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Decision analysis of countermeasures for the milk pathway after an accidental release of radionuclides

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ABSTRACT

A facilitated workshop was arranged to plan countermeasures that could reduce the dose arising from the consumption of radionuclide-contaminated milk products. It was assumed that a hypothetical accident in a nuclear facility had led to the release of considerable amounts of radionuclides, which subsequently spread across one of Finland's most important agricultural regions and contaminated the milk produced there. The participants in the workshop, interest groups on food issues, considered all the factors influencing the countermeasure decision, not only radiological or monetary ones but less tangible psychosocial effects as well.

The participants preferred the countermeasures *provision of uncontaminated fodder* and *production control* to *banning and disposal.* The analysis showed that these countermeasures could be implemented even if the radionuclide concentrations in foodstuffs were below internationally recommended intervention levels. Banning and withdrawal of milk products from sale was not a favourable option, because of the high costs and disadvantages to producers and the industry, and because the disposal of enormous amounts of milk causes a considerable environmental problem. The study revealed the need to further develop methods to realistically assess the radiological and cost implications of food countermeasures. The feasibility and constraints of actions also need further investigation.

The experience gained strongly supports the format of a facilitated workshop to tackle a decision problem that concerns different stakeholders. The participants considered the workshop and the decision analysis very useful in exercises. They also expected a similar approach to be applicable in a real situation, although the suitability was not rated as high as for exercises. It is concluded that a facilitated workshop is a valuable instrument for emergency management and in exercises, when revising emergency plans or in order to identify issues that need to be resolved.

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TIIVISTELMÄ

Työssä selvitettiin hypoteettisen ydinonnettomuuden avulla millä vastatoimenpiteillä voidaan vähentää maitotuotteiden kautta saatavaa säteilyannosta. Onnettomuuden ajateltiin saastuttaneen keskikesällä laajan alueen Pohjanmaata, joka on yksi Suomen tärkeimpiä maidontuotanto- ja jalostusalueita. Tutkimuksessa arvioitiin toimenpiteillä saavutettua annoksen todellista vähenemistä sekä toimenpiteiden aiheuttamia kustannuksia ja toteuttamiskelpoisuutta. Lisäksi selvitettiin mitä tietoa eri tahot tarvitsevat päätöksenteon tueksi. Työssä tutkittiin myös miten vastatoimenpiteiden suunnittelua voidaan parantaa soveltamalla päätösanalyysin menetelmiä toimenpidevaihtoehtojen luomisessa ja päätöksiin liittyvien tekijöiden arvottamisessa. Päätösriihen ja sitä edeltävien valmistelevien kokouksien osallistujat olivat toimenpiteiden suunnittelusta ja esittelystä vastaavia viranomaisia.

Harjoituksen perusteella on arvioitavissa, että kotimaassa tapahtuvissa ydinonnettomuustilanteissa on hyvin todennäköisesti mahdollista toteuttaa kansainvälisten toimenpidetasojen alapuolella toimenpiteitä, jotka ovat oikeutettuja ja optimoituja. Kansainvälisesti hyväksyttyjen toimenpidetasojen ylittyminen merkitsisi kaupan olevien maitotuotteiden käytön kieltämistä. Tehtyjen arvioiden perusteella käyttökielto aiheuttaa eniten haittaa.

Tehdyn kyselyn mukaan suurin osa osallistujista piti päätösriihtä ja päätösanalyysia käyttökelpoisena harjoitustilanteessa. Myös harjoituksen hyödyllisyys kokonaisuutena arvioitiin suureksi tai erittäin suureksi. Todellisessa tilanteessa sovellettuna menetelmää pidettiin käyttökelpoisena vaikkakin hieman huonompana kuin harjoitustilanteessa. Päätösriihi täydentää siten hyvin tavanomaisia valmiusharjoituksia.

CONTENTS

1 INTRODUCTION

The real-time on-line decision support system RODOS (Ehrhardt and Weis, 2000) has been developed within the Framework Programmes of the European Union with the aim of providing consistent and comprehensive support for off-site nuclear emergency management. The Radiation and Nuclear Safety Authority (STUK), on the other hand, has studied countermeasures that could be implemented in the different phases of a nuclear accident. STUK organised, as part of the RODOS project, a series of facilitated workshops, conventionally called decision conferences, in 1997 (Hämäläinen *et al.*, 1998). These workshops dealt with countermeasure planning and decision-making in the early phase of a nuclear accident and they were arranged in co-operation with the System Analysis Laboratory (SAL), Helsinki University of Technology. The following year the early phase protective actions were re-analysed by applying an interview technique (Hämäläinen *et al.*, 2000b) and a facilitated workshop was planned to embrace the later phases of the accident. The present report describes the facilitated workshop and its preparation with the RODOS decision support system.[1]

The planning of feasible countermeasure strategies after accidental releases of radioactive material can be very demanding. This is because there are, at least in a large-scale accident, many different factors (radiological, economical, social, political, etc.) that have to be taken into account, and interventions affect so many different fields and strata of society (clean-up workers, inhabitants, consumers, industry, tourism, etc.). Multi-attribute decision analysis provides a suitable framework for dealing with the complexity of the decision problem. It helps to clarify the objectives ('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 ('radiation dose'). It provides a reasoning framework that intertwines the beliefs, preferences and value judgements of the stakeholders and achieves a transparent ranking of the different strategies available.

[1] The same case study is also documented, from a slightly different viewpoint and for a Finnish audience, in Sinkko *et al*. (2001).

The main findings from previous work in the RODOS project show that a facilitated workshop is a useful way to analyse protective actions and to support the decision-making process (Ahlbrecht *et al.*, 1997; Bäverstam *et al.*, 1997; French, 1996; French *et al.*, 1993 and 1996; Hämäläinen *et al.*, 1998, 2000a and 2000b). It gathers together all interest groups in meetings at which all relevant concerns can be discussed and possible decision strategies can be constructed and evaluated. The process is best supported by interactive decision support software, which allows building multi-attribute and other decision models. The group is aided in their discussions by a facilitator and, usually, analysts, who are familiar with decision aiding techniques. They assist the workshop by keeping the discussion focused on the problem in hand, and they ensure that all participants both contribute their views and fully understand the points made by the other group members. In this way they help create a shared understanding of the problem and the resolution.

A workshop was arranged a week after a hypothetical release and representatives of different interest groups, i.e. the stakeholders, were invited. The aim was to reassess the situation and to decide on a countermeasure strategy that not only minimises the dose that the public receives from the consumption of contaminated milk products, but that also takes wider implications into consideration. This was important as countermeasures were intended to be in place for a longer time span, i.e. during the coming weeks and months. Also, the different interests of the stakeholders needed to be accounted for. Phrased in the terminology of radiation protection, the intervention strategy looked for should be *justified* (it should achieve more good than harm) and *optimised* (the net benefit should be at its maximum when all attributes are considered).

There are important differences in the characteristics of the early and later phases of nuclear emergency management. In the early phase any decision has to be taken under great stress and pressure of time and in a situation where the total extent of the calamity is barely known. This is likely to improve during the aftermath of an accident. Then time-pressures are mostly relaxed and much more information is available. But the issues involved - health, agriculture, trade, tourism, to name a few - are of growing complexity and call for a thorough analysis. This is particularly essential since typical countermeasures have long-lasting and far-reaching consequences. An important objective of the present work was to shed light on later phase countermeasures. For practical reasons, the analysis was restricted to the milk pathway. In many accident scenarios this is a major route of radionuclides to humans.

National and international bodies have recommended action levels for foodstuffs (Council Regulation No 3954/87, EU Radiation Protection 87, IAEA Safety Series Nos. 109 and 115, FAO/WHO Codex Alimentarius Commission). These are, however, generic in nature and rest on assumptions, like the one for *withdrawal and substitution of foodstuffs,* that alternative food supplies are readily available. The cost-benefit analysis used to derive these generic levels merely struck a balance between monetary costs and the radiation dose. Other, more intangible factors, such as political or psychosocial ones, were deliberately excluded and accounted for only implicitly, for instance, when rounding up the derived values. Another important aim of the present work was thus to explicitly determine these 'other' factors and also to introduce the values and beliefs held by the decision-makers into the decision-making process. What are the other factors that need to be considered in the decision-making process, what are the necessary value trade-offs, and how should uncertainties be modelled and accounted for? Can countermeasures be justified and optimised below recommended action levels?

Examining and defining the information needs in decision making and finding successful formats for decision support system/decision-maker communication were also topics of the present work. The participants of the workshop needed to be acquainted with the accident scenario and the state of affairs. An information package was intended to contain all information that is needed to grasp the accident situation and to be able to make an informed decision on countermeasures.

Conceptually, decision support in nuclear emergency management can be broken down into different levels (Ahlbrecht *et al*., 1997): first comes an assessment of the present and future radiological situation, at the second level is the simulation of protective actions and the quantification of their benefits and costs, and finally, different available strategies are evaluated and ranked. This is roughly the concept that the research project RODOS has adopted with the aim of addressing all aspects of nuclear emergency management. A major achievement of this project was the RODOS decision support system for nuclear emergency management. At its development stage available to us (version 3.13) it contained, amongst other things, modules for atmospheric dispersion and deposition, for tracing radionuclides in the food chain, for dose assessment, for simulating early and later phase countermeasures. The methodology proposed for the RODOS system to evaluate and rank countermeasures is described *inter alia* in Caminada *et al.* (2000), but modules for this task were not integrated in version 3.13. The RODOS software was used to evaluate the radiological situation.

Summing up, the present work had several goals: (1) to increase understanding of the countermeasures that can be taken to mitigate the detriment posed by radionuclides in the milk pathway; (2) to identify the factors that influence and, more importantly, dominate the decision; (3) to present, study and assist in developing decision support systems for nuclear emergency management and the facilitated workshop approach.

The report is structured as follows. The events that occurred on the day of the accident and the countermeasures that were recommended at that stage are outlined in Chapter 2. Chapter 3 presents the countermeasure strategies that were proposed for the later phase. The focus was on countermeasures that had the potential to reduce the dose received from the consumption of contaminated milk products. The workshop arrangements, the attribute tree, preference weighting, sensitivity analysis and the results are described in Chapter 4. The more general discussion is written in Chapter 5. The report ends with Conclusions.

2 THE DAY OF THE ACCIDENT

2.1 The accident scenario

For the purpose of the study it was assumed that a core damaging and containment leak accident[2] had occurred in the nuclear power plant in Olkiluoto on a working day in the middle of June. In order to increase realism the scenario is based on PSA-analysis. The main events are given below:

> A minor earthquake at 06:00 caused the loss of the external grid, which initiated the accident sequence. It also broke the backup battery cabinets. The automatic overpressure protection of the reactor was successful and hydraulic SCRAM succeeded. The containment was isolated. The overpressure protection valves closed. The auxiliary feed-water could not be started during the next 45 minutes and the manual pressure reduction of the reactor failed. Consequently, the pressure could not be lowered to the operating range of the low-pressure emergency cooling system. The core started to melt under high pressure 50 minutes after the initiator. Within 90 minutes the pressure reduction of the vessel could be recovered and the pressure of the vessel was lowered. The core cooling systems could not be recovered, however. The lower drywell (pedestal) was flooded. Two hours after shutdown, the vessel breached into the water-filled containment. The containment failed due to a corium spray hitting penetrations above the water level. Thus, there was a direct path from the containment atmosphere to the reactor building, bypassing the filter and stack. The reactor building remained intact and, since it is very large, some deposition occurred in the reactor building. The corium remained under water. (Niemelä, 1997)

The release began two hours after shutdown, at 08:00, and lasted for 12 hours. The release rate was not constant, and it was assumed that the initial intense rate of release diminished roughly exponentially within 12 hours. The effective

[2] The occurrence frequency of such a containment failure accident leading to a significant release is estimated to be less than one in 1,000,000 per reactor-year for this NPP.

release height was 50 meters, which corresponded to an initial sensible-heat release rate of a few megawatts (the actual release height was 10 m).

There were many uncertainties in the consequence assessment, but only uncertainties about the release fractions were considered. A release was assumed to happen definitely and it was assumed that the weather for the next few hours could be predicted[3]. Furthermore, the branch of the containment event tree could be identified and therefore the nuclear safety experts were able to give probability distributions for the release. The 5th, 50th and 95th percentiles of the cumulative distribution functions were used to encompass the uncertain situation (Table I).

The accident day was a rainless day over southwestern Finland with weak winds (4-9 m/s) from the south and southwest. The wind turned during the night and started to blow to the southeast. There were sporadic rain showers during the night and in the morning hours on the next day. Thereafter the weather was dry again.

Table I. *Release fractions for the 5%, 50% and 95% fractiles of the containment failure groups' cumulative distributions.*

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

[3] Weather data was based on past on-site measurements.

First day decisions are based predominately on the plant-status. Measurements and model predictions are used to build up a picture of the radiological situation and of the factual and potential consequences. Initially this picture is vague and subject to considerable uncertainties. Precautionary actions on the first day are likely to be interim in nature and apply typically to a few days. Within this time it is hoped to arrive at an improved and more reliable picture of the situation: monitoring is drastically intensified; the fall-out situation is analysed by a variety of means and organisations; samples are measured and airborne spectrometry of the ground contamination contribute important pieces of information. In essence, this results in sequential decision-making. A few days after the release occurred, urgent decisions made on the first day are re-evaluated, withdrawn or extended and altogether new aspects and options are scrutinised. Decisions cannot be withdrawn or extended too often, though, without risking loss of confidence and other adverse psychosocial effects. Also, losses to industry, tourism, and the like are evident. This urges the decision-makers to anticipate the future as far as possible.

For a successful implementation of protective actions, the intervention area has to be well defined and easy to recognise by the public. It very likely consists of a set of administrative units, which in Finland are municipalities for many interventions. Hence, the benefits and harm introduced by protective actions had to be aggregated within municipalities. The timing and duration of the proposed protective actions were, in the early phase, related to the presence of the radioactive plume and, later on, to the contamination level in milk. A small set of intervention strategies, determining the bundle of protective actions (sheltering, evacuation, etc.) that is applied in the affected municipalities, was proposed and subject to a detailed decision analysis.

2.2 Countermeasures recommended to the general public

Early phase countermeasures to protect the population in this accident scenario were analysed in Hämäläinen *et al*. (2000b). The findings were discussed at a preparatory meeting, and it was concluded that the most favourable strategy was *iodine prophylaxis*[4] in Eurajoki, Luvia, Pori, Merikarvia and Siikainen and, additionally, *sheltering* throughout the passage of the plume in Eurajoki and Luvia (Figure 1). Since core melt had occurred, emergency plans also urged for an immediate *evacuation* of the plant vicinity (5-km circle around the NPP). This information was available at the outset of the workshop.

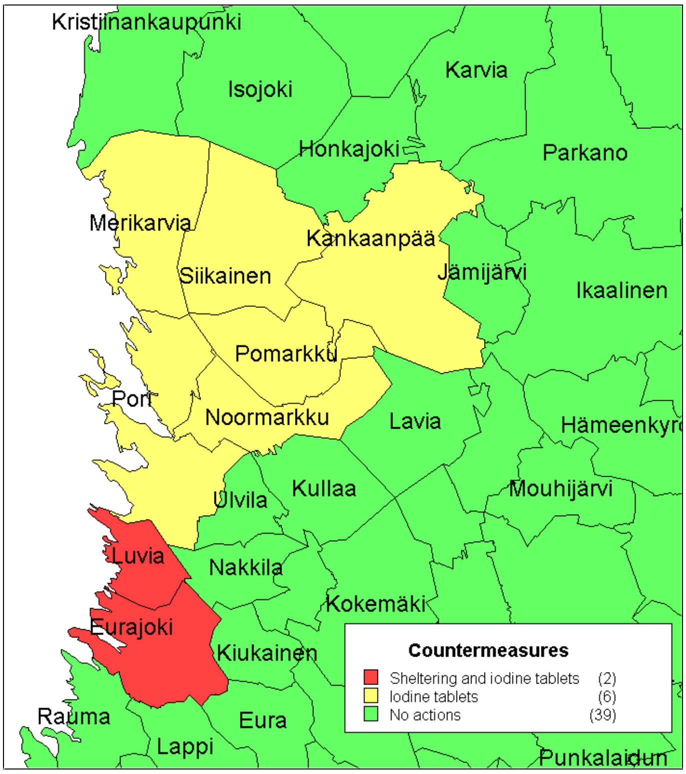


Figure 1. *Urgent actions to protect the population.*

[4] The timely distribution of stable iodine tablets relied on the (optimistic) assumption that tablets are readily available. Finnish residential units are obliged to keep a stock of stable iodine tablets and small households are encouraged to store iodine tablets.

2.3 Countermeasures recommended for dairy-farming

In a nuclear emergency situation, one of the first obligations is to protect the endangered population. As some foodstuffs, e.g. leafy vegetables and milk, and feedstuffs could be contaminated during the first days, precautionary agricultural countermeasures also need to be considered before plume arrival.

The fictitious accident happened a couple of weeks before the first grass harvest, which would have been due at the end of June. Most of the lactating cows (85%) were on pasture at that time. Two proactive measures were considered before the arrival of the plume: (1) *Sheltering of cows and provision of uncontaminated fodder* and (2) *harvesting of the grass before it becomes contaminated.*

Sheltering of cows and provision of uncontaminated fodder

In the precautionary sheltering of livestock cows are moved into barns before the radioactive cloud arrives. They are kept inside and fed on uncontaminated fodder and water. Fodder and water supply are protected from contamination as far as possible.

It was assumed that stored fodder was available in farms or that it could be transported into the intervention area. Because air-exchange in barns could not be blocked and a minimum of ventilation had to be maintained, a relatively small amount of radionuclides was inhaled and transferred to the milk. As there were other larger uncertainties, minor contamination due to inhalation was not taken into account.

On the day of the accident the proactive sheltering of cows was planned for one week. After that, in the light of a more accurate assessment of the fallout, it was intended to be re-evaluated during the facilitated workshop and either withdrawn or adjusted. The spatial extent, i.e. the municipalities within which the measure was recommended, also had to be specified.

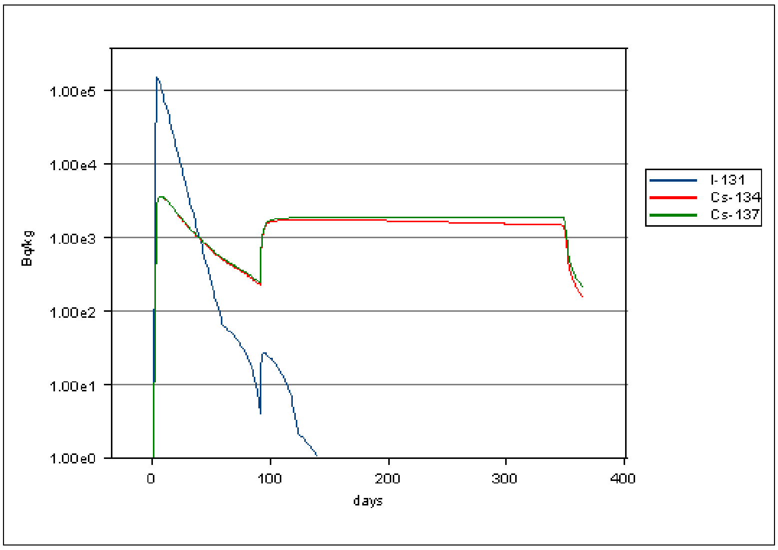


Figure 2. *Time behaviour of the activity concentration in milk.* ^{131}I *concentration in milk reached its maximum on day 3.*

Presumably based on plant status and measurements, necessary information on the fallout composition was provided. As can be seen from Figure 2, ^{131}I contamination in milk was expected to be dominant during the first month. For iodine isotopes in dairy products, the Council of the European Community has adopted a maximum permitted level of 500 Bq/kg (Council Regulation No 3954/87). This level and a level a decade lower were used to define the intervention areas. The consequences of two intervention strategies were thus assessed, *viz.* provision of uncontaminated fodder in those municipalities where the ^{131}I concentration in raw milk on day 3 was expected to exceed 500 Bq/kg and 50 Bq/kg, respectively (Figure 3). The calculations were performed with the 50% fractile scenario.

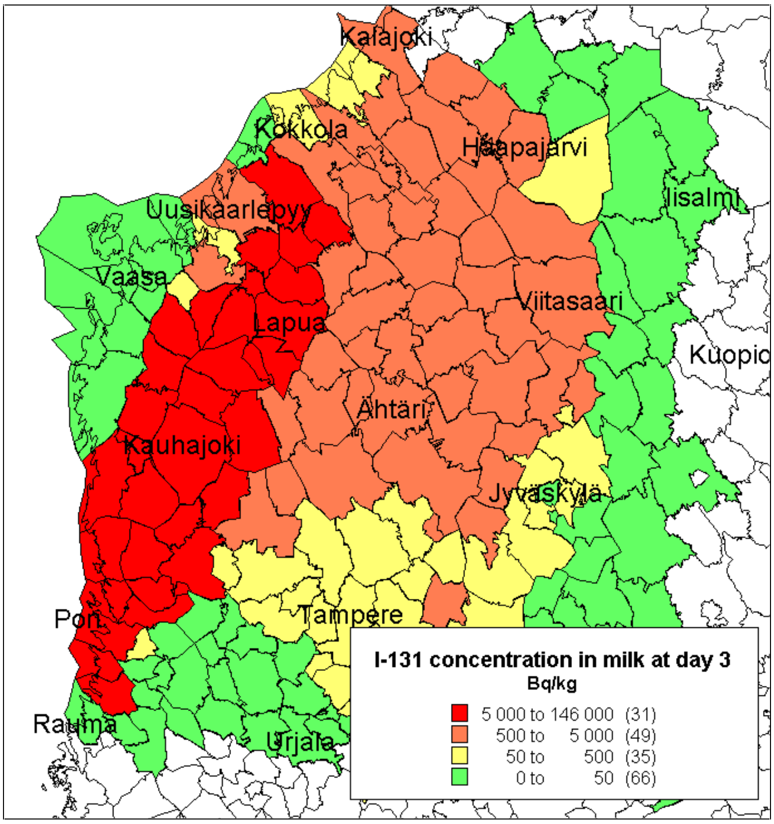


Figure 3. *^{131}I activity concentration in milk on day 3. The average activity concentration in municipalities is mapped*[5].

The RODOS system was used for the radiological consequence assessment. The atmospheric dispersion and deposition module RODOS/ATSTEP (Päsler-Sauer, 2000) was used to assess the fallout. This information was the input requirement for the food-chain and dose module RODOS/FDMT (Müller and Pröhl, 1993; Müller *et al.*, 1999). It modelled plant specific deposition of radionuclides, contamination of feed- and foodstuffs and nuclide transfer through the food chain to humans.

[5] In the information package distributed to the participants in the workshop 'traffic light' colours were used to indicate the area where actions were advisable according to the EU's maximum permitted levels.

In a meeting held before the workshop the first day agricultural countermeasures were ‘decided’. An assessment of the consequences of the two strategies is given in Table II. All values were integrated over the first week. More specifically, the *collective dose* encompassed the (50 years’) committed dose to the consumers and was due to the milk production in the contaminated area within the first week; it accounted for the local production rates and the local activity concentration in milk. Within the action area milk was practically uncontaminated during the time the countermeasure was in place. The collective doses in Table II are due to the milk production outside the action area.

The collective dose is the only relevant measure for the radiation risk because milk is collected over wide areas and redistributed over the whole country so that the eventual consumers cannot be identified. The individual dose to the milk producers in the affected area can be, if necessary, controlled by changing the local milk delivery.

The collective dose was translated to the expected extent of additional cancer incidence and to the additional number of fatal cancer cases. Children were explicitly accounted for because they were particularly at risk of contracting thyroid cancer.

Only direct monetary costs were assessed: costs proportional to the amount of replacement fodder needed were attributed to the strategies. Feeding on pasture was replaced with provision of uncontaminated grass silage, which was assumed to be available from stock. A typical market price of 3 to 4 cent per kilogram was assumed and allowance for transportation (2 cent per kg) was made.

Table II. *Consequence assessment when cows are fed on uncontaminated feed for one week. Two intervention areas were investigated, viz. municipalities where the ^{131}I concentration in milk was expected to exceed 500 Bq/kg and 50 Bq/kg, respectively. No Action served as a reference. All values were integrated over one week.*

	No Action	**500 Bq/kg**	**50 Bq/kg**
Collective thyroid dose in children [manSv]	8710	56.6	0.7
Thyroid cancer incidence [No.]	69.7	0.5	0.0
Thyroid cancer fatality [No.]	7.0	0.0	0.0
Collective effective dose [manSv]	533	3.4	0.04
Other cancer incidence [No.]	39.4	0.2	0.0
Other cancer fatality [No.]	19.7	0.1	0.0
Costs [million euro]	0	1.1	1.3

Feasibility of countermeasures was a central issue in the problem. Table III provided background data that helped to develop an understanding of the extent of the problem and also helped to match the resources needed with the ones available.

Table III. *Production data in the first week. The computation area was about 100,000 km^2. The intervention areas were based on the intervention criteria 500 Bq/kg and 50 Bq/kg, respectively.*

	Whole computation area	**Intervention area 500 Bq/kg**	**Intervention area 50 Bq/kg**
Milk production [million kg]	22.37	13.18	15.84
Lactating cows [No.]	107,000	63,000	76,000
Replacement fodder needed [million kg]		21.97	26.40
Replacement fodder needed [No. of 500 kg bales]		43,940	52,800

Harvesting of grass before it becomes contaminated

Harvesting of grass before it becomes contaminated was the other option considered. Obviously, there were tight time constraints on this measure. For example, within areas nearby the plant there was no time to even contemplate such a measure. The warning time was after all only 2 hours. However, there were large areas where the plume was not expected to arrive within, say, 16 hours (green area in Figure 4). Since it takes farms typically 2 days to get in their harvest, experts judged that 16 hours allowed the farms in these areas to harvest at least half of their fields.

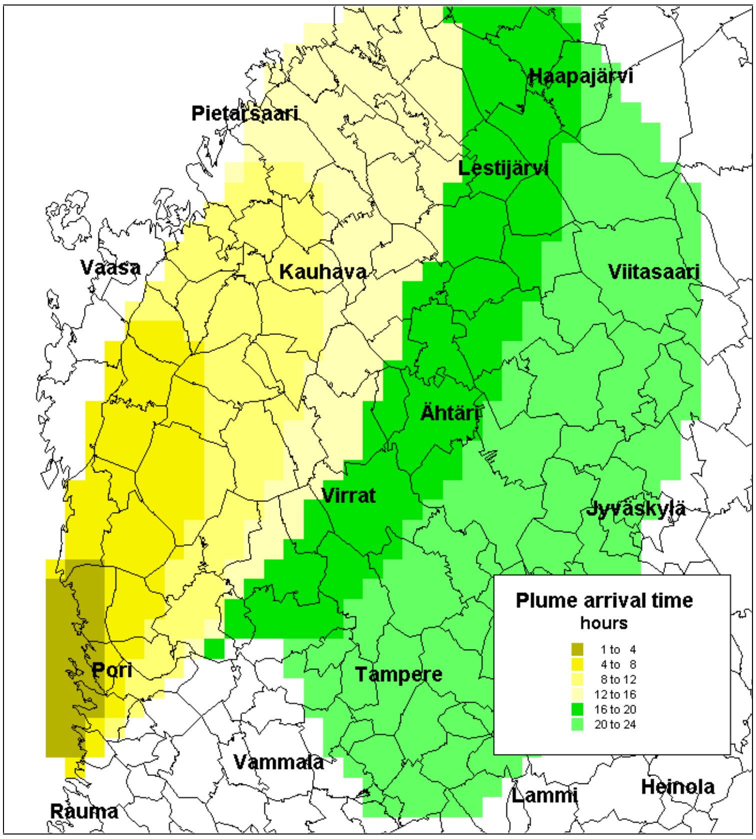


Figure 4. *Expected arrival time of the plume in hours relative to the start of the release.*

Usually silage is used as fodder during the winter period. In an accident situation, this fodder may well serve the implementation of the countermeasure *providing uncontaminated fodder,* a follow-up measure discussed in Section 3.2. It will be seen then that logistical problems in supplying uncontaminated fodder and resource limitations cannot be neglected. To assess all the radiological implications of the measure the whole winter period had to be considered.

The drawback of the measure was its cost penalty. The accident happened a couple of weeks before the first grass harvest would have been due (end of June). Consequently, the whole harvest was less than it would have been normally - by an assumed 25%. Compared to harvesting as scheduled, a cost penalty arose from this loss in the first harvest and was approximated by the market price of grass silage. The consequences of harvesting in advance are given in Table IV.

Decisions taken on the first day were not part of the workshop, which was intended to deal entirely with the aftermath of the accident, i.e. from day 7 onwards up to the end of the harvesting season. However, information on actions already taken had to be provided at the outset of the workshop in order to familiarise the participants with the state of affairs. A preparatory meeting was held to ‘decide’ on these actions. As a result it was advised to keep lactating cows in barns in all municipalities where the ^{131}I concentration in milk was expected to exceed 50 Bq/kg. In addition, harvesting the grass before contamination occurred was recommended in those municipalities where there were more than 16 hours available before the plume was expected to arrive.

Table IV. *Consequence assessment for harvesting as scheduled and harvesting two weeks in advance.*

	Harvesting as scheduled	**Harvesting in advance**
Collective thyroid dose in children [manSv]	207	198
Thyroid cancer incidence [No.]	1.7	1.6
Thyroid cancer fatality [No.]	0.2	0.2
Collective effective dose [manSv]	976	936
Other cancer incidence [No.]	97.3	93.3
Other cancer fatality [No.]	48.6	46.6
Costs [million euro]	0	1.7

3 A WEEK LATER

3.1 General

It was assumed that the fallout had been roughly mapped (presumably via airborne gamma measurements) during the first week following the accidental release and that numerous samples of milk and fodder had been analysed. It was concluded that the fallout could be explained by the 50th percentile release. Initially prevailing uncertainties were considerably downsized, but dose assessments were still believed to be only accurate within a factor of 2 or 3.

Figure 2 shows that in the first weeks there was considerably more activity in milk due to ^{131}I than due to the caesium isotopes. ^{131}I activity reached its peak on the 3rd day and then declined rapidly, about two decades within the first month. After this month the situation changed and the caesium isotopes started to dominate. The pasture season ended in mid-September and the feeding regime was switched to silage that, for the most part, had been harvested throughout the summer. This is echoed in Figure 2 by an abrupt increase in the activity concentration in milk around day 90. The figure suggests a serious problem during the winter season too. In most parts the situation was less dramatic, however, as the figure depicts the assessment for the most severely affected municipality. The end of the pasture season marked the end of the analysis period. The change of roles of iodine and caesium after one month suggested a subdivision of this period: the first period spanned weeks 2 to 5 after the accident and ^{131}I concentration in milk provided the reference for any intervention level; the second period comprised weeks 6 to 12 and the ^{137}Cs concentration in milk at the beginning of this period provided the reference.

Raw milk is processed in dairies into fresh milk, sour milk, milk powder, butter, cream, cheese, etc. The last entry in Table V shows, for example, the production routine at the dairy of Seinäjoki - the largest dairy in the region we are looking at. It processes 30 to 40 percent of the incoming raw milk into fresh and sour milk and the rest into butter and milk powder. The Seinäjoki dairy does not produce cheese, which is done by smaller dairies specialising in cheese production. The activity transfer from raw milk to the products is described by *processing factors*[6] (Table V). These factors express the concentration ratio between products and raw milk. The production processes enrich, dilute or secrete radionuclides; for example when making butter the activity concentration drops by 50% for iodine and 80% for caesium. The *processing efficiency* corresponds to the mass ratio of product and raw milk and expresses the yield of the final product per unit of raw milk. The eventual activity concentration in products also depends, at least for short-lived nuclides, on the processing and typical storage time. The longer shelf-lives of butter and milk powder can be utilised to achieve reduced activity levels of short-lived nuclides like ^{131}I.

The countermeasure *milk processing* into butter, cream and cheese utilises the lower processing factors of these products. Milk powder is special because the water content that is evaporated during production is replaced before consumption. This does not change the collective dose. But the increased storability can be taken advantage of and this is considered in the countermeasure *storage of milk products*. It acts on the storage time parameter in Table V.

Eventually the products reach the shelves of retailers. In the aftermath of an accident the production is routinely monitored. Products that exceed maximum permitted levels have to be banned and withdrawn from the market. The countermeasure *banning* takes the products off the shelves.

3.2 Countermeasures for milk products

The situation and the measures taken a week earlier were reassessed at this stage. Different courses of actions were available. The measure *supply of uncontaminated fodder* could be lifted or it could be continued. Alternatively, milk could be *processed* into butter and milk powder. Finally, milk could be *banned and disposed of*. These were the most applicable countermeasures analysed at this stage.

[6] A related quantity used elsewhere in the literature (for example, IAEA Technical Report Series No. 363) is the *food processing retention factor*, which expresses the fraction of radionuclides retained in the food after processing. Dividing the food processing retention factor by processing efficiency yields the processing factors used here.

Table V. *Factors used to quantify milk processing. The 'processing factors' express the concentration ratio between products and raw milk. The 'processing efficiencies' correspond to the mass ratio of product and raw milk. The last line of the table shows the proportion of the raw milk going into each production line. These are specific to a dairy and the values given here apply to the dairy of Seinäjoki.*

	Fresh milk	**Milk powder**	**Butter**	**Cream**	**Cheese rennet**	**Cheese acid**
Processing factor for iodine	1.0	8.3	0.5	0.7	0.6	1.4
Processing factor for caesium	1.0	8.3	0.2	0.7	0.6	0.6
Processing and storage times (days)	1	30	10	2	30	2
Processing efficiency	1.0	0.12	0.05	0.1	0.1	0.1
Production	0.3-0.4	0.6-0.7	0.6-0.7	0.0	0.0	0.0

Sorbents reduce the absorbed fraction and could be added to cows' feedstuffs or directly added to their gut in the form of boli. Their use in the form of boli is not legal in Finland, however, and the option was not further analysed.

Provision of uncontaminated fodder

Provision of uncontaminated fodder was advised a week earlier in those municipalities where the ^{131}I concentration in milk exceeded 50 Bq/kg (Figure 3). The measure was reassessed for the coming month. The question was: is it advisable to withdraw it or should it be continued, and how should its regional extent be adjusted? To find an answer, the consequences were evaluated for the options (1) *withdrawal*, (2) *continuation of the measure* and (3) *reduction of its intervention area* to those municipalities where the activity in milk exceeded 500 Bq/kg on day 3. Columns 2, 3 and 4 of Table VI show the outcomes.

Costs proportional to the amount of replacement fodder needed were attributed to this countermeasure. It was assumed that replacement fodder had to be taken from elsewhere and a market price of 3 to 4 cent per kg was used in the assessment. Transportation overheads were accounted for by 2 cent per kg.

More aspects were taken into consideration during the facilitated workshop. For example, the provision of replacement fodder for a month over such a large area posed considerable logistical problems.

Milk processing

Making changes to the production routine was a countermeasure that was investigated as an alternative. As described in Section 3.1, the production processes enrich, dilute or secrete radionuclides (see Table I). Also, the longer shelf-lives of butter and milk powder can be utilised to achieve reduced activity levels of short-lived nuclides such as ^{131}I. As a countermeasure it was assumed that all milk is processed into butter and milk powder during the coming month. The measure was evaluated in two intervention areas: the larger one was limited by an activity concentration of ^{131}I on day 3 of 50 Bq/kg and the other one by 500 Bq/kg (Figure 3). Columns 5 and 6 in Table VI show an assessment of the attributes.

The process yields milk powder and butter in a ratio of 9 to 1. The costs of this countermeasure were approximated by the production costs of milk powder; no allowance was made for the costs associated with the change in the production routine or the like. For example, the prospect of contaminating the production facilities caused concern and certainly clean-up costs will be incurred. These concerns were addressed during the workshop, however.

Banning

Banning was seen as a last-resort measure. This measure was also evaluated for the two intervention areas mentioned above, *viz.* the one marked by 500 Bq/kg and the other by 50 Bq/kg. It was expected that banning causes a considerable environmental problem since vast amounts of milk would need to be disposed of. From a radiological standpoint, however, it was expected to be fully effective since no products with contamination levels beyond intervention levels reach consumers. Residual doses are due to the milk that comes from outside the intervention area.

Disposal of milk incurs expense. But loss of income, too, can be attributed to this measure. The producer’s price for milk is, on average, 35 cent per kg and, with subsidies and quality bonus, 45 cent per kg. The latter was assumed when assessing loss of income. The costs for disposal depend largely on the methods used to dump the milk. Different options were discussed: dumping into the sludge well, ploughing in fields, bringing to dumping grounds, giving it to the calves to drink. Most of these create a considerable environmental problem and they were expected to have a very adverse response in society and the media. Such concerns were addressed in the workshop, during which the feasibility of this measure was rated. As a guiding figure, 2 cent per kg was assumed for the costs.

Table VI. *Consequence assessment for the countermeasures 'no action', 'uncontaminated fodder', 'production changes' and 'banning' during weeks 2-5 after the accident. Two intervention areas were investigated, viz. municipalities where ^{131}I concentration in milk on day 3 exceeded 500 Bq/kg and 50 Bq/kg.*

	No Action	**Clean fodder**		**Production changes**		**Banning**	
Area def. by Bq/kg of iodine		500	50	500	50	500	50
Collective thyroid dose in children [manSv]	6680	43.6	0.8	124	82	43.6	0.8
Thyroid cancer incidence [No.]	53.4	0.3	0.0	1.0	0.7	0.3	0.0
Thyroid cancer fatality [No.]	5.3	0.0	0.0	0.1	0.1	0.0	0.0
Collective effective dose [manSv]	450	2.8	0.05	14.5	11.8	2.8	0.05
Other cancer incidence [No.]	34.3	0.2	0.0	1.3	1.0	0.2	0.0
Other cancer fatality [No.]	17.2	0.1	0.0	0.6	0.5	0.1	0.0
Costs [million euro]	0	4.8	5.8	9.1	10.9	26.1	31.5

Again, the feasibility of the countermeasures had to be assessed. Table VII provided the background data.

Table VII. *Production data for weeks 2-5. Values were calculated for three areas, viz. the whole computation area (about 100,000 km^2) and the municipalities where the ^{131}I concentration in milk on day 3 exceeded 500 and 50 Bq/kg, respectively.*

	Whole computation area	**Intervention area 500 Bq/kg**	**Intervention area 50 Bq/kg**
Milk production [million kg]	95.88	56.50	67.88
Lactating cows [No.]	107,000	63,000	76,000
Replacement fodder needed [million kg]		94.17	113.1
Replacement fodder needed [No. of 500 kg bales]		188,340	226,200
Additional milk processed [million kg]		22.60	27.15
Milk to be disposed [million kg]		56.50	67.88

Provision of uncontaminated fodder continued

In the above tables values are assessed for weeks 2 to 5, i.e. all quantities were integrated over this time period. Basically, this was the time period during which the iodine problem remained virulent. Thereafter caesium became focal and the interest extended to the end of the harvesting period, i.e. weeks 6 to 12.

The countermeasure *providing uncontaminated fodder* could either be prolonged or withdrawn during these weeks. Again, two intervention areas were investigated, but this time the activity concentration of the caesium isotopes (^{134}Cs and ^{137}Cs) in milk at the beginning of the period under investigation provided the reference (Figure 5). Two intervention levels were derived, i.e. 1000 Bq/kg from the EU's maximum permitted levels for caesium type isotopes, and a ten times lower level. It is worth noting that the resulting intervention areas were considerably smaller than the former ones. The same attributes were evaluated as before (Table VIII) and similar background information was provided (Table IX). The integration time of the tabulated quantities embraced weeks 6 to 12.

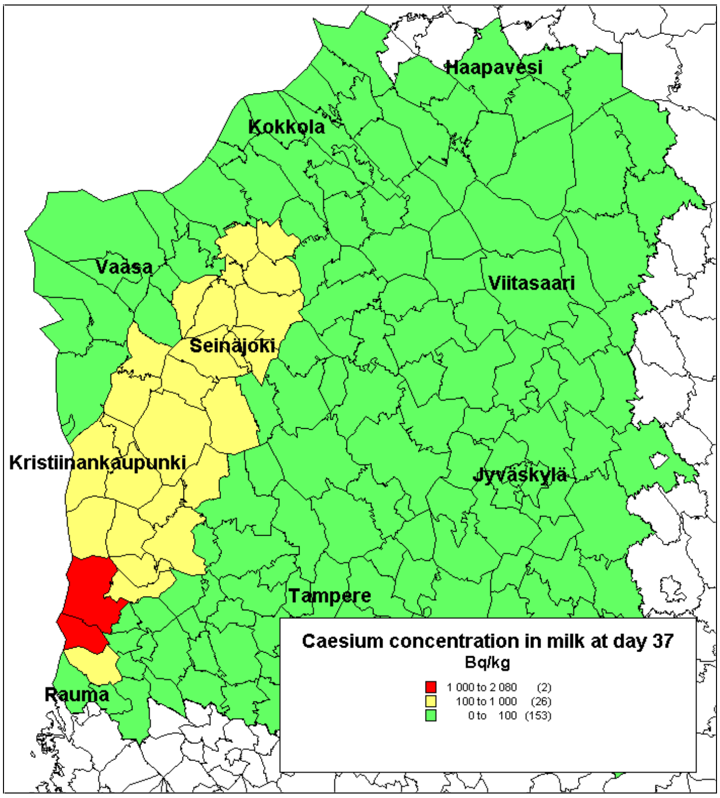


Figure 5. *Caesium concentration in milk 37 days after the accident.*

Table VIII. *Consequence assessment for the countermeasures 'no action' and 'uncontaminated fodder' during weeks 6-12 after the accident. Two intervention areas were investigated, viz. municipalities where the caesium concentration in milk on day 37 was expected to exceed 1000 Bq/kg and 100 Bq/kg, respectively.*

	No Action	*1000 Bq/kg*	*100 Bq/kg*
Collective thyroid dose in children [manSv]	122	119	39.2
Thyroid cancer incidence [No.]	1.0	1.0	0.3
Thyroid cancer fatality [No.]	0.1	0.1	0.0
Collective effective dose [manSv]	44	42.9	10.7
Other cancer incidence [No.]	4.2	4.1	1.0
Other cancer fatality [No.]	2.1	2.0	0.5
Costs [million euro]	0.0	0.01	2.5

Table IX. *Production data for weeks 6-12. Values were calculated for three areas, viz. the whole computation area (about 100,000 km²) and the municipalities where the caesium concentration in milk on day 37 was expected to exceed 1000 and 100 Bq/kg, respectively.*

	Whole computation area	Intervention area 1000 Bq/kg	Intervention area 100 Bq/kg
Milk production [million kg]	169.381	0.174	30.167
Lactating cows [No.]	107,000	200	20,000
Replacement fodder needed [million kg]		0.290	50.278
Replacement fodder needed [No of 500 kg bales]		580	100,556

3.3 Decision table

The investigated countermeasures for weeks 2 to 5 and those from week 6 onwards up to the end of the harvesting period can be combined in many sensible manners. Table X shows the selection of the six strategies that were assessed prior to the workshop. These spanned the whole period from day 7 onwards up to the end of the harvesting season.

Table X. *The definition of the selected strategies.*

	During weeks 2-5 in an area where I-131 conc. in milk on day 3 > 50 Bq/kg	During weeks 6-12 in an area where caesium conc. in milk on day 37 > 100 Bq/kg
Strategy 0	no action	no action
Strategy 1	provision of uncontaminated fodder	no action
Strategy 2	provision of uncontaminated fodder	provision of uncontaminated fodder
Strategy 3	milk processing into butter and milk powder	provision of uncontaminated fodder
Strategy 4	milk ban and disposal	provision of uncontaminated fodder
Strategy 5	milk ban and disposal	milk ban and disposal

Table XI condensed the analysis performed so far by combined the assessments of countermeasures during weeks 2 - 5 (Table VI) and 6 - 12 (Table VIII). It was a major input to the workshop.

Table XI. *Consequence assessment for the strategies defined in Table X.*

	Strategy 0	**Strategy 1**	**Strategy 2**	**Strategy 3**	**Strategy 4**	**Strategy 5**
Collective thyroid dose in children [manSv]	6800	128.8	40	121	40	0.8
Thyroid cancer incidence [No.]	54.4	1.0	0.3	1.0	0.3	0.0
Thyroid cancer fatality [No.]	5.4	0.1	0.0	0.1	0.0	0.0
Collective effective dose [manSv]	494	44.0	11.2	22.5	11.2	0.05
Other cancer incidence [No.]	38.6	4.2	1.1	2.1	1.1	0.0
Other cancer fatality [No]	19.3	2.1	0.5	1.0	0.5	0.0
Costs [million euro]	0	5.8	8.3	13.5	33.6	45.4

4 WORKSHOP ON FOLLOW-UP ACTIONS

4.1 Workshop arrangements

A facilitated workshop was organised a week after the hypothetical release. A variety of stakeholders and representatives of organisations concerned with food-related emergency management were invited to contribute their views and judgements. The objective was collectively to analyse the problem, to bring together the different interests and reach agreement on the decision to be taken. Amongst the participants were representatives from the Ministry of Agriculture and Forestry, the National Food Administration, the Finnish Food and Drink Industries' Federation, the Association of Rural Advisory Centres, Valio Ltd/Milk Pool and STUK. The workshop was a one-day event and was facilitated by Prof. R. P. Hämäläinen. Analysts both for the decision modelling part and for a radiological consequence assessment provided assistance whenever necessary.

Prior to the workshop an information package was prepared and sent to the participants. It contained a brief description of the accident and of the fallout situation. The precautionary actions taken to protect the population were also mentioned. An important part of it concerned the assessment of the radiological and financial consequences of the countermeasures. This information was provided in the form of decision tables. A list of predefined attributes, the parties involved in decision-making and their duties were attached. All in all, it was designed to contain all the relevant information necessary to understand the accident situation and to be able to make an informed decision on countermeasures.

A portable decision support system was used to support the analysis. It consisted of seven portable notebooks, a wireless local area network, a projector and two decision analytical software products, Web–HIPRE[7] and Opinions-Online[8] (Figure 6). Web-HIPRE, a Java applet for multiple criteria decision analysis, was used for the decision modelling and analysing the results. It implemented the multi-attribute value theory (MAVT) and featured the

[7] http://www.hipre.hut.fi

[8] http://www.opinions-online.com

aggregation of individual models into a group model, an aspect that made it especially suitable for the workshop. Crucial feedback was obtained by Opinions-Online, a voting, survey and group collaboration system. Both these tools took advantage of Web technology and supported collaborative interaction with the decision model in the sense that they made it possible to collect and combine the results of individual groups.

For the purpose of the exercise, a Web page containing information about the case and the methods used was created (Figure 7). Afterwards, the results of the workshop were also published on the Web page.

The participants formed six interest groups according to their background, i.e. *farmers, food industry*, *food agency*, *food safety authority*, *radiation safety authority* and *citizens*. Each group was equipped with a notebook that allowed them to interact directly with Web-HIPRE and Opinions-Online. An essential difference between this and many earlier workshops was that the participants used the system by themselves. Approximately half of the participants had no earlier experience in decision workshops or decision support systems, which placed high demands on the usability of the system.

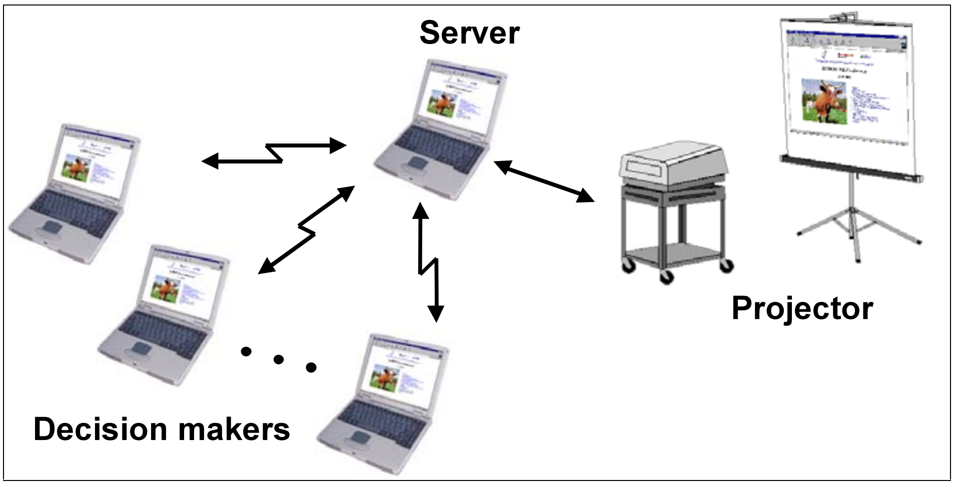


Figure 6. *The technical arrangements.*

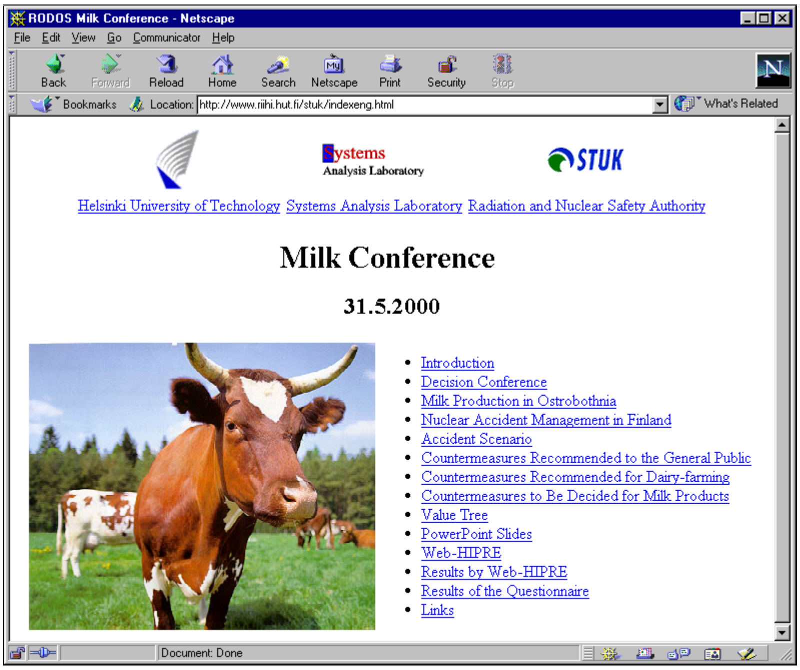


Figure 7. *Web page for the workshop (http://www.riihi.hut.fi/stuk/indexeng.html).*

The workshop lasted for six hours, which seemed appropriate. At any rate, it would have been difficult for the participants to allocate more time. The time frame, however, was such that preparatory meetings were needed as in a real situation in order to prepare the matters in advance.

4.2 Attributes relevant for the analysis

Based on the experience from the previous facilitated workshops (Hämäläinen *et al.*, 1998 and 2000b) and from preparatory meetings, a preliminary set of attributes was listed and defined. It was sent in advance to the participants annexed in the information package. At the beginning of the workshop the attribute list was presented and put up 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 following set of attributes (see also Figure 8).

Radiation related health effects

The standard assumption within the radiation protection community is that exposure to radiation increases the risk of contracting cancer, however small the exposure. If the individual risk is very small and almost negligible, stochastic health effects are still expected when large population groups are exposed. The collective dose was provided as a measure for these stochastic health effects. But it was also converted to the expected number of fatal cancer cases because this was believed to be more expressive for persons outside the radiation protection community. A risk factor or *nominal probability coefficient for stochastic effects* (IRCP 60, 1991) of 5 x 10^{-2} per Sievert was used to assess the probability for fatal cancers. A related measure was the *incidence* of cancer cases. Excepting thyroid cancers, it was assumed that roughly half of the cancer cases can be cured, i.e. there are twice as many incidents as fatal cases.

Thyroid cancer deserved special consideration because it is predominantly children that are afflicted. In addition, thyroid cancer 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 was another aspect that needed 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. It is above all the consumption of radio-iodine contaminated dairy products that increase the risk of contracting thyroid cancer. Children consume, relative to their body weight, more milk than adults and they are also more sensitive to radiation. In calculating the thyroid dose in children (0 - 15 years of age) account was taken of their proportion in the population and of their different consumption rates of milk. The risk factor used to calculate the number of fatal thyroid cancer cases was 0.08 x 10^{-2} per Sievert. A breakdown into the number of *thyroid cancer cases* (which appear almost solely in children) and *other cancer cases* was accepted.

Also, the risk of additional traffic accidents was addressed. The group contemplated about the potential death toll that would have to be paid if a countermeasure that drastically increases the freight transportation volume were to be implemented. It was concluded that the road accident risk was small compared to the radiation related risk.

Anxiety and reassurance

Contamination of food is a very sensitive topic. Children in particular are consumers of dairy products and any potential contamination of these foodstuffs will create stress and concern. Countermeasures may also create anxiety because it is often the case that the severity of an accident is perceived through the protective actions taken, i.e. the more extensive these are the more severe the accident must be and consequently the higher the health risk. But it was also argued that countermeasures have the potential of reassuring the population. Some of the participants liked to conceive of both of these attributes as expressing the same thing and being in effect nothing more than the two extremes on the same scale. Nevertheless, it was decided to include both since in that way both viewpoints could be articulated, i.e. those who preferred only one attribute could always ignore the other by placing zero weight on one or other of these attributes.

Social disruption

It was seen that the accident and how it is reacted to, poses a severe threat to the whole sector of dairy production. Firstly, there would be a loss of income due to direct restrictions in selling dairy products that exceed maximum permitted levels. But then consumers may also react unpredictably and, for example, reject all products that are somehow related to the affected area. Export may suffer from a total loss of confidence in Finnish foods, a loss that is very hard to make good. In short, it was clearly recognised that countermeasures may have disadvantageous repercussions on the dairy industry and this aspect needed expression. For example, turning milk into cheese may be a sensible action in order to meet food standards (for instance, European Commission regulated *maximum permitted levels for foodstuffs and feeding stuffs*) and may also be relatively cost efficient, but the flip side of the coin is that consumer confidence may be lost. All this amounts to a threat that is posed to farmers and employees in the dairy industry of the loss of their livelihood subsequently causing social disruptions.

Feasibility

The technical feasibility of countermeasures was discussed on many occasions. In the fallout area a significant amount of milk is produced. It was mentioned that it would be an enormous logistical problem to transport less contaminated replacement feedstuff into the fallout area, and if the contaminated area were larger this action would not be feasible at all. Banning or changes to the production routine are likely to cause considerable disposal problems. In addition, there are no disposal plans and legal issues are not solved. The delivery time for sorbents (ammoniumferrisyanidium) is about three months. These objections indicate the need to identify and include in the planning phase any constraint that may prevent or lessen the efficiency of an action. The feasibility attribute was aimed at capturing the different applicability of the actions in respect to logistics and/or disposal.

Monetary costs

The *monetary costs* attribute comprised the direct costs of protective actions. Cancer treatment costs, associated loss of GDP, and other costs that were proportional to the number of cancer cases were excluded in order not to double-count the cancer cases.

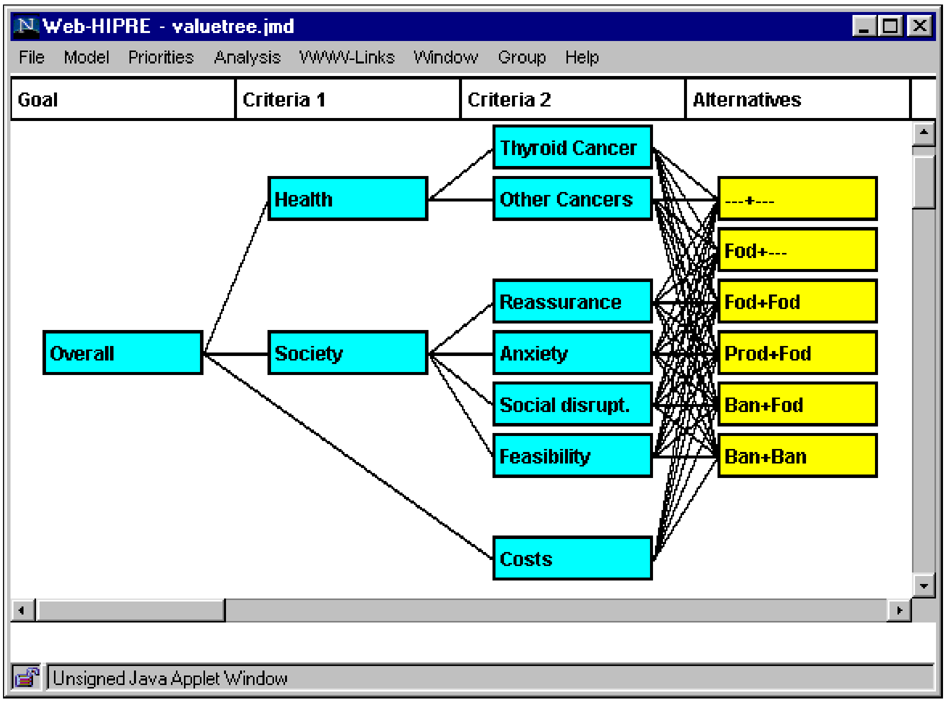


Figure 8. *Value (or attribute) tree used in the analysis.*

Inter alia the Chernobyl accident and recently BSE disease (bovine spongiform encephalopathy) have indicated perceived risk and related attributes (e.g. confidence) to be major factors in the final decision-making in policy problems. Confidence in authorities is often thought to be of crucial importance for the 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 that still affect their risk perception and consequently their behaviour, for instance, as consumers. These types of attributes were not considered in the workshop. Expert organisations should, however, be aware of the reasons why perceived risk and related attributes are added in final policy decisions. Attributes, such as 'confidence' and 'unknown effects', which seem to increase the safety marginal, should thus be kept in mind but not considered on the technical level while preparing recommendations.

4.3 Analysis of the problem

Six selected intervention strategies were proposed by the preparatory team and accepted as a working hypothesis for the decision analysis (see Table X). For these strategies the values of the 'hard' attributes, i.e. costs and health effects, were calculated in advance (Table XI). The 'soft' attributes, such as social disruption and anxiety, were directly rated. In the technique used the attribute, say anxiety, was given a value of 1 for the most preferred strategy in respect to anxiety and zero value for the least preferred one. The other options were rated between zero and one, according to the strength of preference for one option over another in terms of anxiety.

Since the risk attitude of the participants was not of major concern in this case study, the degree of preference for an option in respect to an attribute was encoded by value functions. The values in Table XI and those given to the 'soft' attributes were scaled between 0 and 1, where 0 represented the worst and 1 the best value of an attribute. Linear value functions were applied throughout the decision model to speed up this phase of the analysis. This meant, for example, that one cancer case was effectively perceived to be as great a loss to society independently of how many cancer cases are to be expected.

In order to obtain the overall benefit that was achieved by each strategy, the decision-makers assessed the weights of the attributes. These weights represented their judgements as to the relative importance of the levels of the attributes. Each of the six interest groups assessed the weights with the Web-HIPRE software but only one weight per attribute, as the group members agreed on a single value.

The Swing method (von Winterfeldt and Edwards, 1986) was used to elicit the preference weights of the attributes. In this method all attributes were initially at their lowest preference levels and the participants were asked, if just one of the attributes could be moved to its best level, which one they would chose. After this change had been made, they were asked which attribute they would next choose to move to its best level, and so on until all the attributes had been ranked. The first ranking attribute was given a weight of 100 and the weights of all the other attributes were assessed by comparing the importance of their respective swings from the lowest to the highest level with the swing in the first ranking attribute.

The overall ranking of the strategies was derived from the weighted average of the scores for each attribute. Each group aggregated the values, and in possible problem situations experts familiar with the software provided assistance. Each interest group eventually had a ranking of the strategies that incorporated their value judgements. The individual models were stored in the server and the results could be displayed on the projection screen. The individual models were eventually aggregated into a group model, which showed the overall ranking by all the groups together. In the group model (Figure 9), each element on the criteria level described the corresponding group. The scores for these elements were the group's individual scores for each strategy. The aggregation was done by averaging the overall score that each strategy achieved within each group, and each group element was equally weighted.

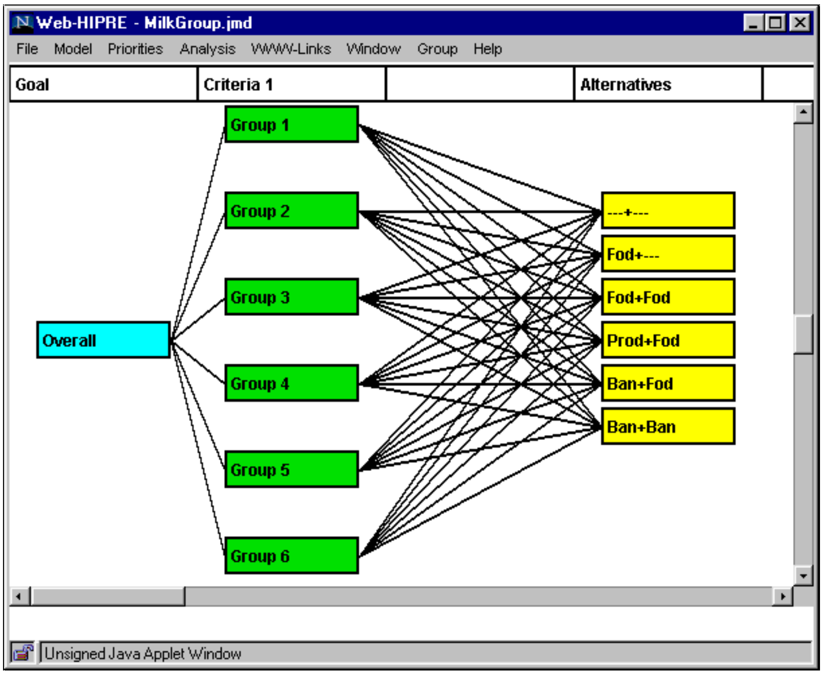
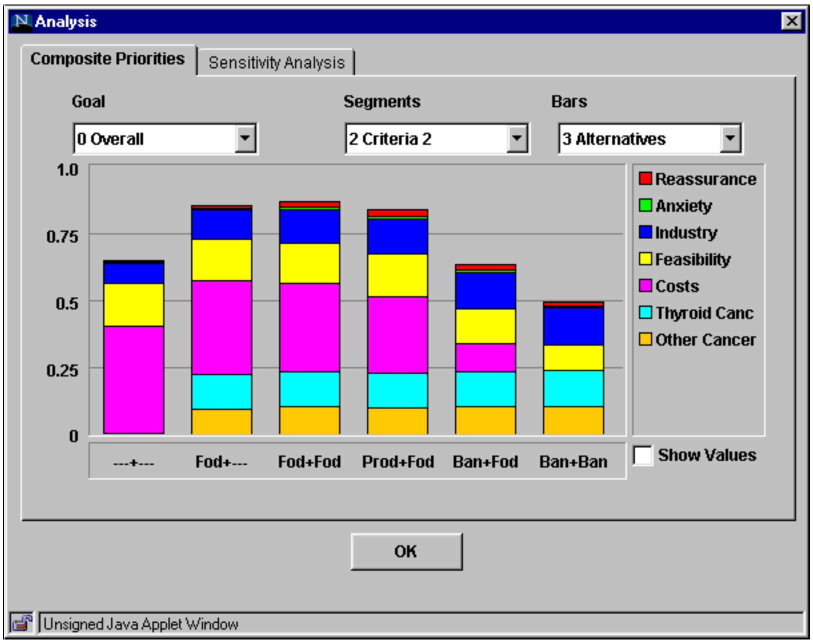


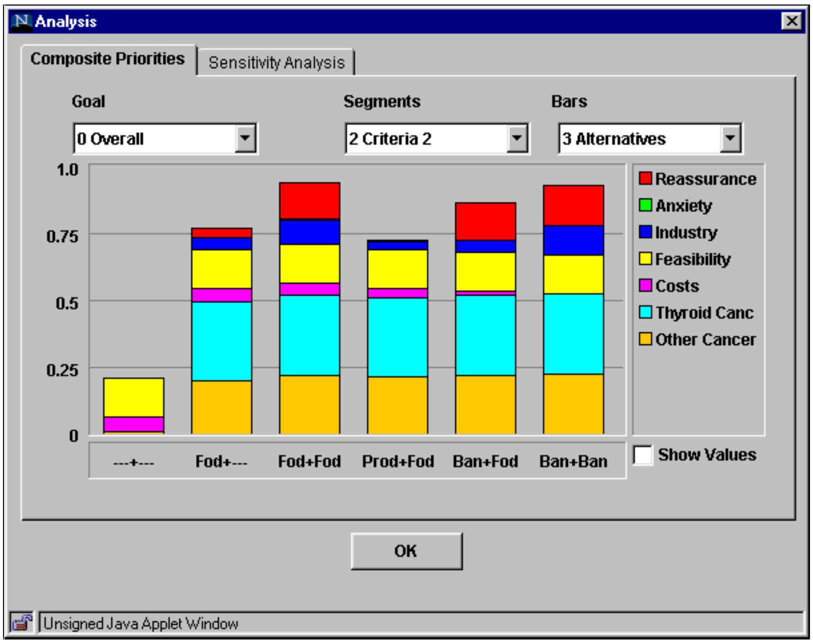
Figure 9. *The group model.*

4.4 Results

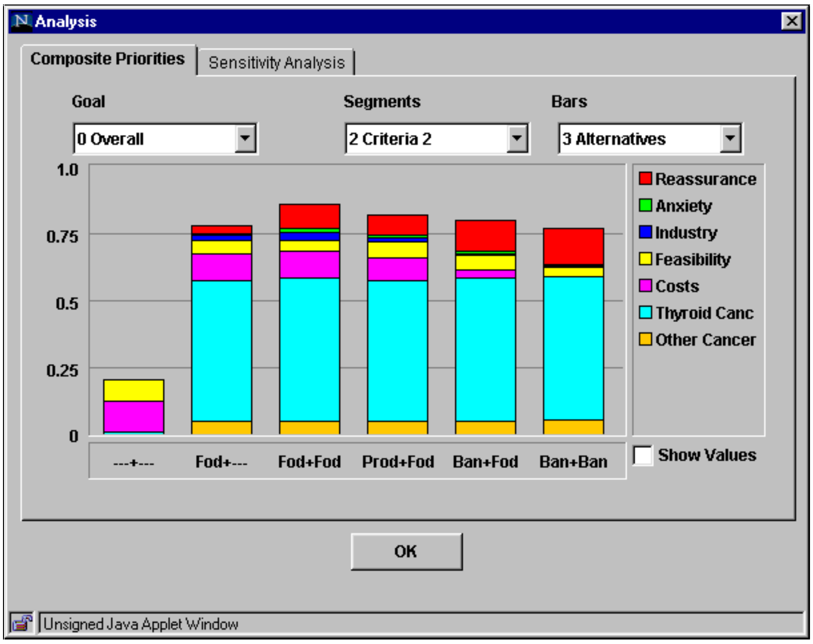
Initially, each interest group independently evaluated the strategies. Figures 10a - 10c show the evaluation of the strategies for groups one to three. These figures not only show the overall ranking but also what factors are important and which are decisive in the ranking. For example, it can be seen that costs were decisive for group 1, whereas groups 2 and 3 emphasised the health effects. Most groups put a lot of weight on health effects and therefore *doing nothing* (strategy 0) was not a viable option for them, since it meant several dozen cancer cases.



Kuva 10a. *Evaluation of the strategies by interest group 1.*



Kuva 10b. *Evaluation of the strategies by interest group 2.*



Kuva 10c. *Evaluation of the strategies by interest group 3.*

Although each interest group made an independent value judgement, the rankings that resulted had some aspects in common. Strategy 0, i.e. *doing nothing*, scored low within all groups and this was mainly due to the fact that adverse health effects were so disproportionate. Any other strategy investigated resulted in considerable dose savings and hence rather moderate health implications. Consequently, monetary costs, social disruption and psychosocial factors turned out to be more important.

Strategy 2, i.e. *provision of uncontaminated fodder throughout both periods,* was ranked best by all but one group. This strategy scored evenly on all attributes, i.e. costs were moderate and the health threat was kept within reasonable bounds. The strategy also achieved a certain degree of reassurance without undue disturbance of business and life. Finally, it was not considered to pose a considerable threat to the economy and it had a good chance of being implemented.

As mentioned earlier, all models were aggregated into a group model (Figure 11). This model also reflects the predominate preference for strategy 2. As expected, a change in the weight with which each interest group contributed to the aggregated model did not have much influence on this.

In the questionnaire, the participants were asked which strategies would be generally acceptable to them (Table XIIc). Strategies 2 and 3 were approved by 13 participants. It was pointed out during the workshop that dairies have the potential to make changes to the production routine in order to ensure the safety of their products. This is reflected in the answer, since strategy 3 was the only one that required changes to production.

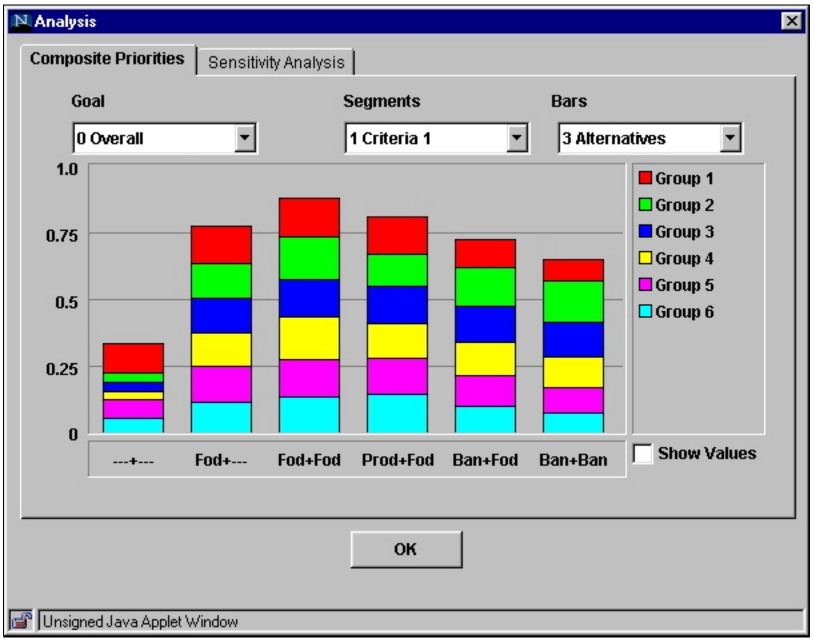


***Figure 11**. Aggregated groups priorities of the strategies.*

Still further insight was gained by analysing the sensitivity of the outcome for changes in the weight given to certain attributes. Figure 12 shows, for example, the implications of group 1's decision when stressing the cost factor. When it had a weight of 0.42 strategy 2 scored best, but as soon as the costs weighed more than 0.52 strategy 1 started to be favourable. A sensitivity analysis of the other groups' outcomes showed that the rankings were rather sensitive to change in the weight that was given to the cost attribute. The sensitivity in respect to costs was mainly due to the fact that the strategies were almost equally successful in avoiding radiation-induced cancers, so that the other factors, including costs, became decisive.

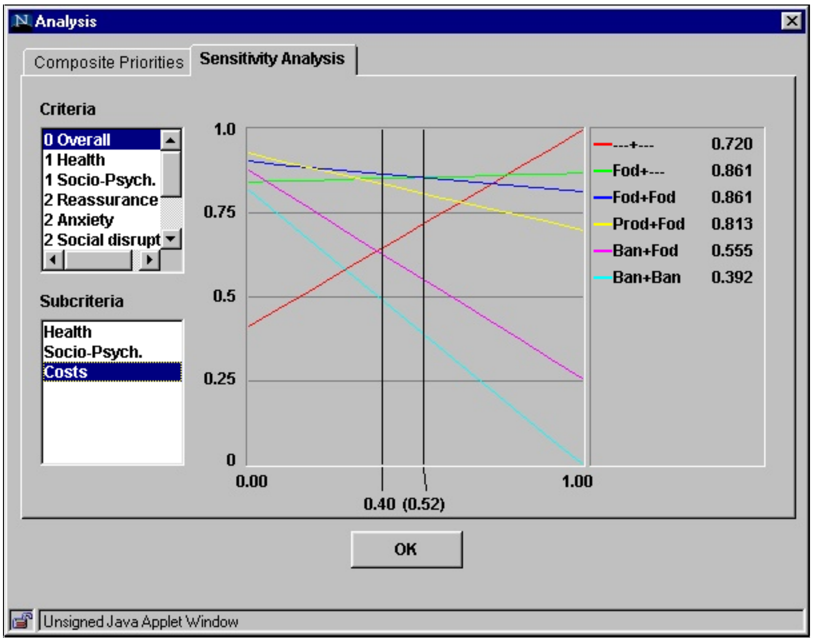


***Figure 12**. Sensitivity analysis of the cost attribute (group 1).*

4.5 Questionnaire

At the end of the workshop the participants were asked to fill in a questionnaire by means of Opinion-Online. The feedback is summarised in Tables XII and XIII. All the participants considered that the workshop was useful, and most of them also thought that a similar approach could be valuable for training and exercises. The attitude towards an application in the case of an emergency was slightly more hesitant, but in general still positive. Generally, it was seen that the ranking that emerged from the decision analysis corresponded to intuitive expectations.

Uncertainty issues played a minor role during the workshop, although it was recognised that both the assessments of the attributes and the weights the attributes received were only reliable to varying degrees. In the questionnaire these uncertainties were believed to be typically about 20 percent[9]. There was greater hesitation as regards the assessment of costs.

Table XII. *Evaluation of the Opinion-Online questionnaire (13 answers).*

a) Suitability of the approach

	++	+	-	--	can't say
A workshop is suitable for providing a comprehensive picture of the situation in training and exercises.	0	10	1	1	1
A workshop is suitable for providing a comprehensive picture in the case of emergency.	0	7	3	2	1
A workshop is suitable for finding a strategy during training and exercises.	3	8	2	0	0
A workshop is suitable for finding a strategy in case of emergency.	1	7	4	0	1
The ranking achieved with Web-HIPRE corresponds to my intuitive expectations.	0	12	0	0	1
It was difficult to grasp and follow the method used to elicit the trade-offs between attributes.	0	1	10	1	1
The case study was useful in general.	1	12	0	0	0

[9] It seems that it was overlooked that the scenario description mentioned dose assessments as being accurate only within a factor of 2 to 3.

b) Reliability of assessments

	<5%	±5%	±10 %	±20 %	±50 %	>50 %	can't say
How accurate do you judge the assessment of							
– health effects	0	0	5	6	1	0	1
– social effects	0	0	1	5	2	3	2
– costs	0	0	2	2	4	4	1
How accurate was the weighing of the attributes?	0	0	3	8	1	0	0

c) Strategies that were approved by the participants

	No. of answers
Strategy 0, no action - no action	0
Strategy 1, clean fodder - no action	3
Strategy 2, clean fodder- clean fodder	13
Strategy 3, milk processing- clean fodder	13
Strategy 4, ban on milk - clean fodder	11
Strategy 5, ban on milk - ban on milk	3

As mentioned earlier, the participants were provided with an information package in advance. It contained in somewhat condensed form the information given in Chapters 2 and 3. Further, it contained a list of possible attributes and a brief description of the parties involved in the decision-making. The main points in this information package were repeated during the briefing at the outset of the facilitated workshop. While most of the participants found the amount of information suitable (Table XIII), two thought that there was too much and another two missed some information that they desired, for example, thematic maps of the deposition and activity concentration in butter and cheese. All the thematic maps provided were appreciated, though.

With a few exceptions, the participants judged both the strategies and the attributes to be relevant. The attributes were mostly accepted, but some participants found it hard to express some aspects of their value judgement, or they were disturbed by some redundancy in the attributes. Others expressed the opinion that some attributes were difficult to apply and assess. Concerning the strategies, it was remarked that they were not sufficiently deliberated upon and not realistic enough. There were also too few strategies that have been assessed in advance. It was remarked, for example, that dairies could change the production processes in ways that were not considered in the information package (assorting milk was given as an example). Some participants found it difficult to grasp the definition of the strategies.

More general comments were that it was a valuable experience and worth of being repeated or built upon. One participant was slightly annoyed by the jargon used occasionally.

Table XIII. *Evaluation of the information package (11 answers).*

	yes	no	can't say
Was the amount of information suitable?	7	4	-
Were the thematic maps useful?	11	-	-
Were the proposed strategies relevant?	8	3	-
Were the proposed attributes relevant?	9	1	1

5 DISCUSSION

It was observed here as well as in earlier facilitated workshops that decision analytical tools and group techniques are useful. Most of the participants considered the format of a facilitated workshop and the use of an interactive decision support system applicable in exercises and many of them also in real-life situations. The workshop revealed many issues that could be utilised in nuclear emergency preparedness and management.

A lesson learnt from our previous workshops was that it could be very time-consuming to start from scratch, to define the attributes and assure that all participants understand their meaning. Therefore, we drafted a set of attributes that was presented at the outset of the workshop. The facilitator stressed the preliminary character of the attributes and urged the participants to revise them whenever necessary. Eventually the group settled on the attributes described in Section 4.2. The questionnaire revealed that the participants were rather confident about the assessments of the attributes.

Although we did not undertake a systematic analysis to derive optimal intervention levels for the accident scenario, the analysis nevertheless suggests that countermeasures at concentration levels well below established intervention levels can be justified in certain accident scenarios. In this study, intervention levels a decade below internationally recommended ones were justified. To ease the calculation of the health consequences, neither regional extent of a countermeasure nor the timing was a parameter that could have been varied freely in order to find an optimum level. We used intervention levels to define the regional extent of a countermeasure and only two choices were assessed beforehand. We also fixed the application times of the countermeasures (the first set of measures was applied during weeks 2 to 5 and another set during weeks 6 to 12). Only one measure could be in place at any one time and different countermeasures could only be implemented in succession.

The decision analysis reveals the intervention strategy that ranks best and is justified and optimised. The benefits of this strategy are greater than the associated detriments and the net benefit is maximal within the selected set of strategies. In the justification and optimisation process the decision-makers have to trade-off the levels of all relevant attributes and not only monetary costs and avertable dose as in a simple cost-benefit analysis. In this process decision-makers have to make the most of the resources available to society. It is sensible to assume that they put at least as much effort into avoiding radiation induced health risks than they do into avoiding similar non-radiation related health risks. A measure used in cost-benefit analysis to express this effort is the α-value. It expresses the amount of money that is assigned to avoiding a unit collective dose. For strategies 2 and 3, which scored best, the α-values were 9,000 euro and 15,000 euro, respectively. These values are well within the range of internationally recommended α-values, which vary from 3,300 to 110,000 euro per manSv (ICRP Publication 63).

The ranking of the strategies proved to be rather sensitive to changes in the weight of the cost attribute. This finding suggests that, above all, the economic implications of countermeasures need further research. In this study only a simplified picture of economic realities was given.

It was seen that the imposition of activity limits (for instance, the European Commission's maximum permitted levels for foodstuffs) might remain an academic exercise since consumers may reject any suspicious products and are free to choose whatever product they like. The need for a certification system was addressed in this context as a means to assure consumer confidence.

The feasibility of countermeasures was addressed during the preparatory meetings, but there were many more discussions throughout the workshop. It was not always easy to judge the feasibility of a countermeasure because expertise was not available in all relevant fields. The general observation was that some indicators are needed that allow the experts to assess the feasibility aspect. Ideally these indicators are expressed in units that the experts are accustomed to. For example, to judge the logistical feasibility of *provision of uncontaminated replacement fodder*, the number of trucks needed to supply daily needs was more expressive than the number of bales, which in turn was more expressive than the tons of replacement hay needed. However, it would be certainly worthwhile to investigate this question further.

The hypothetical fallout area was a major milk production area of Finland. If feeding on pasture grass were to be replaced with uncontaminated fodder, over three million kilograms of replacement fodder would be needed each day. To transport these amounts several hundred trucks are needed. Most of the participants thought that this could be arranged. The banning and disposal of milk, on the other hand, would create an enormous disposal problem. Almost two million litres of milk is produced every day and such amounts cannot be fed to the calves. Both dumping into the sludge well and ploughing into fields were considered to be doubtful methods. In addition, the legal aspects of such a measure are unclear and no emergency plans exist for the dumping of large amounts of contaminated substances such as milk or milk powder, processing water or grass. For these reasons, and because milk is produced every day and hardly storable and consequently any alarming contamination of milk calls for an almost immediate decision, it was suspected that the disposal of milk was not a feasible option at all. It was mentioned that hormonal treatment of the lactating cows might provide a transitional solution, though not an immediate one, to reduce the milk production. In the long run, i.e. if the milk remains unusable for a considerable time, slaughtering the animals was thought to be a better solution. It was not possible, however, to resolve these issues during the workshop.

6 CONCLUSIONS

It is important that all relevant parties come together to deliberate on countermeasures in nuclear emergency situations. The experience gained in the workshop strongly supports the format of a facilitated workshop to tackle a decision problem that concerns different stakeholders. The realistic nature and the disciplined process of a facilitated workshop yielded valuable information for emergency planning. The workshop exemplified that the chosen setting can be fruitfully applied during exercises, especially during those of the later phase of emergency management. The feedback from the workshop was very positive and encourages the view that it could be a valuable instrument when revising emergency plans or in order to identify issues that need to be resolved.

Multi-attribute decision analysis provided a suitable framework to deal with the complexity of the decision problem. It helped to clarify the objectives ('avoid radiation-induced cancer cases') and to identify the attributes ('radiation dose' or 'number of cancer cases') that can be used to measure the success of a strategy in achieving the objective. It provided a reasoning framework that intertwined beliefs, preferences and value judgments of the stakeholders and achieved a transparent ranking of the different strategies available.

Information technology played an important role in the workshop. It was a new quality of the workshop that the participants could directly interact and experiment with their own decision models, and they encountered no noteworthy problems in doing so. Since both Web-HIPRE and Opinion-Online are Web-based applications and can be accessed by the ubiquity of Web browsers, they provided an easy-to-use user interface and required very little introduction. With this software support, instant aggregation of group decisions and of a consensus model were easily obtained. A special Web page was created for the workshop and provided all relevant information on the case study; it also made updated results of the decision analysis available.

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 decision-makers' mobility is restricted. This was demonstrated by the ease that the equipment was transported to 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 conduction of the workshop. It allowed the participants to concentrate on the issues at hand and not too much time went into mastering unfamiliar technology.

The study revealed the need to further develop methods to assess the radiological and cost implications of food countermeasures. The food industry is dynamic and complex in nature. In order to provide consequence assessments it is necessary to take process, economic, demographic and geographical information into account. Also the feasibility and constraints of protective actions need further investigation.

At this point it may be worthwhile to look back to the initial objectives and see how they were met. We first wished to shed light on countermeasures that aim to avoid or at least reduce the dose received from the consumption of contaminated dairy products. We analysed a handful of strategies in a hypothetical accident scenario and managed to assess the collective dose, the expected number of additional cancer cases and the costs. Also, some additional information could be provided that allowed us to judge the feasibility of a strategy.

Another goal was to introduce the values, beliefs and preferences that were held by the different interest groups. We believe that the decision analytical approach provided a suitable framework to account for all this. It proved worthwhile because it helped the participants to go through all the phases of the decision-making process in a logical and efficient manner. For example, when constructing the attribute (or objective) hierarchy, they 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 some definitions were clarified and others revised. But probably more important was that it created a common understanding of the decision problem. At a later stage the participants were asked to consider explicitly the necessary trade-offs between the attributes, and 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. In addition, it stimulated a degree of commitment that is needed from all interest groups to carry out effectively any intervention agreed upon.

Finally, we wished to promote the computer-supported facilitated workshop approach. The workshop provided the participants with a forum that allowed them to communicate efficiently and share their views of the decision problem. This helped to create a common understanding of the problem domain and opened minds for the wider implications of milk countermeasures. The participants learned about the views of other groups that have an interest (and a say) in the matter. The benefit of the decision analysis approach in the facilitated workshop was that it gave the participants a means to structure the whole problem. It urged them to clearly set and define the objectives, deliberate on alternative actions, i.e. how objectives are achieved, and equally importantly, to think what are the consequences of the actions taken. The process focused on the essential information needed in decision-making and provided for outsiders.

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