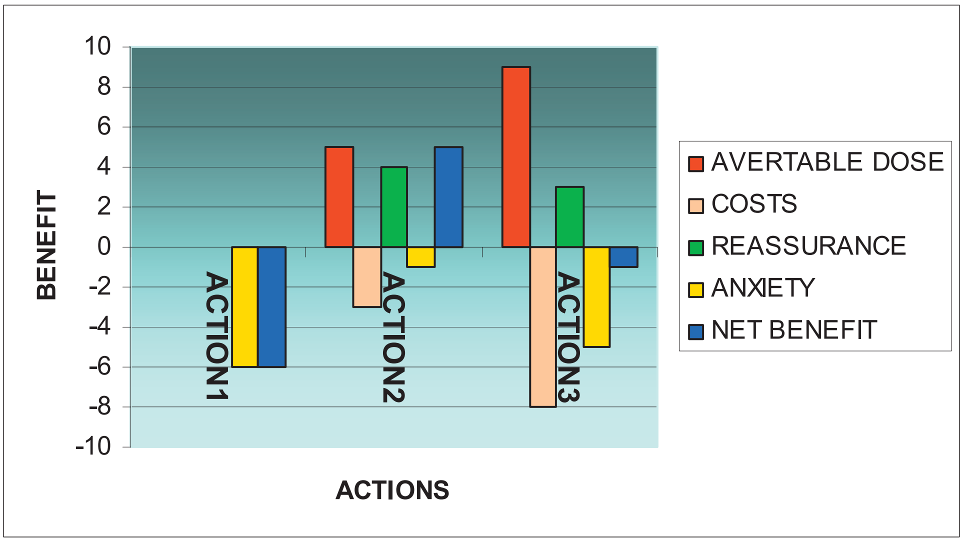

Figure 1. Principled justification of three actions considering four attributes. The height of the bars illustrates their relative importance in the decision. The bar on the far right (blue bar) is the aggregated, summed up net benefit in each action. In action one avertable dose, costs and reassurance have been considered with a value of zero. Action two is justified.

The relative importance of attributes is subjective and no universal values exist (Sinkko et. al. 1994, V). The values are related to the unique problem and they change according to opinions and resources. As a consequence, intervention levels based on generic planning or case studies are very rough and their applicability to a new situation should be verified.

There should be a clear understanding of the countermeasures and factors affecting the decisions. The timing, duration and target area of actions, and the group aimed to be protected by the actions could be quite easily assessed and should be clearly defined. The objectives and attributes are not self-evident. In workshops much time was spent on defining factors and wording used in value elicitation. Especially intangible attributes such as anxiety, reassurance can commonly be interpreted differently. It seems to be beneficial to define the attributes in advance in order to save time and to guarantee that all key players understand their meaning in the same way. The definition of attributes in advance is contrary to the standard way of using decision analysis and possibly leads to such biases as availability or anchoring. Value assessments could thus be based on information that is visualised and useful modifications in attributes are not made. For example, if anxiety is available in the list it might be given too much weight or technical feasibility omitted if not mentioned. However, nuclear accidents are rare and key players are not very familiar with the radiological issues or related terminology. It was found that in order to harmonise the discussion it is practical and efficient to start with a predefined, preliminary model of attributes (Sinkko et. al. 2004, I). The participants were asked to fill in questionnaire after the workshops in order to find out their opinions on the decision analysis and the workshop method. The questionnaire confirmed that the participants were rather satisfied with the predefined attributes and ensured that all relevant factors were included in the model (Ammann et. al. 2001, VII).

The following set of generic attributes has been deliberated upon with the insight gained during this work (Ammann et. al. 2001, VII; French et. al. 1993, IV; French et. al. 1996; Hämäläinen et. al. 1998; Hämäläinen et al. 2000, VI; Sinkko et. al. 1994, V). Although attributes are elicited in different case studies covering early as well later phase actions such as evacuation, milk pathway, clean-up and forest, attribute validity in a new situation should be verified:

Collective dose to the public. The standard assumption within the radiation protection community is that exposure to radiation increases the risk of cancer, however small the exposure. If the individual risk is very small, stochastic health effects are still expected when large population groups are exposed. This attribute could be measured as the projected collective dose to the public (manSv). It could also be converted into the *expected number of fatal cancer cases or number of cancer incidents* to be more comprehensible for persons outside the radiation protection community. A risk factor or nominal probability coefficient for stochastic effects of 5 x 10^{-2} per Sv could be used to assess the probability for fatal cancers (IRCP 1991). Excepting thyroid cancers, it could be assumed that roughly half of the cancer cases can be cured, i.e. there are twice as many incidents as fatal cases. A figure to be calculated with a DSS as an input in the decision-making process could be estimations of the additional number of cancer cases or collective doses with and without countermeasure options (i.e. avertable doses).

Individual dose to the public. Some members of the public might be subject to a relatively high stochastic risk or be at risk of incurring deterministic effects (the critical group could be defined as in Basic Safety Standards, IAEA 1996). Their risk has to be considered individually and can be measured by the individual dose. It is worth noting that there is a correlation between collective and individual dose attributes if both are used in a decision analysis (Sinkko et. al. 1994, V). This attribute could be measured with *effective external dose and / or organ dose* in normal living conditions and when an action is taken integrated over the action period (e.g. sheltering or evacuation time, units in mSv).

Number of thyroid cancers in children. Thyroid cancer deserved special consideration because it is predominantly children that are affected. In addition, thyroid cancer, which has a latency time of only a few years, is rare and is easily seen in statistics. The better response to treatment of thyroid cancer is another aspect that needs expression, i.e. roughly 10% of thyroid cancers prove fatal, whereas on average an assumed 50% of all other types of cancer cause premature death. The risk factor to calculate the number of fatal thyroid cancer cases is 0.08 x 10^{-2} per Gy (ICRP 1991). A figure to be calculated: *thyroid dose in children* from intake of radioiodine in normal living conditions and when an action is taken (mGy).

Number of thyroid cancers in adults. A breakdown of the number of *thyroid cancer cases* into those expected in children and those in an *adult* population might be useful. A similar breakdown for other cancer types might also be helpful. A figure to be calculated: *thyroid dose in adults* from intake of radioiodine in normal living conditions and when an action is taken (mGy).

Dose to the workers. Projected individual dose received by the workers carrying out protective actions generally outdoors (mSv). If large numbers of emergency service employees are exposed to radiation (e.g., during clean-up actions) the increased number of expected fatal cancer cases in the group or their *collective dose* could also be used as an attribute (manSv). Dose limits to workers have to be observed. A figure to be calculated: *effective external, organ- and/or skin dose* during work hours (mSv).

Statistical non-radiation fatalities. The collective physical risk is largely dependent on the number of people affected by protective actions and it may not be much higher than the risk associated with normal human activities. For example, it has been concluded that the health risk introduced by stable iodine prophylaxis, prolonged sheltering or evacuation is very low (Aumonier and Morrey 1990). Since there is only sparse information on accidents caused by other countermeasures, the general statistics could be used as an initial approximation for other countermeasures, e.g. for the risk of road accidents during evacuation. This attribute could be measured as the *number of fatalities or reduced life expectancy* in the alternatives considered.

Individual non-radiation fatalities. In some accident scenarios there might be a population group that is at higher risk of suffering death in the course of taking countermeasures. It might be important to consider individual risks, for example, when evacuating the young, the elderly or patients in very bad weather conditions, since evacuation under such circumstances might endanger their lives. This attribute could be measured as the *number of fatalities or reduced life expectancy*.

Social disruption. An accident and how it is reacted to, poses a severe threat to the industry and primary production. Firstly, there would be loss of income, for example, due to direct restrictions in selling products that exceed the maximum permitted concentration or contamination levels. But then consumers may also react unpredictably and reject all products that are somehow related to the affected area. Exports may suffer from a total loss of confidence in a country's products. All this amounts to a threat to posed to producers and employees in industry, and the subsequent loss of their livelihood can cause social disruptions. Evacuation or relocation may break down the social network, which cause disruptions. *Direct rating* of alternatives.

Anxiety of the population. Anxiety could be defined to be a combination of fear and the emotions of sadness, guilt, anger and shame. (Izard 1977). The majority of the persons living in the contaminated area may show varying degrees of psychological reactions in response to an accident (e.g. miscarriage of unborn children). But stress may also be introduced by the protective actions. The severity of an accident is likely to be perceived through the protective measures taken, i.e. the more extensive these are, the more severe the accident must be and consequently the higher the health risk. *Direct rating* of alternatives.

Reassurance of the population. 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* of alternatives.

Anxiety of the workers. Emergency actions will cause stress among workers who are implementing them. *Direct rating* of alternatives.

Environmental issues. Protective actions may remedy or insult the living conditions of flora and fauna. Environmental issues may be related to specific countermeasures, for example, waste management in clean-up actions may cause environmental damages whereas clean-up itself may improve the situation. *Direct rating* or another numerical value depending on the case.

Social feasibility. Some actions may not be perceived as adequate (slightly contaminated foodstuffs), restrictive or even not accepted (relocation). People are not ready to follow recommendations which are against their wishes or attitudes. *Direct rating* of alternatives.

Technical feasibility. Technical feasibility is understood in relation to defined quality or quantity. This attribute is in many cases a constraint preventing the implementation of an action. Large cities can hardly be evacuated and sheltering, too is difficult. In some cases actions may differ in their feasibility, e.g., sheltering is more feasible than evacuation in bad weather conditions. *Direct rating* or another numerical value depending on the case.

Flexibility of strategies. There may be substantial uncertainties in consequence assessment and therefore it should be possible to modify strategies as more information is collected. *Direct rating* of alternatives.

Monetary Costs. This attribute might contain the direct and indirect costs of protective actions. Cancer treatment costs, associated loss of GDP, and other costs that are proportional to the number of cancers should not be included in this attribute in order to avoid double counting. *Monetary unit.*

Risk studies have suggested that perceived risk and related attributes (e.g. confidence) might be major factors in the final decision-making in policy problems (National Research Council 1989). Confidence in authorities is often thought to be of crucial importance for risk perception in an expert organisation. Recent studies, however, have shown only a weak relationship between confidence and risk perception. A much stronger correlation has been found between risk perception and unknown effects (Sjöberg 2001). Contrary to the opinion of experts, politicians and members of the public believe that there are many unknown effects that are not yet understood but still affect their risk perception and consequently their behaviour, for instance, as consumers. These types of attributes were not considered in the workshops. Expert organisations should, however, be aware of the reasons why perceived risk and related attributes might be added in final policy decisions. Attributes, such as ‘confidence’ and ‘unknown effects’, which would increase the intervention level, should thus be kept in mind but not considered on the expert level while preparing recommendations.

Political objectives and attributes might be part of decision-making on protective actions but they need to be clearly defined. Politics is by definition activity directed to social matters, a programme or procedure and it could not be as such a measurable attribute. Politicians and authorities write and maintain political programmes and the definition and incorporation of these attributes in the decision-making process is their natural task.

One objective of this study has been to analyse protective actions on a national basis and derive national interventions levels. Therefore it was stressed that the intervention levels recommended by international organisations should be forgotten for a while in the workshops. However, some intervention levels, e.g. radionuclide concentrations in foodstuffs should have been considered in the workshops because of their mandatory status as EU regulation. It cannot be deducted from the result of their overall influence on the intervention levels derived in this work. International recommendations are important reference levels and will be compared in a real situation.

Although the number of actions considered in the workshops do not cover all possible actions some, remarks on intervention levels could be made. The calculated intervention levels are given in Table I. More countermeasures were considered than is given in the table, but in the method applied here the intervention level could be recalculated only for the best ranked action. In addition, taking into account the time constraints in the workshops it was impossible to undertake a systematic analysis to derive optimal intervention levels for the accident scenario. More flexible tools to modify protective actions and assess their consequences would have been needed, too.

Table I. Intervention levels in terms of averted dose derived from results of workshops compared with the levels recommended by ICRP, IAEA and EU. The IAEA and EU levels for milk are generic action levels and maximum permitted levels, respectively.

	Derived from workshops	ICRP	IAEA	EU
Iodine prophylaxis	10 - 100 mGy 0.7 - 1.4 mGy [1, 6]	50 - 500 mSv	100 mGy	some tens to a few hundreds mGy
Sheltering	0.5 - 5mSv/24h 1 - 2 mSv/12h [1, 6]	5 - 50 mSv/day	10 mSv/ < 2 days	a few to few tens mSv
Evacuation	10 mSv/month [2] 5 - 50 mSv [3]	50 - 500 mSv/ < 1 week	50 mSv/ < 1 week	a few tens to a few hundreds mSv
Milk ^{131}I	50 Bq/kg [5, 6]	10 mSv/ 1 year [7] 1000 - 10 000 Bq/kg	100 Bq/kg	500 Bq/kg
Milk ^{137}Cs	100 Bq/kg [5, 6]	10 mSv/ 1 year [7] 1000 - 10 000 Bq/kg	1000 Bq/kg	1000 Bq/kg

1) Early release phase with uncertainties. Assessment is based on certainty equivalent value
2) Individual dose in the first month. Evacuation was planned for six months and avertable dose estimation was 22 mSv.
3 Evacuation time was not considered
5 Provision of uncontaminated fodder or upgrading milk to cheese or butter to protect the milk pathway.
6) Action level.
7) Restriction to a single foodstuff.

The analysis of the milk pathway nevertheless suggests that countermeasures at concentration levels a decade below internationally recommended intervention levels can be justified in certain accident scenarios (Ammann et al. 2001, VII). The banning and disposal of milk was never considered optimal. Banning would create an enormous disposal problem and the legal aspects of such a measure are unclear. No emergency plans exist for the dumping of large amounts of contaminated substances such as milk or milk powder, processing water or grass. Milk is produced daily and is difficult to store; and therefore any alarming contamination of milk would consequently call for an almost immediate decision. For these reasons it was suspected that the disposal of milk was not a feasible option at all.

Understanding uncertainties and determining the risk marginal is problematic. During the pre- and release phases of an accident the released amount of radionuclides is the main source of uncertainty. The range could be several orders of magnitude. The consequence tables of 5, 50 and 95 per cent release fractiles were calculated and shown to the participants in the workshops. Many participants were not familiar with decision analysis and some did not feel comfortable with modelling tools and had problems in understanding the procedures how uncertainties were incorporated in the analysis. It is likely that the 95% fractile had a strong influence on their decision and as a consequence the action levels in Table I are lower than might be expected from the normative utility analysis. In the workshops there was not enough time to explain in detail the utility analysis. A way forward to incorporate uncertainties in nuclear emergency management is to perform the utility analysis in advance and scrutinise it in the workshop.

Many times in the workshops it was pointed out that the way the public is informed about the accident and the countermeasures taken are crucial (French et. al. 1993 IV; Hämäläinen et. al. 1998). People's reactions depend on what information they are given and how they interpret the situation. In risk communication the goal cannot only be to make the messages more effective by improving the understandability and the credibility of those who disseminate information (National Research Council 1989). Such an approach might serve their interests but could degrade the overall quality. Good risk communication helps the recipients to solve their problems at the same time. People need timely delivered clear, understandable and unambiguous information in order to cope with situation (Eränen 1997). Decision analysis will help to reveal this information because its focus is in decision-making. It is important not to conceal pertinent information and knowledge that is needed for decision-making in an emergency (Susskind and Field 1996). It is equally important to tell what is known and what is not known and not to speculate.

5.2 Decision analysis

It is important to learn where in the decision-making process decision support in the form of a workshop would be appropriate. Facilitated workshops do not fit comfortably in the representative decision-making process as a forum for making final decisions concerning many key players (French et. al. 1996). Preparation of a decision is often divided into so many phases carried out by so many people that a single decision-making point cannot be identified. In a workshop a single decision-making point is presupposed. Commonly, elected officials and authorities do not participate in consequence assessment or in the preparation or evaluation of a decision; instead they expect prepared advice from experts (Apostolakis and Pickett 1998, Lowry, Adler and Milner 1997; Sauri 2002). After the Nordic workshop held in 1995, the Lord Mayor of Helsinki and the former Minister stressed that higher level officials desire advice as to both alternative actions and the grounds for a decision (Siitonen 1995).

Experience gained from this work supports the view that facilitated workshops fit well into the planning phase in a decision-making process where the key players with expertise in different areas evaluate the options to be given for final debate before the formal decision is taken (cf. Fig 2). The decision-maker's control of optimisation is ideal. In practice she or he would rather wait, avoid the commitment to the outcome and take distance if necessary (Renn et. al 1995). A common problem with all participatory methods is that there is no interaction between the key players' group and politicians or higher level authorities. The input could be improved by the analytical process, and by a fair and competent stakeholder group, but it could not be thought that careful input would overcome political forces.

Time is limited with the key players, too and a two-day facilitated workshop as proposed by researchers (see, e.g. Phillips 1993, French 1988) does not fit always comfortably with the decision-making process in practice. Spontaneous decision conferencing could solve the time constraints (Hämäläinen et. al. 1995). This study supports the view that if the information is in the proper form the workshop could be carried out in a shorter time. Prior to the optimisation process, preparatory meetings and discussion with different key players might be needed to collect information and sound out views on the problem. It is also seen to be important to establish face-to-face dialogue with the victims of an accident (Dubreuil 1999; Susskind and field 1996).

Decision on protective actions could affect large sections of the population and have important social and psychological impacts. The decisions taken need to be explained and justified and will be subject to scrutiny for a long time afterwards (Hämäläinen et. al. 1998 and 2000, II). Decision analysis could assist in this process. During the analysis, protective actions are defined, and the consequences and their importance are assessed, which would provide a way of explaining the actions taken and actions omitted. The majority of participants felt that formal analysis provides transparent decision-making that can be utilised for this purpose. The primary benefit of the decision analysis could be improved understanding and communication (Kadvany 1995).

The participants were asked to fill in questionnaire after the workshops in order to find out their opinions on the decision analysis and the workshop method. All the participants considered the workshops useful, and most of them also thought that a similar approach could be valuable for training and exercises. The attitude towards its application in the event of a real emergency was slightly more reserved, but in general still positive. The suitability in an early phase of an accident was rated the lowest.

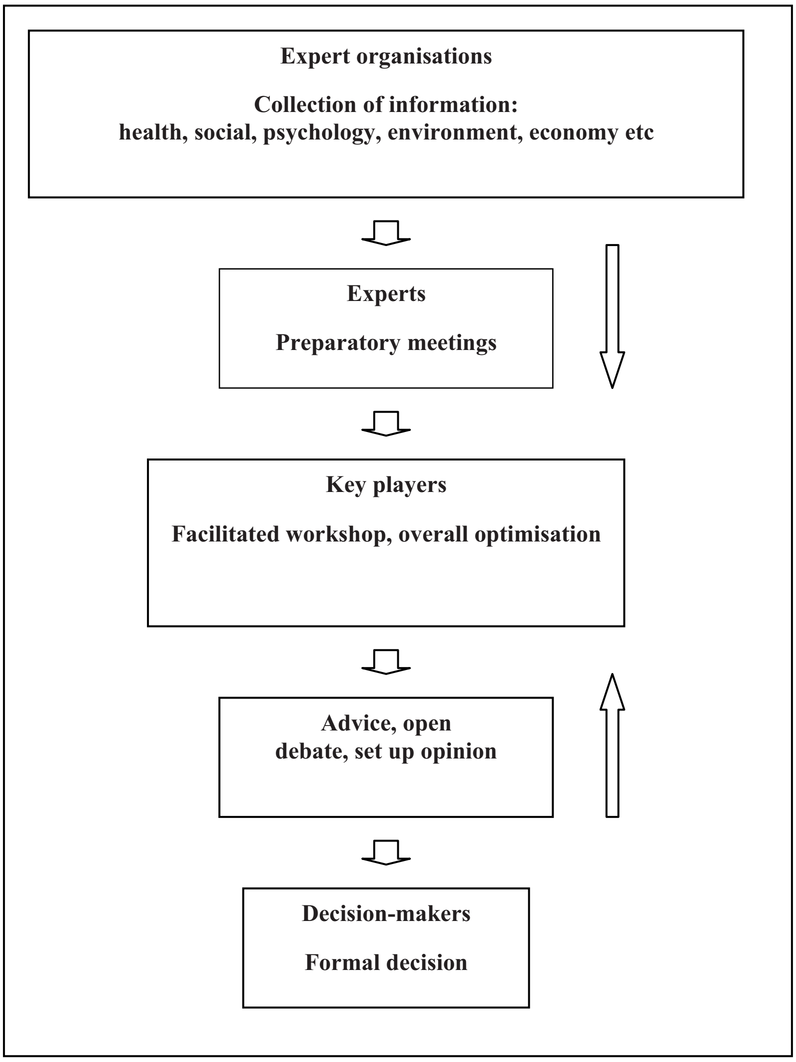

Figure 2. A schematic view of an ideal committee type decision-making process applicable in representative decision-making process.

The impression is that the participants were not very familiar with this type of analytical approach and opinions were divided for and against. Some found that the benefits were obvious but some did not feel comfortable with the modelling tools and had problems in understanding of the procedures such as weighting of attribute scales and utility analysis. The definition of the attributes and the countermeasures, and decision table were easily adopted. One reason why some were reluctant to decision analysis might be that they were expecting a recurrent decision-making process where experience is available. This attitude not to seek judgemental support has been observed also in other workshops (Bartzis et. al. 1999, III). This kind of method had been seldom applied in radiation protection and before the workshop there was no training for participants. Only a few hours were spent on the issues and consequently there was not enough time to explain in detail all the decision analytical methods used during the workshops. In future new applications of the approach to appropriate problems are likely to increase acceptance and understanding of the techniques. The applicability of decision analysis could also be improved by avoiding the excessive verification of theoretical correctness, which is often difficult to understand by participants. The procedural correctness of the decision analysis is left to be taken care of by a facilitator.

The most difficult part of the analysis was the elicitation of the risk attitudes as required in theory when facing uncertainties (Hämäläinen et. al. 2000, VI; Bartzis et. al. 1999, III). The lottery questions were asked in order to establish the form of the utility functions. It was clear that most participants had problems perceiving the idea of utility function. Using lotteries seemed too abstract and the questions too difficult for the participants in order to be able to give meaningful answers. The outline of the analysis could be prepared in preceding meetings and given in the information package. This could lead to an anchoring bias, but if a technique how to deal with uncertainties is not understood the result of the analysis might prove useless. In practice, a good approximation to a full utility analysis is to use multi-attribute values evaluated at the expectations of the attributes (French 1996, Stewart 1995). Although subjective the expectations values could be better understood that hypothetical lotteries.

The choice of action was strongly influenced by trade-offs. Because of its importance the method needs further improvements. *Swing weighting* is recommended as an assessment method for the trade-offs (Von Winterfeldt and Edwards 1986). The decision-maker is asked to compare a pair of hypothetical actions which differ only in their values along two attribute scales. In the workshops, however, it was found that hypothetical options needed clarification and did not suit well to the problem at hand. It would be more logical to ask directly how much more important an attribute range is compared to another's range of values, as was done in the first workshop in Denmark (French et. al. 1993, IV). The *Even swap* method could also be applied (Hämäläinen et. al. 2003). This is a form of bartering where the values of attributes are changed so that one attribute will have the same value in all alternatives (Hammond et al, 1999). If all alternatives are rated equally for a given attribute, it could be ignored. The method could be applied iteratively and eliminate attributes until a clear choice emerges.

In a workshop we observed a high trade-off of 10 million € per averted cancer death. This amount of expenditure is clearly outside the range recommended by international organisations, i.e. 0.05 - 1.8 million € per averted cancer death (3000 - 100,000 US$ per manSv, see e.g. ICRP 1993; IAEA 1994). Another viewpoint has been presented by Keeney (1994). All costs would eventually be passed on to the general public. Environmental regulations may include lower wages, higher taxes and, ultimately, less income available for health care, nutrients etc. According to the estimation of Keeney (1994) based on life expectancy and GNP in different countries, roughly 10 million € paid for regulation will cause one statistical fatality. There was not much discussion on this specific trade-off, so it cannot be stated whether the participants would truly be willing to suggest this kind of an investment (Hämäläinen et. al 1998).

6 Conclusions

The objective of this work was to plan systematically countermeasures in advance and to develop methods to include objectives of all key players in the decision. New theoretical methods were utilised and demands for open group decision-making were considered and tested in the workshops. The developed method applied employs a group process where responsibility is placed on the participants to assimilate information and to provide judgements. It has a clear structure based on the theory of the Decision Analysis which provides reasoning and learning framework that intertwines the beliefs, preferences and value judgements of the participants and achieves a transparent ranking of the strategies available. Decision analysis had a major role in facilitated workshops. It guided focused discussions and offered a structured way to tackle the problem. An important feature was also that it allowed participants to try different judgements to see the consequences without a final commitment. This allowed them to re-evaluate their opinions. The applied facilitated workshop method was considered to fit in accustomed decision-making process, to offer a forum for constructive dialogue and to be open, equitable and auditable.

Decisions which concern a wide section of the population should be open and transparent (McDaniels et. al. 1999; Sauri 2002; Susskind 1996). One finding of this work is that transparency and communication could be clearly increased by applying the structured approach of decision analysis (Sinkko et.al. 2004, I). The decision-making process was made fairer and more competent by involving key players as has been proposed by, e.g., Renn et. al. (1995). The participation of key players increases the cost and complexity of the process, and the decision where to stop a participatory, analytical regime has to be made by seeking a balance between accuracy, time and resources. There is no need for analytical approach in recurrent decisions. People are accustomed to routine, repeated decisions where experience is available. Rare, complex problems such as large protective actions could evidently benefit from a facilitated workshop based on decision analysis.

The decision analytical approach offers a suitable framework to aggregate values, beliefs and preferences that are held by the different interest groups. In the case studies it helped the participants to tackle the problem in a logical and efficient manner. For example, when constructing the attribute or objective hierarchy, the key players were encouraged to think about all the factors that are important to them in this context. An important achievement of the induced discussion was that many definitions were clarified and others revised. But probably even more important was that it created a common understanding of the decision problem (Sinkko et. al. 2004, I). At a later stage, the participants were asked to consider explicitly the necessary trade-offs between the attributes. The given preference statements revealed the perceived importance of each attribute in relation to all the others. Thus, the analysis did not merely yield a ranking of the strategies investigated; it also revealed the reasoning behind them. The primary benefit of decision analysis is the improved understanding and risk communication. This is important because the decision taken needs to be explained and justified afterwards. In addition, it increases the level of commitment that is needed from all interest groups to carry out effectively any intervention agreed upon.

Susskind and Field (1996) have argued that face-to-face negotiation among key players could be the only way to settle the acceptable level of risk. The experiment conducted by Arvai (2003) supports this view. In the participatory decision-making process people were more supportive of the resulting risky decisions than participants in the control group. The risk was also perceived as being lower and the benefit higher in the participatory group. The process was seen to be fair, reasonable and amenable, allowing key players to announce their views and concerns. Slovic (1997) has argued that risk management could be developed by involving public in the process instead of trying to increase trust and to improve the communication. The experience gained in the workshops strongly supports this view, notably the latest workshop where the risk communication issues were discussed with the participants (Sinkko et. al, 2004).

The workshops method conforms to the basic principles in nuclear emergency management i.e., justification and optimisation of protective actions as is stated by international organisations. It also exemplified that the chosen setting can be fruitfully applied to the planning of early as well as later phase protective actions in advance. The participants considered workshops and decision analysis techniques applicable during the later phase in a potential real situation. Its suitability was not rated as high as for planning in advance. The applicability for the early phase, which is very intense and rapidly developing, had the lowest rating.

The realistic nature and the disciplined process of a facilitated workshop and commitment in decision-making yielded understanding as to what information should be collected and in what form. It was found to be important that information collected and given to key players is in the proper form for decision-making as is described in Decision Analysis (Hämäläinen et al. 2000, VI; Ammann et al. 2001, VII). The aggregation of unstructured information could easily result in a collection of views which cannot be utilised in the decision-making process.

Experts are tempted to do research and publish the results in a form suited to scientific reporting rather than adapted to decision-making. They may resist providing any results at all until they are definitive enough to withstand peer scrutiny (Brown 2003). However, experience suggests that with insufficient information a facilitated workshop conducted early on will guide and focus subsequent research and collection of data. Every workshop has made proposals for research topics and data collection (Hämäläinen et al. 1998, V; Hämäläinen et al. 2000, VI; Ammann et al. 2001, VII). As a consequence, a workshop could reduce collecting masses of data that will make no difference to any decision. Technical meetings or the stakeholder networks could shed light on information needed in decision-making. However, the final weight on the importance of information could be obtained after the trade-offs have been made. It indicates the topics which are most important in decision-making and shows where allocation of resources to research would be most beneficial. One explanation of the observed poor adequacy of consequence assessment data for decision-making is that reactor accidents are rare. This allows experts to be insensitive to decision-makers' interests and the flaw to be revealed (Brown 2003).

The information package to be given for decision-makers should comprise technical information to help to understand the accident scenario and selected information on how to make a reasonable choice between alternative actions. During this work much insight was gained in objectives and attributes people consider in deciding on protective actions. This was achieved by writing down the definitions of attribute before preparatory meetings and workshops and showing them to the co-workers and participants of the workshops. This helped communication and saved time in workshops (Hämäläinen et. al. 2000, II). Because in an accident so many technical issues have to be coped with, it would also be reasonable to prepare more material for workshops than is recommended in the Decision Analysis. The Decision Analysis assumes that participants are the problem owners i.e., familiar with the issues. That is not necessary the case in nuclear emergency management. For example, it was found useful to prepare material on health risks similar to radiation (Sinkko et. al. 2004). A skeleton of a decision model with a tentative ranking of options could be sent to the participants beforehand. In workshops the model could be discussed and revised. The judgements given should be clear and open to debate. This view, which is also supported by research, that even when all aspects of all alternatives are fully described, people have difficulties in making explicit trade-offs themselves (Gregory, Lichtenstein and Slovic 1993).

The work revealed the need to further develop the methods to assess the radiological and cost implications of countermeasures realistically. The models are typically able to calculate areas of deposition, the fallout pattern and rough radionuclide concentrations in foodstuffs. That helps to cope with the situation, but the information is not in the form needed for decision-making. In order to provide more realistic consequence assessments it is necessary to take production, economic, demographic and geographical information into account. Also, feasibility and constraints, such as logistics and legislation of protective actions, were found to need further investigation. No regulations or plans seem to exist in the EU or in the Nordic countries to dispose of radioactive waste that may result from decontamination or other protective actions.

Decontamination, disposal of contaminated products such as milk, grass, fly ash, and compensation for property and products after a nuclear accident may raise legal questions (French et. al. 1996; Ammann et. al. 2001, VII). Nuclear energy acts, the radiation safety act and nuclear liability acts aim to cover domestic accidents in many countries which have their own nuclear energy production. Transboundary accidents build up a somewhat different situation as regards compensation. The conventions ('Paris Convention' 1964/1982, 'Brussels Supplementary Convention, 1964/1982, 'Vienna Convention, 1963 and 'Compensation Convention' 1997) do not fulfil completely compensation issues (OECD/NEA 2000). Many nuclear energy producing countries are not members of any these conventions.

Compensation for damages will need political decisions in actual accident situations. In domestic accidents and in accidents in those countries which are parties to the relevant international conventions on third-party liability there is a legal framework for compensation. There are no other specific regulations for compensation for damages caused by a nuclear accident. Compensation issues have led to many trials. Susskind and Field (1995) have proposed that first the responsibility has to be accepted, the legal process has to be fair and timely, and all unintended damages should be compensated for, not offering money in return for taking risks.

Information technology played an important role in the last workshops (Amman et. al 2000, VII; Sinkko et. al 2004). It was a new feature of the workshop, i.e. that the participants could directly interact and experiment with their own decision models, and they encountered no noteworthy problems in doing so. Since Web-HIPRE is a Web-based application and can be accessed by the ubiquity of Web browsers, an easy-to-use user interface that required very little introduction was provided (Hämäläinen and Mustajoki 1998, Mustajoki, and Hämäläinen 2000). The complete description of decision support tools for individual as well as for workshops or negotiation is given by Hämäläinen (2004, see also www.decisionarium.hut.fi). With this software support, instant aggregations of group decision and a consensus model were easily obtained. A special web site was created for the two last workshops. A page comprising analogous facts to the information package could be valuable in a real accident situation; updated results of the decision analysis could also be made available. Internet technology offers a fast and open channel to deliver information equitably and increase common knowledge of all key players.

The technical equipment used during the workshop is easily installable at different locations. This facilitates the use of the system, for example in situations where key players' mobility is restricted. This was demonstrated by the ease with which the equipment was transported and installed at the meeting location. Since the software is Internet-based, it enables remote participation and the use of external information, such as video material from the accident location. The equipment and state-of-the-art software support greatly eased the conducting of the workshop. It allowed the participants to concentrate on the issues at hand and not too much time was spent mastering unfamiliar technology.

After the facilitated workshops reported here and in many workshops organised in seven European countries within EUs research project EVATECH the participants were asked to evaluate the workshop method (http://www3.sckcen.be/samen/). Almost all participants considered the workshop method as very applicable in planning protective actions. This provides strong evidence that the workshop method fit for use. Although the method has been positively received by different types of key players more workshops should be organised to make the approach more known and more research are needed in planning of protective actions.

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