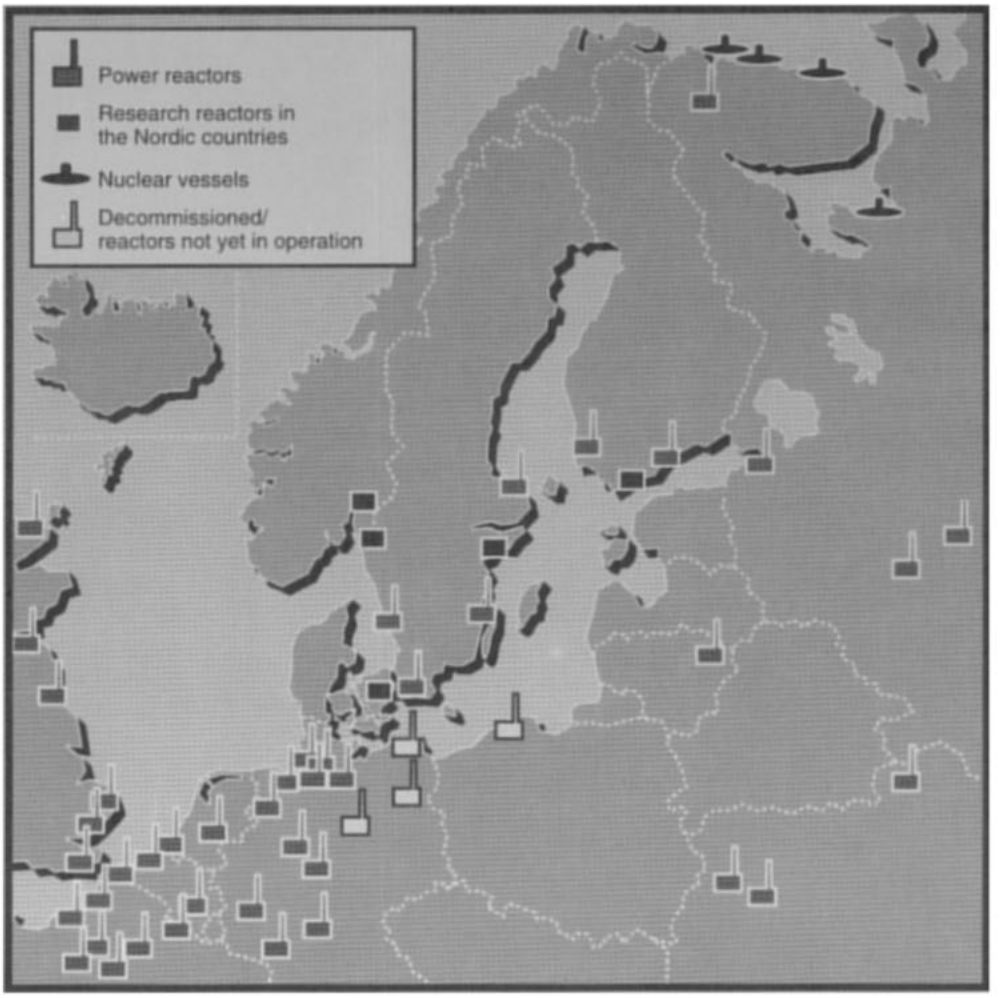
Nuclear Safety

Intervention Principles and Levels in the Event of a Nuclear Accident

TemaNord
1995:507



Intervention Principles and Levels in the Event of a Nuclear Accident

Intervention Principles and Levels in the Event of a Nuclear Accident

Final Report of the Nordic Nuclear Safety Research Project BER-3

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April 1994

TemaNord 1995:507

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TemaNord 1995:507

ISBN 92 9120 613 X
ISSN 0908-6692
Printing and distribution: Nordic Council of Ministers, Copenhagen
Printed on Paper Approved by the Nordic Environmental Labelling
Information about the NKS reports can be obtained from:
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P.O.Box 49
DK-4000 Roskilde
Telefax (+45) 46 32 22 06

The Nordic Council of Ministers
was established in 1971. It submits proposals on co-operation between the governments of the five Nordic countries to the Nordic Council, implements the Council's recommendations and reports on results, while directing the work carried out in the targeted areas. The Prime Ministers of the five Nordic countries assume overall responsibility for the co-operation measures, which are co-ordinated by the ministers for co-operation and the Nordic Co-operation Committee. The composition of the Council of Ministers varies, depending on the nature of the issue to be treated.

The Nordic Council
was formed in 1952 to promote co-operation between the parliaments and governments of Denmark, Iceland, Norway and Sweden. Finland joined in 1955. At the sessions held by the Council, representatives from the Faroe Islands and Greenland form part of the Danish delegation, while Åland is represented on the Finnish delegation. The Council consists of 87 elected members - all of whom are members of parliament. The Nordic Council takes initiatives, acts in a consultative capacity and monitors co-operation measures. The Council operates via its institutions: the Plenary Assembly, the Presidium, and standing committees.

ABSTRACT

In order to promote Nordic harmonization of the most likely protective measures to be taken in the case of large nuclear accidents, this report presents the background material needed to make common decisions on sheltering, evacuation and relocation. Brief comments only are also made on iodine prophylaxis and foodstuff restrictions.

Viewing the national monetary costs per person for such measures in relation to the income per capita - and in relation to the currency exchange rates of Feb. 1994 - there are by and large no arguments to find for different intervention levels in any of the four countries, DK, NO, FI and SE.

As applied α-values (the estimated monetary cost of a manSievert) are observed to have a large range, attempts were made to find the economic value of a health detriment. These pointed to the Willingness-To-Pay method, and a pilot project was performed in Denmark. On this basis a set of intervention levels - similar to internationally recommended levels - is proposed.

Other factors influencing decisions in emergency situations are discussed. Risk perception, risk communication and psychological factors, as well as the modern decision-aiding tools capable of handling such factors are also described.

Key words:
ATTITUDES; COST ESTIMATION; DENMARK; DOSE LIMITS; EMERGENCY PLANS; FINLAND; GOVERNMENT POLICIES; HUMAN FACTORS; ICELAND; NORWAY; POPULATION RELOCATION; RADIATION PROTECTION; REACTOR ACCIDENTS; RECOMMENDATIONS; REGIONAL COOPERATION; REMEDIAL ACTION; SOCIO-ECONOMIC FACTORS; SWEDEN

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The editor wishes to thank especially the BER-3 working group members for their written contributions and participation in the many lively discussions.

The illustrations are from Jack Valentin: En bok om Strålning, illustrated by Cecilia Torudd.

Contents

Summary

This report deals with the intervention measures to be taken after a nuclear accident. It also deals with steps towards Nordic - and international - harmonization of such measures.

Differences in the response of the authorities to an accident, if not well motivated, give rise to confusion and unnecessary concern. In order to avoid unnecessary differences all factors that have influence upon the decision must be analyzed and compared in advance by the Nordic countries. Protective action following a nuclear accident may consist of population sheltering, distribution of stable iodine tablets, evacuation of a contaminated area - later followed by relocation, and perhaps eventually by repopulation of that area. Each measure also implies certain negative consequences.

From the viewpoint of radiological protection, the central issue is whether the protective action can avert radiation doses sufficiently to offset the negative effects that are inevitable as a consequence of the measure under consideration. Thus, the introduction of a particular protective action should be judged, on the one hand, in the light of the doses that can be averted considering all possible exposure pathways and, on the other of its cost. The term cost is used here to cover all the negative consequences of such action, not just the direct monetary cost.

A joint set of intervention levels, supplemented by joint rules on how to apply these levels, is the central elements in a harmonized intervention policy.

The aim of the *BER-3 project* within the Nordic Emergency Preparedness Programme is to prepare for the Nordic authorities the background material needed to make common decisions on the most likely protective action to be taken in the case of large nuclear accidents.

This report treats sheltering, evacuation and relocation in detail. Brief comments are made on Iodine prophylaxis and foodstuff restrictions.

This work is based on the internationally accepted *basic principles for interventions* (ICRP and IAEA).

Sheltering

Sheltering means staying inside or moving into dwellings or other buildings, closing doors and windows, and turning off any ventilation systems in order to prevent the inhalation of radioactive material from the outside air, as well as to reduce the direct exposure from the cloud and from deposits of short-lived surface activity. Sheltering is assumed to last a few hours. A period of 6 hours was chosen for the present project.

In the calculation of the avertable effective dose resulting from sheltering, it seems reasonable to assume that the introduction of sheltering would mean that those members of a population who were out of doors would take shelter inside buildings, those already inside would remain inside. For indoor doses, the following reductions must be taken into account: closure of doors, windows and ventilation.

For a person being sheltered, the avertable dose can thus be calculated as: *the sum of the doses when sheltering is not performed minus the sum of doses (from all pathways) when sheltered.*

The national monetary cost per person

for sheltering for 6 hours in the national currencies of the four Nordic countries was found to be :

DKK:125; FIM:85; NOK:110; SEK:120 or expressed in ECU using the current (April 94) rates of exchange for Denmark, Finland, Norway and Sweden, respectively: 16.5; 13.4; 13.1; 13.2.

Evacuation

Evacuation is the urgent removal of people from their normal place of residence, or from places of work or recreation, for a limited period of time (less than a week), primarily in order to avoid deterministic (acute) effects and high risks of stochastic (late) effects that would otherwise arise in the short term.

The implementation of evacuation means that doses can be avoided from the inhalation of radioactive material and from external exposure resulting from the passage of a cloud containing radionuclides, and from surfaces where radioactive materials with short half-lives have been deposited. The inhalation dose will usually be much larger than that from external radiation from the cloud. A period of one week of evacuation was chosen for the present calculations.

If it is assumed that the dose is zero when people are evacuated to a "clean" area, the avertable doses can be expressed as the sum of the doses that they would otherwise have received.

Evacuation is a protective action that would be implemented to avoid short-term exposures. The intervention level at which evacuation should be introduced can be determined in two ways, one based on the *avoidance of deterministic effects* and the other on *optimization.*

If it is anticipated that the doses received may enter the deterministic region, evacuation is justified and should be introduced, even if the release is not certain to occur but has a fairly high probability of occurrence.

If it is anticipated that the doses may be lower than the threshold dose for deterministic effects, evacuation may still be introduced if it is cost-effective, i.e. if the benefits of dose avoidance more than outweigh the cost of evacuation. The intervention level determined by means of optimization will probably always be lower than that based on the avoidance of deterministic effects.

As shown below, the monetary costs of evacuation are calculated from the relocation costs per month by correcting for the relevant length of time.

The monetary cost per person of:

a) *evacuation for one week from residental areas* is:
DKK:875; FIM:630; NOK:863; SEK:816
(In ECU resp.: 115; 99; 103; 90)

b) *evacuation for one week from industrial areas* is:
DKK:3,523; FIM:2,403; NOK:3,127; SEK:3,477
(In ECU resp.: 465; 378; 373; 383)

Relocation

Temporary relocation and/or permanent relocation are two of the more extreme protective measures available to limit the exposure of the public to radiation in the event of a major nuclear accident.

Temporary relocation is the term used to indicate the *organized - voluntary or imposed - removal of people from the area affected by an accident for an extended but* *limited period of time* (e.g. several months) to avert exposures principally originating from radioactive material deposited on the ground and from inhalation of resuspended material. It is important not to confuse temporary relocation with evacuation, which refers to the urgent removal of people from an area to avert or reduce their exposure from an airborne plume or from short-lived deposited radioactive materials. The decision on the need for temporary relocation is usually a less urgent one than that dealing with evacuation.

Permanent relocation means *total removal of a population from an area with no expectation of return within their life-time.* This will typically involve the construction of new accomodation and infrastructure in an area remote from the contaminated zone.

In case of relocation, the avertable doses are the external gamma dose that would otherwise be received from activity deposited on ground and structure surfaces, and the inhalation dose from resuspended material. Avertable doses relating to food consumption should be considered separately.

The monetary costs per person if relocation starts at time zero are summarized below:

a) *For one month, from residential areas*:
DKK:3,750; FIM:2,700;
NOK:3,700; SEK:3,500
(In ECU resp.: 495; 425; 441; 386)

b) *For one month, from industrial areas*:
DKK:15,100; FIM:10,300;
NOK:13,400; SEK:14,900
(In ECU resp.: 1,990; 1,620; 1,600; 1,640)

Repopulation

After a recovery period, the relocated population will not necessarily want to return, but an economic benefit can nevertheless be calculated if the area abandoned is supposed repopulated. In this case the benefit is only the capital services that can be saved. On this basis repopulation can be justitied if the capital service saved per year exceeds the value of the dose received per year after repopulation has taken place.

Repopulation after 5 years, capital services saved per person:
DKK:76,323; FIM:63,366;
NOK:75,503; SEK:82,166
(In ECU resp.: 10,070; 9,960; 9,000; 9,060)

However, care should be taken that the dose from residual contamination does not become unacceptably high after return to the area.

Argument for Nordic Harmonization

When the above costs are seen in relation to the income per capita in the four Nordic countries - as well as in relation to the currency exchange rates of February 1994 - there are by and large **no arguments to find for different levels of action in any of the four countries with respect to the monetary costs of the three protective measures mentioned above: sheltering, evacuation and relocation.**

Iodine Prophylaxis

Taking stable iodine may reduce the uptake of inhaled (and ingested) radioiodine into the thyroid. This countermeasure should be considered in particular in the early phases when inhalation of radioiodine is a major exposure pathway. In situations where uncontaminated food supplies are readily available, it is more appropriate to reduce the doses that would otherwise be received through ingestion of radioiodine by imposing restrictions on the production and consumption of foodstuffs.

In the Nordic countries, policies concerning *iodine prophylaxis* are established jointly by the *radiation protection* and *health authorities.* If Nordic harmonization is desired, the iodine question requires re-evaluation by these authorities. The policies seem to vary in two respects:

- The availability/distribution of iodine tablets varies from an obligation to have four tablets/person in each building containing more than four apartments - through having central stores from which tablets are distributed in the event of an accident - to the possibility of purchasing tablets if desired.
- The implementation of iodine prophylaxis varies from being prescribed by the authorities at fairly low levels of external dose rate to little likelihood of its being prescribed at all.

In this document iodine prophylaxis is not dealt with like the other early protective actions, except for mentioning that the intervention level can be derived on a risk-to-risk basis. Thus internationally recommended values should be used except when the risk of adverse health effects originating from stable iodine is considered to differ significantly from internationally used values.

Alpha-Value Considerations

(the estimated monetary cost of a manSievert)

When the optimization principle was introduced in radiation protection, a value was assigned to the harm caused by irradiation, the *alpha-value.* This is the monetary value of collective dose reduction, usually given as a sum of money per manSievert (manSv). This value was based on the estimated years of life lost per manSv and is thus dependent on the estimated risk for serious late effects as well as the value assigned to a year of life.

Applied alpha values are observed within a range of 600 to 500,000 USD per manSv. The lowest is derived in Sweden for the prevention of lung cancer by reducing *radon levels in homes.* A similar value of less than 1,000 USD is found in Finland for the reduction of high radon levels in homes. The highest value is used by the Swedish power companies in their *planning of radiation protection work.*

Within the range we find Swedish diagnostic radiology with 6,000 USD and also the value of 100,000 USD recommended by the Nordic radiation protection authorities for general use.

In this project a mid-range value of *10,000 USD/manSv was found in a willingness-to-pay pilot study.* This value is used as a basis for the intervention levels presented in the table shown below.

These intervention levels can readily be transformed to correspond to other values of alpha. A doubling of the alpha value will halve the intervention levels and vice versa.

Only health detriment caused by radiation exposure and the monetary costs of protective action are taken into account. The effect of other factors of a psychological or social nature - such as anxiety, reassurance, public relations considerations, etc.- which decision-makers may consider appropriate to take into account, should be evaluated separately before final decisions are taken.

Intervention levels proposed by the BER-3 project compared to international recommendations

In this table the generic intervention levels in terms of **averted dose** derived in this study are summarized together with those developed by the IAEA and ICRP (see chapters 7 - 9).

Protective action	BER-3	IAEA	ICRP
Sheltering	2 mSv/6h (~ 0.3 mSv/h)	10 mSv/<2 d (~ 0.2 mSv/h)	50 - 5 mSv/<1 d (~ 2-0.2 mSv/h)
Evacuation			
deterministic:	500 mSv/1 day		500 mSv/<1 d [1]
stochastic:			500-50 mSv/<1 week
residential	10 mSv/1 week	50 mSv/<1 week	
industrial	50 mSv/1 week		
Iodine	100 mSv [2]	100 mGy [2]	> 50 mSv [2]
Relocation		30 mSv/1st month	15 - 5 mSv/ month, prol.
residential	50 mSv/1st month	10 mSv/month thereafter	
industrial	200 mSv/1st month		
		1 Sv long time	1 Sv total
Food			10 mSv/a
		Bq/kg:	Bq/kg:
beta + gamma		1,000 (1,000) [3]	1,000 - 10,000
beta		100 (100) [3]	
alpha		10 (1) [3]	10 - 100

[1] Projected dose
[2] Equivalent dose to thyroid
[3] The latter figure for infants' food and milk

Comments on the Different Protective Actions

Sheltering.
A six-hour period is used in this report whereas the IAEA gives a value for up to two days and the ICRP for less than one day. The dose rates are similar, and the intervention levels seem consistent.

Evacuation
Because of the threshold for deterministic effects, the same value was adopted as internationally recommended, 500 mSv. For the derivation of intervention levels based on optimization, two types of area were considered: residential and industrial. For residential areas the value in this project is lower than the international values. For the same time-period the value for industrial areas is similar.

Relocation
The same two types of area were considered for relocation. For the first month, the value found for residential areas is somewhat higher than the international values.

Repopulation
The calculations in this report are based on economic benefit by return (in the 6th year) and show fairly high dose rates of 35 mSv /month for residential areas and 50 mSv /month for industrial areas. If the effective half-life for removal of radionuclides is greater than about six years, the residual lifetime dose, corresponding to a return criterion of, say, 10 mSv/month, will be greater than one Sv. This means that repopulation would result in unacceptably high residual doses.

Foodstuffs
No recommendations are presented.

Other Factors Influencing the Intervention Levels and the Implementation of Protective Action

This study recognizes the importance of *psychological factors, social factors from an individual's viewpoint* and possibly *risk perception* in deriving intervention levels. However these issues are discussed qualitatively only, and the methodology was introduced to include them in the decisions on intervention levels. Further studies are recommended on these questions. Nevertheless the Nordic authorities can at present overcome the difficulties associated with such factors by applying modern decision-aiding techniques in their deliberations on developing a harmonized Nordic Intervention Strategy, including intervention levels.

The *wider social and political factors* still have to be left to the final political decision-makers.

Conclusions and Recommendations

Intervention in the normal life of society is a very complex matter and its consequences should be carefully studied when planning measures to cope with emergencies.

The possible quantification of the psychological impact is being studied in several Nordic countries. The results should be compiled and analyzed in a Nordic perspective.

The range of suggested alpha-values in the Nordic countries is very wide. The "willingness-to-pay" pilot interview project carried out in Denmark indicates a mid-range level of 10,000 USD/manSv.

The methodological approach in this pilot project appears promising.

A similar or slightly simplified study

should be made in each of the other Nordic countries, as there are reasons to expect national differences in how people react to the notions of increased safety and diminished risk. However, it should be noted that the assessment of trade-offs using separate studies is not necessary in carefully performed decision analyses. This kind of judgemental input related to a specific problem could come into being during the elicitation process.

The present international attitude (ICRP and IAEA) to the *range-system* (having an *upper intervention level* above which a protective action should always be implemented, and a *lower level* below which nothing need to be done) is that only one intervention level should be given per protective action. Similarly we recommend that only one intervention level be given for each protective action.

Regarding the numerical values for intervention levels, we conclude that the very small differences in the monetary costs of protective actions found in this study do not justify different intervention levels in the Nordic countries. If different numerical values are used, the reasons must be found in other factors.
Nor do we find reasons for differences from the levels given by the ICRP and the IAEA.

An area which needs more investigation is the economic consequences of protective actions under different accident conditions. Various case studies will probably bring more realism and insight to the handling of the many problems arising during emergencies.

It is difficult to see that the *psychological factors* can differ sufficiently between the Nordic countries to justify different intervention levels.

Social factors - from an individual's viewpoint or from the socity's wider viewpoint - have not been studied here, but some of them may vary much even within one country. Therefore we recommend a systematic study of the possible social impact of protective actions in the Nordic countries.

Flexibility in applying the intervention levels is still necessary because of local and accident-specific conditions. Such conditions could be described in an intervention strategy to be developed by the relevant authorities.

Political factors can hardly be considered at the planning stage and they will vary with time.

1. INTRODUCTION AND SCOPE

A major nuclear accident in one country may require a response from authorities in several surrounding countries. This may range from releasing information to the public to protective action such as sheltering, use of iodine tablets, food restrictions, evacuation, or even relocation in order to avert radiation doses.

The Chernobyl accident revealed great differences in the response of the authorities in various countries. This gave rise to population confusion and resulted in unnecessary concern.

The importance of rapid and frequent contact between the authorities in the Nordic countries has increased with the speed at which the mass media transmit information and - above all - rumours concerning nuclear-related events.

National authorities are generally expected to be able to respond rapidly even in non-urgent cases to protect people against radiation. If there are delays in informing the public, large economic losses might occur e.g. in foreign trade, agriculture and fisheries.

One of the essential arguments for this work is the need for the Nordic authorities to *maintain and promote the confidence that the public has in them* in the aftermath of large nuclear accidents.

According to the International Commission on Radiological Protection (ICRP): "Political and wider social factors will necessarily be a part of the decision making following radiological emergencies. The competent authorities responsible for radiation protection should therefore be prepared to provide the radiation protection input (justification and optimization of the proposed protective actions on radiological grounds) to the decision making process in a systematic manner, indicating all the radiological factors already considered in the analysis of the radiation protection strategy" (ICRP Publication 63, (31)).

In an emergency situation it is therefore *important that radiation protection factors are kept distinctly separate from political factors and that the decision procedure is fully revealed to the public.*

This will increase confidence in people's minds and avoid any mistrust of the radiological protection authorities.

It is thus *essential that different authorities act in a co-ordinated and trustworthy manner.* The public can neither understand nor accept very different levels of public protection in the different countries nor accept differences in decisions under very similar circumstances.

According to international recommendations for planning the protective actions (PA's) to be used in the event of a (large) nuclear accident, the principal factors needing consideration by the radiation protection authorities are as follows:

- identification of the available PA's
- avertable individual/collective doses to the public by implementation of the PA
- physical risks to the public from the PA
- radiation and other risks to the workers implementing the PA
- monetary costs of the PA
- public reassurance provided by the PA
- anxiety caused by the PA or the lack of it
- individual and societal disruption resulting from the PA.

When implementing any intervention, it

is important to define the protective actions in the same way in the Nordic countries. Moreover the assessment of the the avertable doses needs to be comparable in these countries in order to achieve harmonization. Therefore this report contains both descriptions of the major PA's available and of the connected dose reductions.

Only a limited number of the major PA's is discussed here. This report does not deal with those which properly implemented are expected to cause neither *undue physical risk to the public* nor *radiation or physical risk to the workers* implementing them. In an accident situation however they would naturally need due consideration.

Early in the work we concentrated on the methodology for justification and optimization of PA's. A case study used cost-benefit analysis and multi-attribute utility analysis to evaluate sets of intervention levels (Gjørup et al. 1992).

Protection against risks to human health depends on the resources available. Therefore it is considered important to calculate the monetary costs of the PA's under Nordic conditions. It is also important to compare the costs in the different countries for the purpose of Nordic harmonization of intervention strategy.

Knowledge of the monetary costs of the PA's also makes it possible to relate Nordic results to the international generic intervention levels solely by comparing the costs and the α-value. The monetary costs of the PA's would undoubtedly play an important role in decisions after a major nuclear accident, but cost might have little influence on decisions if the consequences of the accident are limited in space or in magnitude.

Psychological factors and *risk perception* are difficult to quantify, at least in a generic situation. Nevertheless they are extremely important for the successful implementation of protective actions and thus it was decided to discuss them qualitatively in the report.

Although *political factors* may play an important role in the final decisions concerning PA's after a nuclear accident, they should never be allowed to have any influence on radiation protection considerations. However, the same decision-aiding techniques used for other intangible factors can also be applied to political factors if so desired. For example, decisions on relocation, which need not be taken in a hurry, would benefit from such techniques and fully reveal the decisions to the public.

The aim of the *BER-3 project* within the Nordic Emergency Preparedness Programme is thus to present the background material for decisions on PA's. Furthermore the aim is to propose a set of harmonized generic Nordic intervention levels for major protective measures to be considered by the relevant Nordic authorities when agreeing upon a joint Nordic protection strategy. This includes intervention levels for use should there be a major nuclear accident. An additional aim is to present some relevant decision-aiding techniques to facilitate complex decision making.

In the Nordic countries there are at least two areas in which recommendations and policies already exist on intervention measures that were proposed by several authorities - not just by the radiation protection authorities. These need special attention if the policies are reconsidered.

One of these areas is *restrictions on food*, where a Nordic proposal was developed jointly by the *food* and the *radiation authorities* (Food Safety after Nuclear Accidents, Nord 1992:33). However, the recommendation for limiting the concentrations of radionuclides in food is based on *a preset dose limit* and not on justifying the protective action by a sufficient dose reduction to offset the harm. The recommendation foresees a re-evaluation of intervention within a month after an accident. The present document stresses the principle that can be used for re-evaluating the food intervention levels presented in the above-mentioned recommendation, in order to obtain new intervention levels in line with other intervention that might be needed in a given situation. Recommendations on food restrictions are not presented in this report.

The other area is *iodine prophylaxis.*
In the Nordic countries policy concerning *iodine prophylaxis* is established jointly by the *radiation protection* and *health authorities.* If Nordic harmonization is desired the iodine question requires re-evaluation by these authorities in the respective countries. The policies seem to vary in two respects:

- The availability/distribution of iodine tablets varies from an obligation to have four tablets/person in each building containing more than four apartments - through having central stores from where tablets are distributed in the event of an accident - to the possibility of purchasing tablets if desired.
- The implementation of iodine prophylaxis varies from being ordered by the authorities at fairly low levels of external dose rate to little likelihood of its being implemented.

Iodine prophylaxis is not given special treatment in this document like the other early protective measures. However the intervention level can be derived on a risk-to-risk basis. Thus internationally recommended values can be used except when the risk for adverse health effects from stable iodine is considered to differ significantly from internationally used values.

A working group with participants from Finland (FI), Sweden (SE) and Denmark (DK) was established to carry out the practical part of the project.

The international basic principles for intervention were adopted as the basis for this work. Therefore the status of international intervention policy has been assessed and presented in a separate report (Hedemann Jensen 1992).

It is clear that harmonization is desirable on an even greater scale than just within the Nordic area. Therefore this report also gives a short review of the basic principles in chapter 2, and chapter 7 gives a summary of the internationally recommended intervention levels. These are compared with the Nordic values obtained in a similar manner.

As the present report concentrates on the *monetary costs* of the measures and the *reduction in radiation risk,* chapter 3 discusses in greater detail the philosophy behind and the methods of putting a value on the risk reduction and factors having an impact on the price of preserving life.

Emphasis is put on the willingness-to-pay (WTP) method, which is further examined after an initial literature search presented in chapter 3. A pilot study was carried out using the WTP-method, which is reported separately (Vilstrup 1993) .

Appendix I presents avertable doses from protective actions.

Appendix II presents radiation protection principles for relocation/return.

A description is also given of the most commonly used *decision-aiding techniques,* starting with cost-benefit analysis through multi-attribute value and utility analysis. These techniques can also accommodate the more intangible factors such as those of a psychological and social nature.

Modern decision analysis as an aid for the decision maker in the solving of complex problems is presented more extensively in Appendix III.

A meeting dealing with "decision conferencing", a socially interactive approach to group decision making in order to generate a shared understanding of the problem at hand, and to foster a commitment to action, was organized by the BER-3 group in 1992 in Denmark. It was attended by local government officials, emergency planners and radiation protection workers in the Nordic countries. (French et al. 1993).

The *psychological factors* as well as the problems of *risk perception* to be considered in deciding on intervention measures are treated in sections 4 and 5.

Risk perception and risk communication is analyzed in detail in Appendix IV.

An overview of the costs in the four Nordic countries of the major protective actions are presented in chapter 6.

The detailed background for the calculations is given in appendix V.

The intervention levels derived from the costs of protective actions presented in chapter 6 (and Appendix V) and the value of α from chapter 3 are presented and compared with international generic intervention levels in chapter 8.

Finally chapter 9 describes our conclusions and recommendations for further work in the area of intervention policy.

A *follow-up group* with representatives from the competent authorities in the Nordic countries (except Iceland, which participated on an occasional basis) was established to reinforce contacts between these authorities and the project. Several meetings in this group were used to discuss and adjust the project work.

2. INTERVENTION PRINCIPLES

2.1 Introduction

The International Commission on Radiological Protection (ICRP) published its latest recommendations on the system of radiological protection for practices and for intervention (ICRP 90) in 1991. The ICRP system is based on the following basic principles.

(a) 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 (*justification of the intervention*).

(b) The form, scale, and duration of the intervention should be optimised so the net benefit of the dose reduction, i.e. the benefit of the reduction in radiation detriment, less the detriment associated with the intervention, should be maximised *(optimisation of protection)*.

Dose limits do not apply in the case of intervention. **Intervention Levels (ILs)** can be obtained by application of principles (a) and (b) and these can be used to assist decisions on the introduction of **protective actions (PAs)** in the event of an accident. There will be some level of projected dose above which intervention will almost always be justified, because the dose may result in serious deterministic effects.

2.2 Interventions

The ICRP system (ICRP90, ICRP93) is divided into two different branches:

(a) the system of radiological protection for proposed and continuing practices, and
(b) the system of radiological protection for interventions.

Interventions can be defined in the following way: some human activities can decrease the overall exposure, e.g. by removing existing sources, modifying pathways, or reducing the number of exposed individuals. The ICRP describes all these activities as interventions.

The use of dose limits as the basis for deciding on intervention might involve measures that would be out of all proportion to the benefit obtained and would then conflict with the principles of justification of the intervention. Therefore the *ICRP (ICRP90) does not recommend the application of dose limits for deciding on the need for, or scope of, intervention.*

Despite wide international agreement on the principles and objectives of intervention, differences are to be expected in their practical expression. The most important source of difference, however, will result from the weight given to factors of a socio-political and inevitably less tangible nature.

For example, there may be pressure to introduce PAs in response to a *perceived risk by the public*, even where the actual level of risk and the cost of averting it would not, in itself, justify the intervention. Similarly, there may be pressures to maintain doses below existing dose limits or some other prescribed limits developed for a totally different purpose, despite this being incorrect in principle and possibly counterproductive.

On the other hand, there will be *limits to the resources* a society may be willing, or even able, to commit to intervention and this may lead to higher values of ILs than those resulting from optimisation by cost-benefit analysis.

2.3 Doses Avertable by Intervention

The purpose of introducing protective actions is to **avert radiation doses** partly or completely. The introduction of PAs should, from a radiological protection point of view, be judged in the light of the **avertable doses (ADs)** from the different exposure pathways which are influenced by these actions and their **costs**.

For the calculation of the ADs obtainable by intervention, modelling is required - of the various processes in the transfer of an environmental contaminant to man.

These ADs are comparable with the Intervention Levels (ILs) for the protective action in question.

The models adopted may be of varying complexity depending upon the processes involved in the transfer of the environmental contamination to man.

In a release of airborne material to the atmosphere, the material disperses downwind as a plume. At a rather short distance the semi-infinite cloud model for *γ-radiation* can be used to calculate the *external γ-dose* and the *external β-dose to skin* as the product of nuclide-specific dose conversion factors and time-integrated air concentration.

A person immersed in the plume would *inhale* an amount of radioactive material proportional to the time-integrated air concentration and his/her rate of breathing. The committed inhalation dose will therefore be proportional to the time-integrated air concentration and nuclide specific inhalation dose factors.

Radioactive materials can be *deposited on the ground* by dry or wet deposition. During deposition and after the material has been deposited, the dose at a receptor point is calculated by integrating the dose rate to an individual from each radionuclide deposited on the ground surface. Removal processes such as migration into the soil, weathering, radioactive decay etc. should be included in the time integration of the dose rate. If the surface contamination density within a radius of a few hundred metres is more or less homogeneous, the time-integrated γ-dose rate is proportional to the time-integrated surface contamination density.

Radioactive material deposited on the ground, buildings and vegetation may be *resuspended* into the air, primarily by wind but also by human and animal activity, thereby leading to inhalation doses proportional to the time-integrated surface contamination density.

In general, the models used to calculate avertable doses should be as realistic and appropriate to the circumstances under consideration as possible. They should avoid the incorporation of undue pessimism as this may compromise the underlying objective of establishing Intervention Levels, which is to introduce protective measures that have a positive and maximum net benefit to the individuals concerned.

For the purpose of calculating ADs, the habits assumed for individuals need to be carefully selected. In particular they must be consistent with the philosophy underlying the choice and intended use of the IL.

If the intent is to compare the exposure of an "average" individual with the IL of the dose as a basis for deciding upon protective measures, then *average habits* should be assumed. Equally, if the intent is to obtain a comparison with those more highly exposed, then habits peculiar to this group must be adopted. Whether the comparison is made in terms of average or more extreme individuals in the population is secondary to the need for ensuring that the overall approach is consistent.

It should be recognised that if the doses to the most highly exposed individuals in a population group (critical groups) are compared with the IL for the introduction of a protective measure, many of the affected individuals would, in the absence of the protective measure, have received doses well below the IL.

2.4 Intervention Following a Radiological Accident

The risk to a population following an accident may arise from direct exposure and/or contamination from an unshielded or damaged source and/or the release and dispersion of radioactive material into the environment. The accidental release of radioactive material can occur over a very short period of time (minutes or less) or can last for several days or even weeks, depending on the nature of the accident.

For a protective action to be effective in the short term, it must be introduced rapidly. Members of the public may be exposed to radiation over this period of time either externally or internally by various pathways. The radionuclides released and the pathways by which they reach man will affect the applicability of the protective actions.

The *major protective actions* that might need rapid introduction in the event of a nuclear accident or major radiological emergency, are the following:

- sheltering
- evacuation
- administration of stable iodine
- precautionary restrictions on certain foodstuffs

Subsequently, *additional protective actions* may need to be taken and these include:

- relocation
- continuing foodstuff restrictions
- decontamination

Continuing foodstuff restrictions should be applied independently of the decision on relocation. It is recognised, however, that in the absence of a total ban on locally produced food, relocation would also influence doses via ingestion.

For the sake of completeness there are other PAs such as control of access and egress, use of personal protective clothing, decontamination of buildings and surfaces, and other measures preventing the transport of radionuclides to man through ingestion and inhalation.

Protective actions can only influence doses that may be received in the future.

Only if cumulative doses are likely to exceed the thresholds for deterministic effects, are *past doses* (from the accident) relevant to decisions on relocation. However, it is recognised that past doses may affect social perceptions and so may influence decisions through consideration of social factors. In addition, past doses may be relevant when determining the need for long-term medical care and surveillance of those affected by the accident.

2.5 Urgent Protective Action

The purpose of urgent protective action is to avoid deterministic effects as well as to reduce the risk of stochastic effects.

The avertable effective doses should be compared with the intervention levels for the PAs, and the projected absorbed organ and whole-body doses should be compared with the threshold doses for deterministic effects. The absorbed organ doses should include the doses already received since the arrival of the plume and those which could be received if the PA is not introduced.

During the early stages of an accident involving a release of relatively short duration of aerosols into the atmosphere, and while the plume is passing, the contribution of *the dose from inhalation will usually be much larger than that from external radiation from the plume.*

2.5.1 Sheltering

Sheltering means staying inside or moving into dwellings or other buildings, closing doors and windows, and turning off any ventilation systems so that individuals will inhale less radioactive material from the outside air, as well as reducing their direct exposure to the cloud and to short-lived surface deposits. Sheltering is assumed to last a few hours.

In the calculation of the avertable effective dose from a specific radionuclide obtainable by sheltering, it seems reasonable to assume that the introduction of sheltering will make all people who are outside move inside buildings and that those already indoors will remain there.

The avertable dose for a person being sheltered can thus be calculated as *the sum of the outdoor doses from all pathways minus the sum of the time-averaged indoor doses from all pathways.*

Compared to the contribution from the γ-radiation and the inhalation pathway, the contribution to the effective dose from *external β-radiation* from the plume and from activity deposited on ground *can be neglected.*

The averted dose depends on the type of house. However the overall reduction in dose depends mainly upon the number of people who are outdoors when the measure is introduced. Radionuclides from the air outside will gradually accumulate in the air inside a building through cracks, crevices and pores and the sheltering efficiency will decrease with time, especially for houses that are not air-tight.

Another important factor for judging the efficiency of sheltering is *the time of day.* At night most people are indoors, and the avertable doses from sheltering will therefore not be as large as during the day because people are already sheltered.

2.5.2 Evacuation

Evacuation is the urgent removal of people from their normal place of residence, or from places of work or recreation, for a limited period of time (a maximum anticipated time is 7 days), in order to avoid short-term exposures.

Based upon expectations of the development of an accident evacuation can also be implemented as a precautionary measure before any significant release has taken place.

The ADs pertaining to an evacuation would be from the inhalation of radioactive material and from external exposure from the cloud and from short-lived surface deposits. *The dose from inhalation will usually be much larger than that from external radiation from the plume.*

If it is assumed that the dose is zero while people are being evacuated, the avertable dose can be expressed by *the sum of the doses under normal living conditions from all pathways.*

2.5.3 Iodine Prophylaxis

Taking stable iodine is a measure for reducing the uptake of inhaled (and ingested) radioiodine by the thyroid. This protective action should be considered in particular when the inhalation of radioiodine is a major exposure pathway. In situations where uncontaminated food supplies are readily available, it is more appropriate to reduce doses from ingestion of radioiodine by imposing restrictions on the production and consumption of foodstuffs (ICRP63).

After an intake of radioiodine, the activity in the thyroid reaches 50% of the maximum within about six hours and the maximum in one or two days. Thus, to obtain the maximum reduction of the radiation dose to the thyroid, *stable iodine should be administered before any intake of radioactive iodine; otherwise as soon as practicable thereafter.*

If stable iodine is administered orally within the six hours preceding the intake of radioactive iodine, protection is about 98%; it is about 90% if stable iodine is administered at the time of inhalation. Its effectiveness decreases with delay, but the uptake of radioiodine by the thyroid can still be reduced to about 50% if it is administered within four to six hours after inhalation.

Depending on the distribution policy in the different Nordic countries, there may be large differences in the efficiency of iodine prophylaxis.

2.6 Longer-Term Protective Action

Whereas the protective measures of sheltering, evacuation and the distribution of stable iodine are intended to be of short duration, there are other protective measures that are likely to be of greater duration.

The purpose of longer-term protective measures is generally to reduce the risk of stochastic effects in the exposed population, including hereditary effects in their offspring.

However, it might be necessary to ensure that the level of protection is sufficient to prevent serious deterministic health injuries.

2.6.1 Temporary Relocation

Temporary relocation and/or permanent relocation are two of the more extreme protective measures available to control radiation exposures of the public in the event of a major nuclear accident (see Appendix I).

Temporary relocation is the term used to indicate the *organised - voluntary or imposed - removal of people from the area affected by an accident for an extended but limited period of time* (e.g., several months) to avert exposures principally from radioactive material deposited on the ground and from inhalation of resuspended material. During this period people would typically be housed in temporary, rented accommodation.

It is important not to confuse temporary relocation with evacuation, which refers to the urgent removal of people from an area to avert or reduce their exposure from an airborne plume or from short-lived deposited radioactive materials. The decision on the need for temporary relocation is usually less urgent than that for evacuation.

The doses avertable by means of relocation, from activity deposited on the ground and structure surfaces are *the external γ-dose and the inhalation dose from resuspended material* that would otherwise be received during normal residence in the area.

2.6.2 Permanent Relocation

Permanent relocation is the term used to indicate *the total removal of a population from an area with no expectation of return within their lifetime.* This would typically involve the construction of new accomodation and infrastructure in an area remote from the contaminated zone.

As for temporary relocation, the doses avertable by means of permanent relocation are *the external γ-doses from deposited activity and the inhalation doses from resuspended material.* Avertable ingestion doses from contaminated food should be considered separately.

2.6.3 Foodstuff Restrictions

Depending on the kind of foodstuff, three types of protective action can be implemented:

- prevention of transfer of radionuclides into the human food chain
- banning of food for human consumption
- decontamination of food

The activity concentration in the foodstuffs or the surface contamination density on agricultural land, are the quantities used to express the doses avertable by means of food restrictions. Models of varying complexity are available to predict the environmental transfer of deposited radionuclides into foodstuffs.

Many additional factors peculiar to local and national agricultural practices may need to be specified to enable the evaluation of the predicted doses with adequate reliability. Such factors may also include, for example, the processing of a food product before consumption resulting in the removal of or loss of the contaminant during food preparation or processing and the elapsing of time before the product is actually consumed.

As the exposed population is not easily identified, the avertable dose from foodstuff restrictions is *the collective dose per unit mass of the restricted foodstuff.*

2.7 Intervention Levels (ILs)

Intervention Levels (ILs) relate to a specific protective action taken to mitigate the consequences of an accidental release of radionuclides or of other de facto radiation sources.

ILs are specified in terms of the dose that it is anticipated will be averted by the associated protective action, and ILs are specified separately for different protective actions. The AD is compared to the IL and if it exceeds the IL, the protective action is triggered.

According to the basic principles for intervention, each protective action should be *justified*, i.e. do more good than harm, and the protection achieved by the action should be *optimised*, i.e. do the most good. Generic Intervention Levels (GILs) for separate protective actions can be prepared in advance by optimisation in which only *avertable dose* and *monetary costs* are included.

The outcome is an *optimised generic* ***IL*** *(GIL)*. For sheltering, evacuation, relocation and foodstuff restrictions, the GIL has the following generalised form (see Annex A in Appendix II):

$$GIL = \frac{C}{\alpha}$$

where C is the *monetary cost of the protective measure* and α is *the monetary value of the unit collective dose.*

For sheltering, evacuation and relocation, the optimised ***GIL*** will be expressed in averted individual dose per unit time when the parameter, C, is expressed in cost per unit time of these protective measures. For foodstuff restrictions the optimised ***GIL*** will be expressed in averted collective dose per unit mass of foodstuff if the parameter, C, is expressed in cost of the restrictions per unit mass of that foodstuff.

2.8 Operational Intervention Levels (OILs)

For practical purposes, there is for certain PAs merit in establishing values for *surrogate quantities* that can be more readily assessed than avertable doses from the conditions pertaining when decisions need to be made (see Annex B in Appendix II).

Quantities such as

- *dose rate in air,*
- *surface contamination density* and
- *activity concentration in air*

can easily be measured and applied as surrogates for doses that could be averted by different protective actions. However, in the prediction of avertable doses, such operational quantities should be used carefully and applied together with the local conditions and the circumstances of the accident which include

- *types of radionuclide*,
- *environmental half-lives*,
- *transfer factors for deposited activity*,
- *location factors* and
- *filtering factors for housing conditions*

in the affected areas. Different operational quantities would be used for the different protective measures as illustrated in Table 1.

The term "*Operational Intervention Level (OIL)*" is reserved for these quantities that can be more easily assessed at the time of decision on intervention such as dose rate, activity concentration, surface contamination density, etc. OILs are related to the dose that could be averted, and the relationship between these quantities and the avertable dose will vary considerably with the circumstances of the accident and nature of contamination, with obvious implications for criteria expressed in these terms. The operational quantities would, therefore, be both accident- and site-specific but still inextricably linked to the avertable dose.

The generic ***OIL*** (***GOIL***) for relocation can be expressed as an instantaneous outdoor dose rate in open areas. To calculate the ***GOIL*** for relocation it is necessary to know the site-specific location factors accounting for shielding and occupancy in that area.

Similarly, the ***GOIL*** for foodstuff restrictions can be expressed as a nuclide-specific activity concentration in the foodstuff considered. To calculate the ***GOIL*** for restricting a foodstuff containing a specific radionuclide, use should be made of the committed effective dose per unit activity ingested of that nuclide.

Thus, GOILs are always related to accident- and site-specific parameters.

Table 1. Relevant operational quantities for prediction of avertable doses by urgent and long-term protective actions.

Protective action	Operational quantity
Sheltering	Dose rate, air concentration
Evacuation	Dose rate, air concentration
Stable iodine	Air concentration of iodine, Dose rate from iodine
Precautionary food restrictions	Surface contamination density
Temporary relocation or permanent resettlement	Dose rate, surface contamination density
Foodstuff restrictions	Activity concentration in food

2.9 Summary

Protective actions can only influence doses that may be received in the future.

The purpose of introducing protective actions is to **avert radiation doses** partly or completely. From a radiological protection point of view, the introduction of protective actions should be judged in the light of the **avertable doses** from the different exposure pathways that are influenced by these actions and their **monetary and other costs.**

If the avertable doses are foreseen to exceed the Intervention Level for a specific protective action, this action should be introduced.

The protective actions forming a programme of intervention, which always has some disadvantages, should each be **justified** on its own merit in the sense that it should do more good than harm, and its form, scale, and duration should be **optimised** so as to maximize the net benefit.

Dose limits are intended for use in the control of practices and not for intervention. The use of these dose limits as the basis for deciding on intervention might involve measures that would be out of all proportion to the benefit obtained and would be in conflict with the principle of justification. Therefore, dose limits must not be used for deciding on the need for or scope of intervention. However, at some level of individual dose that would cause serious deterministic effects, some kind of intervention will almost always be justified. The **relevant quantity** to be used in intervention situations is the Intervention Level expressed in terms of **avertable dose** or any relevant quantity related to the avertable dose, e.g. concentration in foodstuffs or on ground surfaces.

If the doses or concentrations that could be avoided by a protective action exceed the Intervention Level for that specific action, then it should be introduced.

References

ICRP90 International Commission on Radiological Protection, *1990 Recommendations of the International Commission on Radiological Protection*, Publication 60, Pergamon Press, 1991.

ICRP93 International Commission on Radiological Protection, *Principles for Intervention for Protection of the Public in a Radiological Emergency*, Publication 63, Pergamon Press, 1993.

3. ECONOMIC RESOURCES AND RADIATION PROTECTION DECISIONS

3.a General Considerations

The term *trade-off* (used in connection with decision making) means selecting the choice by means of analyzing the advantages and disadvantages of two or more alternatives. The modern art of trade-off came into being with the *Pareto criterion* (Pareto, 1896). This criterion requires that, to be acceptable, *any public project should make at least one person better off and nobody worse off.* An alternative definition is the so-called *potential Pareto improvement criterion* (also called the Kaldor-Hicks' test) which requires that *the net gains can be so distributed that at least one person is made better off with none being made worse off.* Then, if the value of the benefits adds up to more than the value of the losses, the project, seen in terms of the potential Pareto improvement criterion, is a good thing (compared with doing nothing) and should be carried out. The gainers can compensate the losers, and no one will end up worse off than when he started. If the goal in view can be achieved by more than one acceptable project, then the project of choice is that yielding the largest difference between benefits and losses.

The ICRP follows the potential Pareto improvement criterion when it states (ICRP, 1990) that interventions in accidental situations should in the first place be *justified,* i.e. they should do more good than harm, and secondly, that interventions should be chosen in such a way that radiation protection is *optimized,* i.e. the difference between good and harm should be made as large as possible. When this state is obtained the risk is *as low as reasonably achievable* (ALARA).

The proper selection of interventions in accident situations requires that the relevant quantities - e.g. exposure of the public to stress of various kinds and economic costs, on the one hand, and reassurance and averted consequences of potential irradiation on the other - can be compared and balanced against each other. One of the most difficult problems in this connection is the question of how economic costs can be compared to averted health detriments.

In the following these questions are discussed in greater detail.

3.a.1 Safety and Risk

The probability that a person will survive (or avoid health detriments) during a coming, specified, period of time is often used as a measure of safety, and risk means, correspondingly, the probability that a person will die (or suffer injuries) during that same period. (The sum of the two probabilities is 1). The loss or gain in years of life corresponding to a given probability of death or survival depends, of course, on the age of the person in question. On average the gain or loss is 10-15 years (for those dying a "natural" death). For people killed in accidents it is 30-40 years.

Until the appearance of ICRP publication no. 60, the ICRP used the word "risk" in the sense of probability of death (sooner or later) from a radiation-induced cancer as a consequence of irradiation, whereas safety meant the probability of definitely avoiding injury or death from radiation-induced cancer. The sum of the two probabilities is 1. Now probability means probability and "risk" is used in less well defined ways in radiation protection. Risk had different definitions in other circles before ICRP 60 appeared. The safety community defined risk as the mathematical expectation of harm (risk = probability x consequence).

It is not possible to establish if a particular case of cancer is a result of irradiation or some other cause. The consequences of the irradiation of a population group can be assessed primarily as a number of years of life lost collectively. At the present time the "risk" is considered by the ICRP (ICRP, 1991) to be approximately one year of life lost per 0.7 manSv. This relationship is determined mainly on the basis of experience from Hiroshima and Nagasaki. It is beset with great uncertainty - partly due to uncertainty in the determination of the number of lost years of life, partly due to uncertainty in the determination of doses, and finally because irradiation conditions in Hiroshima and Nagasaki cannot a priori be taken to be representative of irradiation conditions in other circumstances.

Based on the radiation risk factors given by the ICRP for radiation-induced lethal cancer (0.05 Sv^{-1}), non-fatal cancer (0.01 Sv^{-1}) and severe hereditary damage in all future generations (0.013 Sv^{-1}), and an average loss of healthy life with one case of radiation-induced lethal cancer of the order of 13 years, the statistical loss of life expectancy, ***LLE***, (with some allowance for loss of quality of life for non-fatal cancers and severe hereditary effects) associated with 1 man·Sv can be evaluated as:

$$\boldsymbol{LLE} \approx (0.05 + 0.01 + 0.013) \cdot 13 \approx 1 \text{ year} \cdot Sv^{-1}.$$

Because of uncertainties associated with the risk coefficients, this value of ***LLE*** can only be considered to be accurate within a factor of 2 according to the ICRP. Therefore, the following range of ***LLE*** from radiation exposure is advocated:

$$\boldsymbol{LLE} \approx 0.5 - 2 \text{ years} \cdot Sv^{-1}.$$

3.a.2 Optimization of Radiation Protection

It is important to realize fully that reduction in risk in connection with a factual situation, can, as a rule, be achieved only through the spending of economic and human resources. As resources are limited this means that a reduction in risk in a factual situation requires a reduction in the spending of resources on other desirable goals (also non-safety related ones).

Such a reduction in a specific risk can be achieved only through a reduction in standards of living e.g. an increase in other types of risk, smaller and/or inferior housing facilities, inferior nutrition, inferior clothing, inferior and/or smaller cars, fewer and/or shorter vacation trips, inferior public services, e.g inferior public library services, inferior public transport, inferior standard and poorer maintenance of road systems etc. - all in all an inferior quality of life.

It is evident that unbalanced and excessive spending in some fields may result in unacceptable conditions in others and consequently a reduced quality of life. In order to obtain - with a given economic capability - the optimal quality of life for people (optimal welfare), it is necessary to consider which relative weights they would put on different desirable benefits, naturally including safety.

In situations already existing as facts - e.g., where an area is contaminated with radioactivity it is possible - by means of proper, possibly expensive means - to reduce to a greater or lesser extent the irradiation of the population. Thereby the collective lifetime of the population - i.e. the sum of the years of life of the population considered individually - would be increased in comparison with what it would have been otherwise.

It is a requirement that the cost should not be so large as to imply, in itself, that the collective lifetime is reduced (compared to what it would otherwise have been) to the extent that the gain in collective lifetime resulting from the dose reduction is offset by a lifetime reduction caused by economic stress. The total result with respect to collective lifetime (including possible injuries as a direct consequence of intervention) must under all circumstances be greater than zero - otherwise the economic efforts would be totally lost.

It must also be a requirement that intervention results in an overall positive gain in the form of an increased number of collective years of life and that the subjective value of this gain should be larger than - or at least equal to - the subjective value of those other benefits which will be lost on account of the economic sacrifices that the intervention effort requires (*ICRP: Justification; do more good than harm*).

Normally the degree of intervention can be increased in steps. For each step the cost per extra year of life gained will increase as a rule. When the step is reached where the cost per increased year of life just reaches the maximal amount sustainable by the value of a year of life, the optimal effort is attained. (*ICRP: optimize protection; differential analysis*). The *average* resources spent per year of life gained will, of course, be less than the value of a year of life, but a further step would cost more per extra year of life gained than the value of a year of life.

As can be seen from the above it is necessary that safety as such - i.e. continued life - should be assigned a certain economic value if the well-being of a population, including its safety, is to be optimized. An assessment of this value (e.g. expressed as the value of an extra year of life) has to be made to carry out a weighted comparison in order to optimize the way available economic resources should be apportioned between safety and other forms of desirable benefits.

For the purpose of trade-offs between different options with respect to avoidance of *radiation doses and thus health detriment* and the *cost of a protective action* for this a monetary 'cost' has to be assigned to the health detriment caused by radiation exposure.

That part of the the detriment that is caused by radiation can be quantified by a collective (or individual) radiation dose.
Other health-related negative effects, e.g., anxiety, or positive effects e.g., reassurance, are more difficult to quantify when deriving generic ILs and are therefore excluded from the present considerations.

National authorities may sometimes wish to introduce protective actions even if these measures have little or no positive impact on health. This can occur when the absence of any action may lead to an impression of inadequacy on the part of authorities, e.g. the national authorities could appear to be unprepared and unable to assess the situation and reach conclusions on the protective measures needed. In such cases, the need to gain public confidence and to reduce anxiety may be particularly important. However, the authorities ought always to make clear to the public if the decisions are taken for reasons other than warranted by the reduction of radiological risk.

The methods used in radiological optimization are well documented in ICRP publication 55: "Optimization and Decision-Making in Radiological Protection".

3.b The Value of Gains in Length of Life

Safety as such - i.e. continued life - can be assigned a certain economic value in order to optimize the well-being of a population, including its safety. An assessment of this value - e.g. expressed as the value of an extra year of life - has to be made to make it possible to carry out a weighted comparison of gains and losses in order to apportion the available economic resources between safety and other forms of desirable benefits to obtain the desired goal.

Historically, there have been two basically different methods that agencies have used to approach the question of assigning a value on improvements to life/harm to life.

- One is the *human capital approach*, which equates the value of life with the monetary value of goods that can be produced by the person whose life is at risk.

- The second is the *willingness-to-pay approach* (WTP), which attempts to determine what value individuals themselves put on their lives (Gilette, 1988). A calculation of the human capital value is fairly simple, but an assessment of the value that people put on their own lives is much more complicated. Attempts to relate WTP to human capital value have been made, but "there is no testable relationship between the WTP and the human capital approaches to placing a value on the loss of a human life" (J. Linneroth, 1979).

3.b.1 The Human Capital Approach Versus the WTP Approach

The idea that the monetary value of a person is determined by the discounted value of that person's future output or human capital came into being long before the Pareto principle. It was proposed by Adam Smith in 1776 (Smith, 1776).

Even if the human capital approach has been used extensively, it is a controversial proposition. In the first place because the public "utility" of a person is more properly the difference between the gross national product per capita and the consumption (which has the unacceptable consequence that retired people, children and the unemployed have a zero or negative value), and in the second place because a premature death is not, in itself, a loss to society (in any case not while we are as many as we are. The good contained in a person's life is generally outweighed by the harm done to others by the demands he/she makes on the world's resources (Broome, 1985)). In the third place because - *and not least because* - people value safety on account of their aversion to the prospect of death, and not on account of any concern for their future contribution to the gross national product (Jones-Lee, 1976).

Although the human capital approach is still adhered to in some quarters, it seems inappropriate to base public policy choices on a method with such obvious gaps and biases. Many economists have therefore decided not to base the valuation of a person's life on lost human capital (Miller 1989) and in the search for an alternative method they have chosen to use *the paretian value judgement* which prescribes that the necessary and sufficient condition for an individual's welfare to be greater under option A than under option B is that the individual himself should prefer A to B. This prescription is also known as the condition of the *"citizen's sovereignty"* (Jones-Lee, 1976).

Use of the WTP approach started about 25 years ago and it has now become widely accepted, not only by economists but also to an important extent by public policy analysts (Linneroth, 1982). Miller (1989) reports that it has also been accepted by legal bodies because " it is sufficiently established to have gained general acceptance". This judgement is supported in a report to the "Administrative Conference of the United States" (Gilette and Hopkins, 1988). The authors state: "Economic reasoning suggests that willingness-to-pay is a superior mechanism for valuing human life. A person's willingness to pay to avoid a risk presumably incorporates that individual's valuation of factors that are difficult to measure independently, and thus this approach necessarily considers non-quantifiable variables that cost-benefit analysis is typically accused of ignoring"; and further: "By and large Federal Agencies have not used the human capital approach for some years. What most of them have moved to is the willingness-to-pay approach".

3.b.2 Difficulties with the WTP Approach.

The willingness-to-pay approach (or the "sovereignty of the citizen", the paretian value judgement) was taken up in the literature in the 1960's.

It was soon realised, however, that there was a difficulty. The problem was that most people would value very large probabilities of loss of life at sums approaching infinity. As expressed by Jones-Lee (1989): "If we consider, in particular, large *increases* in probability of death during the current period then it seems clear that, for most people, required compensation will become unbounded well before this probability equals one. If the reader doubts this, then he should ask himself if any sum, however large, would induce him to play russian roulette with three bullets in a six-chamber revolver", or as expressed by Mishan (1982): "If in ordinary circumstances we face a person with the choice of continuing his life in the usual way, or ending it at noon of the morrow, a finite sum large enough to persuade him to choose the latter course of action may not exist". This meant that, if the condition of the potential Pareto improvement - that the gainers should be able to compensate the loser, was to be met, "then a cost-benefit analysis would automatically reject any project which causes anybody's death. ...That however cannot be right...so there is a paradox" (Broome, 1978). It cannot be right, of course, because it would prevent any project from being carried out, irrespective of how many lives would be saved, if only one life was lost.

A theoretical "fix" (to use Broome's terminology) was suggested by Mishan (1969), T. Shelling (1968) and others. Their idea was to consider only marginal changes in risk (low probability of death during the current period). "...Because the number of deaths averted by public expenditures is usually known only statistically, that is, there are no named individuals who would almost certainly die in the absence of the expenditure, the relevant measure need not take into account a person's preference for avoiding death but rather his preference for avoiding some small probability of death. The relevant concept is not life or death, but a (usually small) change in mortality" (Linneroth, 1979). For instance people could be asked what they would be willing to pay for the added safety of having air bags installed in their car. The price given by these people, divided by the probability that the air bags would save their lives, could then be taken as the value of their life. This practice of considering only marginal changes in risk could be called valuing life *"ex ante"* (before the event). Broome (1978) describes it as "a particular device, which has been taken for granted in the flourishing literature ever since".

Broome (1978) however levelled a serious attack on this "device". He wonders "if a definite number of people are going to die, can it then really make such a vast difference whether or not it is known who they are? .... To know a probability is only a certain sort of ignorance. If people know only their probability of dying, then the compensation they demand is chosen out of ignorance...
There are some people who will die as a result of the project. Their interest is to refuse every offer of compensation, but they do not know this". Broome summarises his criticism in this way: "A valuation of a project may be made before it is carried out and before the distribution of its cost and its

benefits is exactly known, on the basis of people's choices about the risks involved. Call this an *"ex ante"* valuation. An *"ex post"* valuation, on the other hand, is one made at the time of the implementation of the project, when the details of all its effects are settled. My claim is that, of the two, the *"ex post"* valuation is the correct one".

Broome's claim was rejected by his colleagues (Jones-Lee, 1979; Williams, 1979; Buchanan, 1979), but Broome did not accept their arguments (Broome 1979). Jones-Lee accused him of not supplying an alternative solution to the infinity problem. Broome replied that he was under no obligation to supply one.

The question of *"ex ante"* versus *"ex post"* valuation was addressed earlier by Hicks (1939) - although in a somewhat different context. Nevertheless it is worth noting the following: "...the optimum conditions can only be interpreted *ex post; it is only after the event* that we can say whether an optimum organisation has in fact been achieved......Nor is this all; if the optimum conditions are interpreted *ex post*, they can make no allowance for risk, since risk is a phenomenon due to uncertainty of the future".

Let us see our situation in this light: We think we are able to calculate the outcome (*ex post*) with respect to the number of lives saved (although not their identity) by various intervention schemes. So our decision (or recommendation) is not one made under uncertainty in the sense that we do not know the extent of the consequences of our actions with certainty. Therefore we should follow Broome and Hicks: the *ex-post* valuation is the correct one; it is only after the event that we can say whether an optimum organization was achieved.

Even if the purpose of intervention in accidental situations is only to save lives, it cannot be ruled out that somebody will be killed more or less immediately (e.g. as a consequence of traffic accidents during relocation). This still leaves us with the problem of compensating infinite claims if we cannot suggest an alternative to the *"ex ante"* solution that has flourished so extensively up to now. As we shall see later, in 3.b.5.2, it is, however, not quite true that Broome had no alternative solution to suggest.

3.b.3 Methods of Assessing WTP

Two essentially different methods of estimating WTP have been employed:

- the so-called *"revealed preference"* also called *"implicit value"* approach, and
- the *"contingent valuation"* also called the *"questionnaire"* approach.

The *revealed preference* approach derives indirect values for people's willingness to pay for risk reduction from their behaviour in situations where they actually trade off money against health risks. Economists have based their estimates on the following factors: the extra wages employers pay to induce people to take risky jobs; the price people are willing to pay for goods that are safety related; the trade-offs people make among time, money, inconvenience and safety.

The advantage of the revealed preference approach is that it is based on actual choices (a real market). On the other hand market prices depend on many factors other than safety, e.g. scarcity or surplus of skilled workers, features other than safety enhancement of safety-related consumer goods, or perceived risk versus real risk. It will usually be necessary to make controls for these factors.

In the *contingent valuation* approach a carefully created hypothetical market is used to ask people directly and explicitly (in contrast to the revealed preference approach), by means of interviews or questionnaires, how much they are willing to pay for a given change in their safety.

The advantage of the contingent valuation approach is that it avoids some of the difficulties that plague the revealed preference approach. Thus the investigator can go directly to money-risk trade-off without the necessity to make controls for other variables as exemplified above, or as Blomquist (1982) expressed it: "One way to avoid the problems with the differences between perceived and measured changes in risk and, in general, avoid problems with data on observable behaviour is to collect information which deals directly with values of life".

Furthermore the contingent evaluation approach yields the individual valuation of safety, which makes it much easier to visualize how the valuation varies with income, age and other factors. Finally - as Åkerman et al. (1991) point out - it can be used for different magnitudes of risk. This last feature is of crucial importance for our recommendation that the value of life should be determined through contingent valuations based on *nonmarginal life gains.*

The disadvantage of the contingent evaluation approach is that it is necessary but may be difficult to prepare the questions, and condition the respondents, in such a way that they are likely to act as they say they would, if the choices were no longer hypothetical but real.

It has often been proposed that a term expressing the valuation that people place on the lives of others should be added to the individual willingness to pay. Bergstrom (1982) argues, however, that such a procedure is inappropriate: "What has been overlooked in these discussions, is that typically if one were benevolently disposed towards others, he would be interested not only in their survival probabilities, but also in their consumption". Bergstrom demonstrated that for pure altruism - in which concern for others respects their preferences - the value of a statistical life should be set at the same level as is appropriate under conditions of pure self-interest. Jones-Lee (1992) has shown that for pure paternalism too - in which concern for others ignores their preferences - the value of a statistical life should be set at the same level as is appropriate under conditions of pure self-interest. If altruism is not pure but safety-focused, the value of a statistical life will increase with the degree of safety-focusing. Jones-Lee estimates: "that for a "caring" society the value of a statistical life will be some 10-40 per cent larger than the value that would be appropriate for a society of purely self-interested individuals".

In this connection it may be of interest to note that Åkerman et al (1991) observed that the variables "children and neighbour influence" [on the decision to mitigate] were insignificant whenever included. Despite survey responses that often indicate concern about children's exposure, the child variable is surprisingly often insignificant in WTP studies".

Bengt Mattson (1990) made a survey of the results of some WTP-studies. From a list of nine based on the *interview method,* Mattson selects three, because they are supposed to represent "state-of-the-art" methods to value change in the risk of fatality" (Fisher et al., 1989). The average of these three studies is a WTP of 23.5 MSEK (1990 SEK). Another study on this list (Acton, 1979) was omitted although it was considered to be one of the best and most reliable (Jones-Lee, 1989). This is a pity because it is that of principal interest to us. It concerns the willingness to pay for ambulances specially equipped for use in cases of heart attack. Heart attack is the most common cause of death, and the gain that can be obtained by the use of such ambulances is substantial. Therefore it is perhaps not too surprising - in view of the principle of diminishing sensitivity mentioned in the subsection below -

that the value of a statistical life derived from this study is only 0.7 million SEK (1990 SEK).

From a list containing 20 *wage-risk* studies Mattson selected in a similar way 15 studies that yielded an average value of a statistical life of 38.8 million SEK (1990 SEK). The same list also contained 8 studies based on preferences concerning safety-related goods. These studies yielded an average value of 5.0 million SEK (1990 SEK) per statistical life.

A critique (Fisher et al., 1989) of 21 empirical studies suggests a value per statistical life of \$1.6 million - \$8.5 million (1986 US dollars).

Several valuations of α (the cost of a manSv) have been given over the years ranging from a value recommended by the International Atomic Energy Agency, IAEA, in 1985 for transboundary radiation exposure of \$ 3,000 Sv^{-1} at 1983 prices (about \$ 6,000 Sv^{-1} at 1993 prices) to several millions of dollars per Sievert used by the nuclear industry in Sweden and in the US. The Nordic radiation protection authorities have advocated up to \$ 100,000 Sv^{-1}, and the ICRP, in their recent publication on intervention levels, used this value for highly developed countries.

However, there will always be other competing health demands in a society, and the allocation of resources to protect health after a large accident ought not to be significantly different from that to protect against other hazards. Otherwise, a significant fraction of a country's economy could be concentrated on preventing relatively few health effects, out of all proportion to how the resources could have been *better spent* on general health care. This was clearly demonstrated in the former USSR after the Chernobyl accident. *In extreme cases it could have disastrous effects on a country's economy, and even place severe economic burdens on future generations.*

3.b.4 Psychology of Preferences

To explain the problem of choices, Kahneman and Tversky (1982) and Tversky and Kahneman (1991) introduced a function that associates a subjective value with any objective quantity that may be gained or lost. They call this a *value function*. Figure 1 shows a typical value function.

The following is an extract from these two papers:

'A value function has three essential characteristics.

- *Reference dependence*: the carriers of value are gains and losses defined relative to a reference point.
- *Loss aversion*: the function is steeper in the negative region than in the positive domain; losses loom larger than corresponding gains.
- *Diminishing sensitivity: the marginal value of both gains and losses decreases with their size.* These properties give rise to an asymmetric S-shaped value function, concave above the reference point and convex below it.

The value function for gains (in the first quadrant) is thus concave downward so that an extra unit gained adds less to the total subjective gain than the preceding one. It becomes progressively flatter as the gain increases.

Such a value function implies a *risk averse attitude*, i.e. a certain outcome is preferred to a gamble with an equal or greater *mathematical expectation*.

The value function for losses (in the third quadrant) is convex downward (the objective loss and its subjective value are both negative) so that an extra unit lost adds less to the total subjective loss than the preceding one.

Such a value function implies a *risk seeking attitude*, i.e. a certain outcome is rejected in favour of a gamble with an equal or lower *mathematical expectation*. This is contrary to the hypothesis widely accepted by economists that people generally make risk-averse choices and will choose a risky venture only when the expectation of the venture is sufficiently high to compensate for the risk.

If the value function for losses is delineated numerically it resembles the value function for gains although they are not identical. The difference is due to loss aversion. Loss aversion means that you request a higher price for a commodity when it is in your possession than you are willing to pay for it if it is offered to you at the market.

It can be shown mathematically that the value function for gains is a power function with an exponent of approximately 2/3.

For losses the corresponding power function has an exponent of approximately 3/4.

The power function model breaks down however when the gains or losses increase out of proportion to the individual's normal economic capacity. For extremely large gains the value function becomes almost flat as the individual becomes indifferent to the choice between enormous gains. For losses the value function becomes very steep (changes from risk searching to pronounced risk averseness) when possible losses become so large that they would ruin the individual. (The value function becomes a vertical line in the case of possible immediate death).

Individuals naturally differ in their attitudes towards risks and towards money and the value functions presented here are only a summary of the attitudes of the majority of people, not a scientific law'.

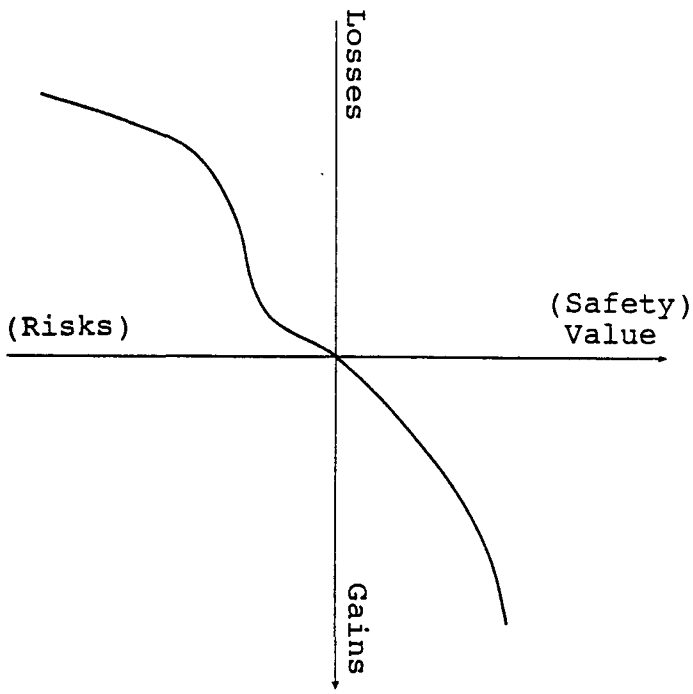

Figure 1.

Ultimately radiation protection measures affecting the general population have to be paid for by this population. The optimum solution is thus dependant on the population's willingness to pay for protection or, expressed in another way, dependant on the value functions corresponding to the preferences of that population.

People's willingness to pay may also be influenced by another psychological factor besides the value functions, namely *decision weights*, which seem to deviate from probabilities, especially for small probabilities. Figure 2 taken from Kahneman and Tversky (1982) shows an example. (The phenomenon of probability weights has nothing to do with perceived risk).

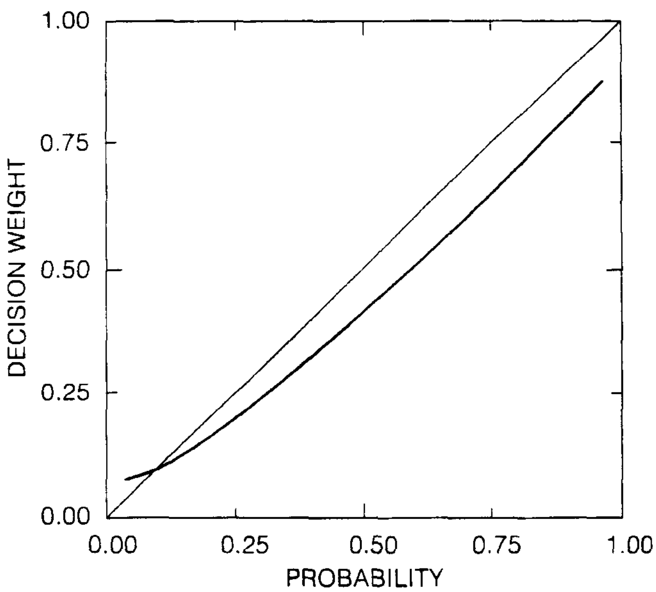

Figure 2.

It appears that the results of calculations of the value of life based upon people's willingness to pay for marginal gains or losses (that is at small distances from the reference point) will depend heavily on the probability of a given health effect - diminishing with increasing magnitude of gains and also of losses, until the point of inflexion of the value function for losses where it begins to display strongly increasing risk averseness.

3.b.5.1 Contingent Valuation Using Non-Marginal Gains

All the investigations of people's willingness to pay have almost invariably (as seen in subsection 3.b.4) been based on their willingness to pay "ex ante" for marginal gains or losses (small probabilities of given health effects).

In view of the above description of psychological preferences, it is therefore doubtful if these investigations give a valid expression for the value of life. Moore and Viscusi (1989) expressed the same concern when they wrote: "The valuation level [an implicit value of one's future life of about $6.0 million] greatly exceeds worker's annual earnings, which is not necessarily inconsistent since it represents the rate of risk-dollar trade-off **for very small risks**, not the amount that workers would pay for **certain life extension**" (present author's emphasis).

A search in the literature for cases where people were faced with questions about their willingness to pay for avoidance of a significant health effect certain to happen (significant loss or gain) has been in vain. Apart from their own experimental demonstrations and the study mentioned above (Acton 1973), hints about the correctness of the main consequence of Kahneman and Tversky's suggestion, that measurements of WTP for very small gains overestimate the value of life, were found however in the following two cases.

Blomquist (1982) noted that for contingent valuations the values of life tend to increase as the risk reductions decline. Mulligan (1977) found that risk reductions of 10^{-5}, 10^{-4} and 10^{-3} corresponded to life values of 3,576; 428 and 62 thousands of US $ respectively (all values are converted to June 1980 US$). This very marked decrease in the value of life with increasing risk reductions may be due to other factors than the two mentioned above; but under all circumstances it demonstrates that *it is a very problematic undertaking to base estimations of the value of life on the subjective value of very small gains.*

Åkerman, Johnson and Bergman (1991) investigated the willingness of homeowners in Sollentuna, Sweden to pay for mitigation of high radon levels in their houses. The sample consisted of 317 houses having levels greater than 400 Bq/m^3. 150 houses had had radon levels reduced. The mean reduction resulting from mitigation was 924 Bq/m^3 and the average reduction achieved was 416 Bq/m^3. The result of the investigation implied that present values of a statistical life range between $23,000 for a 60-year-old at a 9% discount rate (problematic gain in lifetime) to $776,000 for a 20-year-old at a 3% discount rate (a gain of about 35-40 years of life). These are very low values in view of the fact that most estimates of WTP range between $2 million and $7 million per statistical life saved (Fisher, Chestnut and Violette, 1988).

Åkerman, Johnson and Bergman presume that the small sums of money are due to a misperception of the risk by the homeowners, but, on the other hand, they also state that the homeowners probably understand the seriousness of the risk.

A reduction of 416 Bq/m^3 is by no means a marginal gain (it corresponds to an average gain in length of life of about 1 year) and thus corresponds to a point on the value function at quite a distance from the reference point. It is compatible with the experience gained from the pilot study described in subsection 3.b.7.

Our conclusion is that *the valuation of life should be based on contingent valuations, where the gain to be valued is put at a minimum of 1 year, or perhaps better 10 years because the length of life gained on average from the avoidance of death from cancer is of that order of magnitude*. An approach even closer to reality is to ask people to evaluate directly the avoidance of a premature death (corresponding to the gain of the normally expected duration of life from 20-25 years and onwards, after exposure). Dealing directly with the valuation of life also has the advantage of avoiding problems with the differences between perceived and measured risk.

3.b.5.2 The Infinite Value Problem of Lives Lost

The recommendation in the preceding section to abandon marginal gains as the basis for estimating the value of life and instead base estimates on direct valuations of the difference between either dying prematurely, after a substantial latent period after exposure, or continuing to live a normal life after this period, creates no difficulties with respect to the intended purpose of intervention. Nevertheless lives could be lost during an intervention, e.g., as a result of traffic accidents. Therefore it is necessary to propose an alternative solution to the infinite value problem of lives lost in place of the "device" of considering only marginal losses.

The root of the problem is, of course, the asymmetry of the value function for gains and losses and the circumstance that while WTP is clearly restricted by ability to pay for gains there is no such restriction on demands for compensation for losses (Morgan, 1982). As Linneroth (1982) points out: "So far a person's loss from a programme decreasing his prospect for survival has been valued by the compensation which, coming after the change, would restore him to his initial wellbeing - called the *compensation variation [CV]*..". Broome has suggested that one might rely, instead, on the *equivalent variation [EV]*, or that amount of money which the person would be willing to pay to avoid the risk...". Broome (1978) himself put it this way: "For a person whom the project proposes to kill EV is the amount of money which, taken away from him, will leave him with just the same welfare as if he was dead. The idea is conconceptually staggering, but some people might claim to make sense of it, and they might suppose EV to be finite".

Broome's solution (in Linneroth's interpretation above) seems to be equivalent to asking those who are faced with a loss, what they would be willing to pay for a gain that would eliminate that loss.

This means that we have to put a restriction on the "sovereignty of the citizen" limiting the amount he/she is allowed to demand for a loss to what he/she would be willing to pay for an equivalent gain. This prevents claims being made that could inhibit improvements in "collective" welfare. In Broome's words, such an inhibition "could not be right".

To put it another way, we have now committed ourselves to leave two "forbidden areas" of the value function, fig 1: The "infinite value problem" area towards -∞ in the third quadrant and the "marginal range" area around the reference point.

After this ethical reassurance we can proceed with minds at ease, calling a spade a spade, and describe a pilot study based on non-marginal gains (in the first quadrant).

3.b.6 Pilot Study

The pilot study was carried out in Denmark on behalf of the BER-3 Project by Vilstrup Research AS (Vilstrup 1993). A total of 141 interviews was made in national samples, 40 face-to-face and 101 by telephone.

What was new in this approach was a special effort to have the central WTP question answered in a realistic context. The stage was set with initial routine background questions on income, age and family obligations, followed by questions regarding the respondents' perception of the risks of daily life and their impression of society's general efforts to protect them against such risks.

Respondents were then asked to imagine that by paying an amount of money they could have their lives extended by an extra year, enjoying the same health and the same working capacity as experienced in the preceding year, the same income, living expenses and taxes.

When asked what they would and could pay for this - given a reasonable payment arrangement - 26 % quoted a certain amount, 42 % would pay nothing, and 32 % placed themselves in the don't know group or gave evasive answers.

When prompted with a scale of intervals to choose from, the task was easier for many respondents.

In the face-to-face interviews respondents were given a nine-step scale on a display card with a zero option and intervals at DKK 50,000, 100,000, 150,000, 200,000, 300,000, 400,000 and 500,000.

25 % said explicitly that they would or could pay nothing, 42 % selected an interval, and 33 % did not know what to answer.

In the telephone interviews another approach was used for the scale of payment, a kind of decision tree. Respondents were asked whether they would be willing to pay more or less than x DKK, more or less than y DKK etc., until they placed themselves within one of the above-mentioned intervals. Two different starting points were used for the initial choice, DKK 200,000 and 400,000, but with no visible difference in results.

With the telephone approach 33% ended up by saying they would or could pay nothing, 52% placed themselves in an interval, and only 15% were in the "don't know" group.

In both approaches the result was a skew distribution with a peak below DKK 50,000 and a tail ending at the 400-500,000 DKK level.

The pilot interviews indicate that the scale-prompted approach works smoothly, especially in the telephone version, resulting in few "don't know" answers. When used for a full-scale survey the scale should be given a finer calibration in the area below DKK 100,000 in order to justify the calculation of averages and standard deviations.

The rough averages that appear from the pilot interviews are about DKK 40,000 in the face-to-face version and DKK 44,000 in the telephone version.

It may be argued that zero-answers should be ignored in a calculation for this purpose. In which case the averages are about DKK 62,500 and 71,000 respectively.

This corresponds to a rounded alpha value of US$ 10,000 per manSv.

The next step is a qualitative study to describe the nature of people's perception of risk and the reactions to the rather abstract nature of the central WTP issue. It remains to be seen whether the concept-building introductory phase of the questionnaire used in the pilot interviews actually improves the quality of the answers to the WTP question as intended.

When this has been done and the questionnaire adjusted accordingly, the full-scale quantitative survey can be made in a nationally representative sample of, e.g., 1,000 interviews, resulting in a sharper WTP picture and an analysis of possible differences in reaction based on sex, age, social and educational background, risk perception, etc.

In the end this is expected to result in the best possible alpha estimate, presented with proper documentation on the nature of the distribution behind the average and the validity of the approach.

The procedure is self-adjusting with regard to differences in the quality of the year gained, resulting in the best possible average and a quality-adjusted α. However, quality differences will be among the circumstances that explain the distribution of the amounts of money.

These two steps are planned to take place in Denmark, but for time and budget reasons they have not yet been effected.

When the Danish project is complete the next move may be to repeat at least the quantitative study in the other Nordic countries to establish the WTP levels here.

Full WTP measurements are highly desirable in all the Nordic countries because there is no a priori indication that it is justifiable to generalize from Danish figures.

3. c. Investments to Prevent Harm in Areas other than Nuclear Emergency Planning

This section describes examples of Nordic experience of investment in areas other than nuclear emergency planning. For example, investment to prevent harm in general radiation protection and in operational safety in other areas of society such as traffic safety and cancer prevention.

It sounds logical and rational that resources to save life and avoid suffering should be distributed so as to *do the most good.* We would also expect the same principle to be applied throughout society, irrespective of what causes the harm. This is not the case however .

In Swedish legislation on radiation protection and nuclear safety it is emphasized that *available resources should be considered* and the Swedish environment protection law also points out that *costs should be taken into consideration* (Bengtsson 1992). Nevertheless, risks of cancer from air pollution in the large cities are high compared to the risks from artificial radioactive sources. The explanation is lack of money (Bengtsson 1992). This shortage of funds for reducing air pollution is, of course, due to the low priority this problem is given in society.

The Swedish National Audit Bureau is active in this field and their principles were adopted by the Swedish Radiation Protection Institute (Bengtsson and Moberg 1993), who stated that major decisions on radiation protection should be based on a national economic analysis. In these analyses there is no pricing of injuries, but the institute presents some rules-of-thumb for judging reasonable costs. These range from "highly urgent", when the cost for preventing one serious injury is less than 5 MSEK (1 MUS$), to "Do not demand this protective measure unless there are special reasons", when the cost is more than 25 MSEK (5 MUS$) (Bengtsson and Moberg 1993). These rules are applied in setting priorities *in radiation protection planning.*

Decisions on interventions after a nuclear accident present special problems because these decisions are taken *after* the accident but *before* the irradiation. It is very likely that this situation puts much pressure on the authorities to take action at higher costs than in situations where an accident has yet to happen. The International Atomic Energy Agency stresses in its report on generic intervention levels (International Atomic Energy Agency 1993) that *protecting health after a nuclear accident ought not demand resources which are significantly different from what is applied in protecting against other hazards.*

Another problem is the fact that the magnitude of the effects of ionising radiation are rather uncertain at low levels of irradiation. The situation is quite different in traffic, for example, where it is comparatively easy to estimate how many lives can be saved or how many people saved from injury as a result of a certain investment.

3.c.1 Radiation Protection

As soon as the optimisation principle was introduced in radiation protection, a value had to be assigned to the harm caused by irradiation, the *α-value*. That is the monetary value of collective dose reduction, usually given as a sum of money per mansievert (manSv). This value is based on the estimated years of life lost per manSv and is thus dependent on the estimated risk for serious late effects as well as the value assigned to a year of life.

Based on the ICRP recommendations in Publication 26, the Nordic Radiation Protection Authorities advocated in 1984 that up to 20,000 US$ could be spent on reducing the collective dose by one manSv (Radiation Protection Institutes in Denmark, Finland, Iceland, Norway and Sweden 1984).

The interpretation of ICRP Publication 60 led to a revised statement on this value in June 1991 (Nordic Radiation Protection Authorities 1991), advocating that "..up to 100,000 US$ would be a reasonable value to spend for reducing the collective dose by 1 manSv." It was also indicated that this value should be reviewed in five to ten years time.

In *nuclear power plants* costs for radiation protection measures are often weighed against the saving of dose. The NKA Project RAS 410 reviewed the optimisation processes in Sweden and Finland and concluded in 1989 that the α-values for use of lead shields were around 20,000 US$ per manSv, while the α-values for the use of respirators were in the range 25,000 - 125,000 US$ (Vilkamo 1989).

All Swedish nuclear power plants are now using an α-value of 4 MSEK (0.5 MUSD). In 1994 the Vattenfall power company increased their former α-value of 2 MSEK (250,000 USD) , which had been in use since 1992 (Gustafsson 1994). The Oskarshamn nuclear power plant uses an α-value of 4 MSEK (0.5 MUS$) without having taken any formal decision (Löwendahl 1993), and the Barsebäck power plant is expected to decide upon the same value during the winter of 1993-94 (Lindvall 1993).

Applying the risk estimate of 5.6% per manSv for fatal cancer, non-fatal cancer and severe hereditary effects, proposed by the ICRP (1991) for a worker population, to the α-values used in nuclear power plants results in a range of values for death or serious future detriment of 0.36 MUS$ to 9 MUS$

(8 SEK/ 1 US$ October 1993).

One of the eight work areas given greatest attention by the Swedish Radiation Protec-tion Institute is the prevention of lung cancer by reducing *radon levels in homes* (Bengtsson and Moberg 1993). Every case of lung cancer (most lead to death) avoided by reducing the radon in existing houses during 1979-1992 was estimated to cost about 1.3 MSEK (Radon 1993). During the period 1992-2002 measures to reduce the radon in existing houses to 70 Bq/m^3 (radon daughters) are estimated to cost only 0.35 MSEK per avoided lung cancer case. For new one-family houses the costs are lower, about 0.1 MSEK per avoided case of lung cancer, equivalent to an α-value of 600 US$. In Finland this reduction ranges from less than 1,000 US$ per manSv upwards, depending on the level of radon concentration (Castrén 1988).

Diagnostic radiology provides many examples where the costs of saving a collective dose of one manSv are comparatively low. As an example, the introduction of carbon fibre cassettes in Sweden is estimated to save 300 manSv per year after 10 years of spending 2 MSEK per year (Bengtsson and Moberg 1993). Applying a risk for future fatal cancer of 5 % per manSv (ICRP 1991), this means a reduction of 15 fatal cancer cases per year at a cost of about 0.13 MSEK per case. The Swedish Radiation Protection Institute states as a rough estimate for diagnostic radiology in general that the cost per avoided case of cancer is less than 1 MSEK (Bengtsson 1992); (equivalent to an α-value of 6,000 US$).

3.c.2 Traffic Safety

Apart from radiation protection, traffic safety is the main area where the value of risk reduction has been quantified. In 1989 *the Swedish National Road Administration* decided to abandon their former indirect valuation-based procedure in favour of the *WTP approach* for the pricing of a statistical life. The new value, in 1990 prices, was set at 7.4 MSEK (Persson 1992), containing a human value of 6.5 MSEK and material costs of 0.9 MSEK. Recently the value of a statistical life has been increased to 11 MSEK (The Swedish National Road Administration 1993).

In 1989 a *European research project* on the problem of the socio-economic costs of road accidents was launched (EEC Commission 1992) with the objective of assembling information on the methodology for costing road accidents, and to analyse and evaluate the differences in the methods, "...with a view to making recommendations for a common approach to costing, if this is possible." All the Nordic countries, except Iceland, participate in this work. The results of this project are of great interest to the BER-3 project for two main reasons:

- it presents the estimated price of a statistical life from four of the Nordic countries to compare with the values used in radiation protection
- it describes the differences in the calculation methods used in the Nordic countries, which might reflect different attitudes in the different countries and give an indication of problems that could be encountered in the harmonization of counter-measures after a nuclear accident.

The costs in ECU (1990) for a person killed in a road accident in the Nordic countries vary as follows (Willeke and Beyhoff 1990):

Norway	251,619
Denmark	670,776
Sweden	956,110
Finland	1.414,418

This is equivalent to a range of 0.29-1.65 MUS$. (In October 1993 1 ECU = 1.17 US$).

The main elements included in these

estimates are the costs for loss of productive capacity and the human costs. There are great methodological differences between the countries, especially in the valuation of human costs, which explain the differences. In Norway only the loss of productive capacity is included, in Denmark there are no human costs, while Sweden and Finland apply different WTP approaches in evaluating the human costs.

The differences in costs estimated for serious injuries are even greater, Sweden having a figure ten times higher than that in Denmark, again reflecting differences in the costs included. The human costs are in this case considered to be almost 30 times higher in Sweden than in Denmark.

3.c.3 Cancer Prevention

The essential result of radiation protection efforts, in the dose range where no deterministic effects are expected, is a reduction in the number of future cancer cases. This also applies after a nuclear accident. It could therefore be of interest to compare the costs mentioned under 3.c.1 with the costs assigned to cancer prevention in other areas. The costs for cancer prevention in Sweden were compiled by Bergman (1992). This survey shows for example, that the costs of information campaigns to prevent skin cancer caused by UV radiation are estimated to be around 0.02 to 0.04 MUS$ per fatal cancer case (equivalent to an α-value of 1,000 - 2,000 US$). Bergman also states that it is nevertheless difficult to get a positive response to such actions.

3.c.4 Summary

The different monetary values given above, assigned to a statistical life, a case of cancer, a person killed, etc, are the results of complicated, more or less structured decision processes. Arranging the values from the lowest to the highest gives the following approximative order:

- UV radiation
- radon
- diagnostic radiology
- road traffic
- nuclear power.

To a certain extent this order reflects the priorities set by society and, bearing in mind the common perceptions of risk, it can be partly explained:

- the sun is the most "natural" phenomenon we can think of,
- our home is - rightly or wrongly - considered to be the safest place,
- diagnostic radiology is of great benefit to people who might have an illness,
- road traffic is of great benefit but accidents are quite common, whereas
- nuclear power is a focus for people's fears.

It should also be noted that the monetary value for dose reduction advocated by the Nordic Radiation Protection Authorities corresponds to a value in the range of those used in road traffic and those used in nuclear power plants.

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4. PSYCHOLOGICAL FACTORS AND INTERVENTION MEASURES

In efforts to harmonize the response of the authorities to large-scale accidents in the Nordic area, the following is a discussion of some features of human behaviour in disaster situations.

There are important cross-cultural differences in human behaviour but also some universal, common human characteristics. Some of the latter can be seen in disaster behaviour and they should be considered when making decisions on emergency planning.

4.1 Reactions to Warnings in Disaster Situations

There are several myths concerning human behaviour during disasters, that have not been confirmed by observation and studies made after numerous disasters. One of the most common myths is the *belief that people will flee (and often in panic) the very moment that they hear of a threat.*

This is not the case. (Dynes & Quarantelli, 1972; Trost & al. 1977.) It is more likely that *people will stay where they are in a potentially threatening situation rather than leave immediately, even when advised to do so.* If people do flee, they make the decision to move in a controlled manner even when frightened. People prefer leaving in family units and often offer assistance to others during their flight. (Dynes & al. 1972.)

Panic requires a certain set of circumstances. These include perceptions of a direct danger to life that can only be avoided by immediate flight. At the same time there is uncertainty about the possibility of escape, e.g. blocking of escape routes. There is the threat of entrapment, which means death. This arouses a fear so strong that the individual can no longer control his/her fear, nor his/her flight impulse.
(Quarantelli, 1954.)

This combination of circumstances is improbable in a nuclear power plant accident and *usually people can control their fear better than is believed.* However, panic is possible because the subjective interpretation of the situation may differ from the objective circumstances. *Mass panic has never been observed in a disaster,* and a few panicky individuals cause no harm to others nor, in most cases, to themselves. (Quarantelli, 1982.)

Usually people dismiss remote threats and become accustomed to everyday ones. A feeling of invulnerability is a psychic defence mechanism against fear. This helps people to exist in a risky world with the feeling that they live in a safe place.

When faced by a threat they have to change their beliefs and start to interpret the situation in a different way. Usually this takes some time depending, for example, on the environmental cues which are (or are not) observed in the immediate surroundings. If the warning or environmental cue is threatening enough to arouse fear and to make people suspect that their usual interpretation of the environment as secure might be wrong, they will in most cases wish to confirm the warning, or have more information about the situation and the danger before taking any action. Therefore the warning phase of a disaster is an interaction process. On an individual level it is also a decision-making process, the end product of which depends heavily on the information that the individual is given on the danger and the different options he/she has. (Perry, 1985; Janis & Mann, 1977.)

When considering the threat of radiation from a nuclear power plant accident, it is evident that the situation differs in many ways from other accidents and threats. (Perry, 1985.) Two processes, quite independent of each other are taking place at the same time.

- Firstly there is the accident and the real threat of the radiation it causes. This is however only to be discovered by means of special equipment and knowledge and by specialists.
- Then there is the social and psychological reality which is totally created by information: warnings, and news from the mass media and authorities. People have no possibility of comparing information with their own experience and perception of the accident. ***This total dependency on information*** **is one aspect of the nuclear accident situation which makes it more disturbing and also more threatening to people than other dangers.** (Tessarin, 1986.)

4.2 Information in a Nuclear Accident Situation

The dependency on information means that both authorities and the mass media are in a critical position. The most important factor is information management. In a situation of impending danger people do not need as *much* information as possible.

What people need is *clear, comprehensible and unambiguous information.* (Tessarin, 1986.)

The **authorities** have the task of evaluating and rejecting unnecessary information and making connections so that they can produce and issue a clear picture of the situation.

If the authorities are seen to be trustworthy, people will believe the information they are given. So it is *very important for the authorities to act in a trustworthy manner. People lose their belief and trust in authorities if they feel that information is being withheld.*

The same occurs if reports by the media describe the authorities as uncaring and unreliable. (Janis, 1962; McLuckie, 1970.) In a threatening situation people have no choice, they have to rely on the authorities. The **mass media** play a critical role in transmitting the facts, and also in creating a picture of the situation.

It is important to get the mass media to acknowledge their role in creating the psychological reality to which people react. It is vital to establish good communication between the authorities and the mass media before an accident, in order to be in a position to give the population the information they need to be able to interpret the situation correctly and cope with the danger. The mass media should not concentrate solely on making critical observations from an outsider's perspective; they too are deeply involved in the situation, even though they may not realize this themselves.

The time for criticism is afterwards, not during the danger.

Because the mass media will always report even very minor incidents, it is wise for the authorities to release such information as soon as possible and issue any further information when this becomes available. However, the danger of false alarms must always be remembered.
That is why there has to be *a clear-cut difference in the presentation of a warning and the presentation of information on a minor mishap.*

False alarms decrease people's trust in the authorities and their belief in danger, but far worse is the failure to inform of impending danger. (Breznitz, 1984.)

4.3 What are the Psychological Consequences of a Disaster?

The majority of a population in a disaster area may show varying degrees of reaction to stress in the aftermath of a major disaster. Stress depends crucially upon the way in which the stressor is perceived by the individual, and upon his/her assessment of the personal and external resources for coping with it. Common symptoms are depression, restlessness, fatigue, nervousness, irritability, loss of appetite, sleep disturbances and psychosomatic symptoms such as stomach upsets, diarrhea, headaches, etc. (Adams & Adams, 1984.)

However, such stress symptoms do not basically affect the willingness and ability of people to take initiatives and to respond well in the recovery period. Although active participation in constructive action is common, there is always the problem of co-ordinating the activity of a large number of people. Even when voluntary work may be useful and necessary to society, it may be un-coordinated and at times ineffective. (Dynes & Quarantelli, 1980.)

Post-traumatic stress disorder has been acknowledged as a potential health outcome of disasters. The development of this disorder is common after horrific disasters with resultant deaths and casualties. However, not all those who are exposed to trauma develop this syndrome. At worst the syndrome can be very incapacitating and permanent. Research is being carried out on traumatic stress and its treatment. (Raphael, 1986.)

On a family or societal level stress may cause marital or family discord, divorce, and increased consumption of or dependence on alcohol and drug abuse. Stress can also be seen as increased susceptibility to illness, aggression, violence, domestic violence and general adjustment problems and helplessness. Regressive behaviour and adjustment problems are typical reactions in children, especially if parents and teachers have neither the knowledge nor the ability to handle them in an understanding and supportive way. (Drabek, 1986.)

Some characteristics of a disaster may increase the stress experienced by an individual. These include, e.g., suddenness of onset, prolonged duration and uncertainty. These are typical features of a nuclear disaster. If a disaster is unexpected there is no time to initiate psychological and physical defence mechanisms and the stress reactions will be stronger. People do not expect failures in man-made constructions and therefore the victims may feel that those responsible for the disaster are careless and do not value human life. This makes recovery after an accident more difficult. (Baum & Davidson, 1985; Lifton & Olson, 1976.)

Stress reactions after a disaster can be divided into agent-generated and response--generated. The latter being the reactions caused by society's response to the disaster.

The disaster agent itself causes great difficulties to society, but if society's response is well co-ordinated and adequate, it can alleviate the stress and difficulties caused by the agent. However, if society responds in a way which, e.g., neglects the social and psychological needs of the population, it can create problems which worsen the emotional stress experienced by people. (Perry & Lindell, 1978; Quarantelli, 1985.)

4.4 Effects on the Community

Contrary to what is often expected, the morale of a community affected by disaster is more likely to be buoyed up by optimism than shattered by despair. Good morale seems to be rooted in various psychological and social factors, such as altruism and the support of friends. The needs of the community become more important to people than their own personal concerns.

This spirit of altruism also offers far greater emotional support to disaster victims than is offered to accident victims in normal circumstances. This cohesion helps to alleviate the stress and suffering caused by the disaster. However, while morale is usually good in the immediate aftermath of a disaster, it can deteriorate over time, especially if relief efforts are not well handled. (Barton, 1969; Dynes, 1970.)

It has to be noted that the main concern of the general public may be for the loss of their personal possessions. They may, e.g., refuse to be evacuated in order to protect their property, or try to return to a contaminated area before it is safe. This makes it necessary also to isolate and guard the evacuated area and to assure people that their property will be protected during their absence.

Studies have shown that, contrary to general belief, crime rates during disasters are more likely to decrease rather than to increase. The risk of people looting and taking undue advantage of others in disaster situations is likely to be similar to the likelihood of such activities prior to the disaster. However, in the long run profiteering may occur. (Quarantelli & Dynes, 1970.)

The intensity of the emotional reaction to an accident will vary according to whether or not the individual is surrounded by family members or by some other psychologically supportive group. Another general point is that parents are more worried about the wellbeing of family members than about their own. For these reasons it is important to keep family members, neighbours and friends together. They form a social network facilitating recovery after an accident, in particular in the case of evacuation or relocation.

A difference has been shown in the psychological well-being and different physical symptoms between those who are evacuated and those not evacuated, the situation being worse for those permanently relocated and with loss of their social network. (Drabek, 1986; Baum & al.,1983; Harshbarger, 1976.)

The development of an altruistic community is most probable in natural disasters where it is easy to understand what has caused the disaster and what are its consequences. For some chemical disasters the situation is much more serious. When the disaster agent is such that it is difficult to see clearly whether a disaster has occured, and whether there are any health consequences and if these are truly threatening, then opinions are not united. This diversity of opinion can be seen both among specialists and among the general public. Antagonistic groups develop in the community. Members of all groups may feel that they are the victims of the situation and suffer from stress. The psychological consequence of this kind of ambiguous and uncertain threat can be highly stressful, and because of the non-altruistic atmosphere there may be a shortage of social and emotional support. However, it seems to be difficult to totally prevent the development of this kind of situation. (Cuthbertson & Nigg, 1987.) Because stress responses are shaped by belief, the content of the belief should be as realistic as possible.

The best way to promote this attitude is to try to disseminate information that is as clear and unambiguous as possible.

After a nuclear accident *communication problems* will be accentuated as the public is more concerned about the consequences of radiation (eg. cancer, genetic effects) than is justified by the realistic likelihood of such consequences. The uncertainty and ambiguity of radiation affecting personal and family well-being are certain to produce distrust and stress. Even when factual knowledge of a hazard is well established, public perceptions have been shown to diverge widely from objective assessments.

Man-made radiation has been consistently shown to be among the most dreaded of contemporary hazards. (IAEA, 1991.)

Again, *the provision of unambiguous information is absolutely essential.*

Experience clearly demonstrates that people do not typically become incapacitated as a result of stressful or traumatic situations, although it depends largely on the difficulty of the situation. In mildly stressful situations most people function well, but extremely traumatic situations can tax the functioning and resources of almost anyone. In extreme conditions, e.g., those of Hiroshima and Nagasaki, only a minority of people helped others and most people received no help when they requested it. (Wolfenstein, 1957.)

If the coping strategies used by an individual are effective and suitable for the situation one can manage stress and function well.

If the individual has no effective and suitable coping strategies, stress reactions and symptoms can get worse, and in the long run develop into illness.

If stress is chronic, methods of coping may become very important. A study on the Three Mile Island accident has shown that a method based on the management of the emotions was most effective. (Collins & al. 1983.) The effectiveness of different coping strategies varies in different situations. With social support and counselling it is possible to help people whose own coping strategies are insufficient and ineffective.

4.5 What Strategies are Adopted for Coping?

Attempts are made to find intrapsychically satisfactory answers to the following questions in order to cope with an accident (Figley, 1985):

- What happened?
- Why did it happen?
- Why did I react as I did?
- Why have I ever since reacted as I have?
- What if it happens again?

Coping strategies include:

- Direct action to change or avoid the stressor/stressful situation.
- Voluntary work and assistance to others can also serve as a means to alleviate one's own distressing feelings.
- Information-seeking helps to find answers to the above and other questions.
- Palliative activity (alcohol, tobacco, drugs) is also a way to cope with problems, although often counterproductive.

4.6 Stress Reactions Can Be Measured

Stress effects can be quantified using three types of analysis, namely behavioural tests, behavioural measures and biochemical assays.

The *first method* uses behavioural tests such as those dealing with concentration, motivation, etc.

The *second method* makes use of either self-written reports or community records, the latter being more objective and less open to criticism. Community records after an accident can be compared with the pre-accident records for the increase in the use of "crisis phone lines", scheduled appointments at mental health centres, visits to hospital casualty departments, district court cases, police records of domestic violence, total number of police reports, the number of people frequenting the community alcohol centre etc.

The *third method* makes use of biochemical assays of, e.g., catecholamine levels in urine to measure the activity of the chronic sympathetic nervous system.

4.7 Protective Actions that Reduce or Increase Stress

Many protective actions are perceived by the public as mesaures to care for them and thus they reduce stress. Such could be:

- *timely warning,* allowing family members to contact one another
- *clear, precise and unambiguous information* on the situation
- *proper control of food and water*

Sheltering is somewhat problematic in relation to stress, in particular if family members are not together, as when at work and during school hours. If family members are not brought together, sheltering can be a stressing experience. It certainly can increase stress if it lasts longer than a few days. Families will probably try to gather their members, even if time is short before sheltering.

The stress-reducing factor in sheltering is that people can be active and do something themselves to reducing or averting radiation doses.

Evacuation is less painful if it is carried out voluntarily, in a disciplined fashion and in family units, than if it is centrally organized such that people lose their social networks. It might be very difficult to make people obey orders contrary to their own wishes and psychological needs. Experience has shown that people will evacuate themselves in their own cars, in family units, and that they prefer staying with friends and relatives. Public shelters are used as the last resort. (Drabek & Stephenson, 1971; Hultåker, 1977.)

Research has shown that **relocation** is a highly stressful experience in itself, particularly for the elderly, infirmed and "long settled", because relationships and social networks are destroyed. (Lee, 1990.)

The ever present threat of personal change is particularly difficult for those who are not used to making decisions about where the family should reside, or what type of work they should do. This applies in particular to communities where agriculture is the primary occupation and its seasonal and daily routines set the pattern for family and community life.

If agriculture is suddenly forbidden these patterns lose their meaning. In agricultural communities exaggerated control of food would thus become a stressor in itself.

Authorities are in a central position when implementing protective actions. If they are trusted by the general public they reduce stress, but if mistrusted all protective measures may arouse doubt and uncertainty about the danger. This probably increases the stress of the population.

Any additional problems in society only add to the stress of the population. In the IAEA Chernobyl study (IAEA, 1991) it became evident that the impact of the accident and the political disturbances were synergistic.

The situation was even used politically for purposes other than the protection of the people. Similar phenomena are not unknown in other countries.

4.8 The Influence of Psychological Factors on the Numerical Values for Intervention Levels

It is obvious that psychological factors must be taken into account in emergency planning and in implementing protective actions. However, it is less evident how they quantitatively influence the numerical values for intervention levels.

As an example of the features that should be considered in planning for warnings, it is important to realize that *people may not react to warnings if they do not perceive themselves to be in danger*. Relationships between people will also affect their response to warnings.

The proper dissemination of correct information is of vital importance.
The method of dissemination is equally important.

A person's *perceived risk* is one of the most important factors influencing his/her own decision to evacuate. As regards the method of spreading information, the delivery by hand of evacuation notices has been shown to be more successful than less personal methods.

It is not easy to quantify measures as to their ability to reduce or add to the stress of a given situatiuon. There are, however, examples of situations in which intervention levels may be interlinked, yet not in proportion to the degree of resultant stress. Stress can be measurably reduced through the planning and decision-making process.

One example is the overly strict control of food in contaminated areas in the USSR after the Chernobyl accident. This induced stress as people could not support themselves in certain contaminated areas and hence were driven to relocate, which in itself is known to be stressful. More realistic intervention levels for food would have relieved the stress of food restrictions and avoided the stress of relocation. (IAEA, 1991.)

4.9 Concluding Proposals

1. For each protective measure one should consider whether it *relieves* or *increases* stress, or is *neutral* in this respect.

Criteria can be developed to evaluate which of the three is the most likely consequence. Such criteria could be, e.g.:

- Can the protective measure be implemented without public involvement?

If the answer is yes, this will neither increase nor relieve stress, it is neutral.
If the answer is no, stress may be relieved or increased.

- Are family members separated?
  Yes = increase of stress likely
- Are friends separated?
  Yes = increase of stress likely
- Is it possible to publicize and explain the decision so that people understand it properly?
  No = increase of stress likely
- Are lifestyle patterns destroyed?
  Yes = increase of stress likely.

2. If the most likely outcome of the protective measure (or the lack of it) needed to reduce the radiation harm is increased stress, some sort of scale is needed for the increase of stress. A similar scale is needed for the measurement of the stress caused by the accident. The psychological response of affected people is likely to vary within any given population. Stress symptoms are likely to be seen in a majority of the population and a significant portion may develop serious psycological problems. In general, people are not incapacitated by moderate stress, nor are they likely to suffer psychological impairment in the long term.

The basic human response to a not too overwhelming traumatic experience seems to be rational action and appropriate coping strategies.

Stress can be *relieved* by emotional and practical support from appropriate mental health services. The stress may be *so pronounced* that the individual's material as well as social and psychological resources are insufficient to cope with the situation. In this case one's ability to maintain a normal social and family life is impaired.

The reduction in this ability could be used as a measure to judge the importance of stress in decision making.

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5. IMPORTANT FACTORS IN RISK PERCEPTION

Risk issues are indeed complex and often controversial, and risk perception research grew from an awareness of the problematic situation created by discrepancies of judgement and opinion hampering planned action as well as creating intense social tension. Although the research area evolved from what was initially a debate on desirable technological and economic development, specifically regarding the utilization of novel and large-scale technology, and in particular the use of nuclear power for the production of electricity, it covers today a broad range of issues including perceptions of risk in relation to environmental pollution, accidents, industrial establishments and the handling and disposal of noxious wastes.

One response to the question of why risk perception research has become so important and influential is therefore the obvious need of achieving generally acceptable solutions to problems and controversies. This task requires knowledge of how risks are perceived and what actions are needed to enhance economic and socially agreeable development. Another reason for risk perception research is to help meet and satisfy public demands for information on risks. The fulfilment of this task must be based on knowledge of what type of information is required and how it is best presented. The latter objective has stimulated a considerable amount of research under the heading of risk communication.

Below follows a brief characterization of risk perception research and a summary of important factors in risk perception, including an example of perceptions of risk related to nuclear power and ionizing radiation resulting from the Chernobyl accident. (See appendix IV for a more thorough discussion of risk perception and risk communication research.)

The literature on risk research covers a variety of area-specific domains. There are, for example, lifestyle risks (e.g. use of tobacco, alcohol, drugs, narcotics, eating and leisure habits), occupational risks (e.g. work injuries and occupational hazards of other kinds), technological risks (e.g. major industrial accidents, computer failures, releases of toxic substances, etc), consumer risks (e.g. faulty products, medicines, poisonous foods), environmental risks (e.g. global warming, pollution, hazardous wastes, etc.), and catastrophe risks (e.g. natural catastrophes, industrial catastrophes, terrorism). As can be seen in this listing, the research domains overlap to some extent. This overlap, which may involve issues of general importance to the understanding of the perception of risk, has stimulated research co-operation over different areas and disciplines under the more common heading of risk research.

One central and common feature in risk research efforts is related to the enhancement of human health and safety. The goals of risk perception research are therefore focused on understanding what factors and what processes are involved in subjective judgements of risk. Table 1 below shows some of the important factors or dimensions usually listed as influencing the perception of risk. The table is not exhaustive and does not explain inherent interrelationships, but it lists the commonly discussed factors influencing risk judgements.

Perception of risk related to radiation provides an interesting example of how risk perception factors come to play different roles resulting from the general context. Radon gas in the home is usually of greater concern to experts and health authorities than to the general public, including many of those who have had their homes tested and

Table 1. Factors commonly used to explain perception of risk

Factor/dimension	Hypothesized condition for increased perceived risk or risk rating:
	Factors related to the type of hazard
Catastrophic potential	able to cause a concentration of fatalities/injuries in time, or in relation to one single event, in contrast to "normal" risks
Voluntariness	involuntary
Controllability	uncontrollable
Familiarity	unfamiliar to the subject
Scientific uncertainty	little known, or unknown, to science
Controversy	uncertain; different judgements of the risk exist
Dread	terrible; the type of consequences is feared
History	recurrent; previous occurrence of accidents
Onset of effects	sudden; lack of prior warning, or large immediate effects
Reversibility	irreversible; consequences cannot be adjusted or cured
	Factors related to the social context
Fairness	based on unfair distribution of risks and benefits
Benefits	uncertain with respect to benefits
Trust	handled, or estimated, by distrusted experts or authorities
Media attention	highly exposed, and emotionally presented, in mass media
Availability of information	information is perceived as lacking or untrustworthy; rumours increase in importance
Involvement of children	affecting children or foetuses
Future generations	affecting future generations in an unfair or irrevocable direction
Victim identity	causing harm to a known or likeable person
	Factors related to the context of risk judgements or ratings
Risk target	ratings of risks to others than oneself
Risk definition	emphasis on consequences in contrast to probabilities
Contextual framing	closely related in time to a negative personal experience, or in a situational setting inducing negative mood
	Factors related to individual characteristics
Gender	women often give higher estimates of risks than men
Education	less highly educated people often give higher estimates
Age	older people often give higher estimates
Income	people with low incomes usually give higher estimates
Psychological sensitivity	people of an anxious nature usually give higher estimates
Personal skill	people with little or no risk-relevant training or ability give higher estimates

found radon levels exceeding the norms, in sharp contrast to reactions to ionizing radiation resulting from nuclear accidents. The home is one's castle; it is familiar, a voluntary choice, has an affection value, provides a safe haven and many benefits, and is usually considered outside the realm of experts' legitimate concern. The best known radiation accident occurred at the Chernobyl nuclear plant in 1986 and had widespread effects on public perception of the risks of nuclear power, as well as on the perception of the long-term effects of radiation on health.

Given the risk factors in Table 1 above, it is easy to understand the very strong public reactions to the Chernobyl accident. The accident had a *catastrophic potential* with respect to populations at risk, including a number of immediate fatalities, and with respect to its international consequences. Furthermore, people were *involuntarily exposed* to radiation and radioactive fall-out, and individuals had little control over the event or its consequences. Nuclear power is also a rather *novel technology* and its functioning is certainly *unfamiliar* to others than the experts. Details of health effects caused by radiation are *unknown* to the general public and the consequences of low level radiation are still debated among scientists. There had been considerable *controversy* regarding the possibility and consequences of major nuclear accidents preceding the event. There is widespread common knowledge of an association between ionizing radiation and future *cancers*, and cancer is generally feared. The Chernobyl accident was worse than the preceding accident at the Three Mile Island nuclear installation, pointing both to historic precedence and a negative development regarding impact and consequences. It occurred *without prior warning*, and the international impact was unexpected. The immediate damage and the potential *long-term health threat* came closer to *irreversible consequences* than to a temporary failure with mostly short-term effects. Furthermore, after eight years, the event has still not reached a "low point", i.e. a point in time when life goes back to normal, in the locally affected areas of the CIS countries.

In addition, there were *no benefits* involved, only immense costs. *Trust was generally eroded* due to delays in giving information on and following the occurrence of the accident. The *media* covered the event extensively and, because of the delay of factual and trusted information, evil *rumours* spread and were transmitted to the public. The health effects and fate of *children* were excessively discussed. Vivid, *emotion-invoking pictures* were shown of supposed victims. None of these factors is involved in the campaigns which try to convince home owners to mitigate the radon risks in their homes. Neither can the intensive media coverage of the victims of skin cancer caused by excessive sun bathing create such fears and reactions as those due to the malfunctioning of a nuclear plant.

The study of individual and public risk reactions reveals the issues that are of concern to the population. If public risk perceptions are poorly calibrated with authoritative risk assessments, there is reason to investigate the matter in greater detail, fill in or correct missing or misinterpreted information, or take action to increase the level of safety and health. Public aversion to unstable nuclear reactors and radioactive contamination has influenced Western societies to improve the safety standards of nuclear installations, and has created an interest to expand such efforts world-wide. Uncertainty and feelings of vulnerability increase in step with the technological and social complexity of our time. It is therefore important to monitor continuously the content of and changes in sentiment and risk perception.

One of the first studies which inspired and influenced risk perception research was Starr's investigation of the question "How safe is safe enough?", a question fundamental to decision makers generally, and one which suggests the subjective quality of potential answers, and hence the difficulties of reaching an answer acceptable to everybody. Starr pointed to two important factors for risk acceptance, namely the magnitude of the consequences and the degree of voluntariness. These factors are still considered to be among the most important when it comes to what is perceived as a hazard or risk, but other factors have been added, and context factors and personal characteristics have been investigated with interesting results.

The perception of risk depends on the *context* in which a hazard is actualized, on the *type* of hazard which is in focus, and the person, or type of person, who makes the judgement. Thus, it is feasible to distinguish between the contexts of normal, everyday risks and catastrophe risks, as well as events with a sudden impact as against those with a slow or delayed development. Table 2 shows a schematic outline of hazards where research areas are classified relative to the dimensions of context and temporal onset of consequences.

Table 2. Examples of research domains with relevance to risk perception research, based on a suggested classification of hazards in contextual and temporal categories

	Onset of consequences	
Context	Sudden	Delayed
Normal risks	work accidents traffic accidents violence	radon smoking eating habits
Catastrophic risks	earthquakes hurricanes releases of toxic chemicals	global warming ozone depletion water scarcity

In the framework of "normality" there is a greater degree, or perceived degree, of voluntariness to take into account than is the case with catastrophic risks. Thus, the individual's actual or perceived ability to avoid, control or influence, adverse events or effects is important. Contextual factors also relate to familiarity with, e.g., certain technologies, and trust in relevant institutions or experts. Sudden versus delayed effects of an adverse event constitute an important factor, but the perception of risk is nonetheless related to the type of hazard in question and the type of possible consequences. For example, immediate death or injury in a traffic accident is certainly feared, but the long-term effects of cancer cause more worry, especially if they are related to man-made ionizing radiation rather than radon or cigarette smoking. Similarly, possible long-term effects of environmental pollutants, and in fact general environmental degradation, cause considerable public concern, but it is often expressed in the form of worry for future generations. The number of people at risk of victimization, or the number of fatalities/injuries caused by one single event are important factors here, as well as whether the victims were aware of the risks or not. It is usually considered morally unacceptable to expose people to a risk of which they are unaware, and this may include future generations who cannot influence current affairs.

The factor of voluntariness, together with optimistic bias, may influence risk ratings so that that risks to oneself are rated lower than risks to others. These ratings are certainly also related to the characteristics of individuals, their life styles and circumstances. Thus, women usually rate risks higher than do men, especially risks to others, as do other "vulnerable groups", such as those with little income, little education, poor health, the elderly, and those who are psychologically sensitive. Non-smokers obviously have no perception of any personal risk from smoking, although they may agree that the risk is considerable for smokers. Similarly, individuals with certain skills, enabling them to master a hazard or a risk situation, rate the risk lower than others. People who have never experienced an earthquake, or do not live in an area where earthquakes have occurred, do not perceive the risk as high. On the other hand, people who have been exposed to violence or who have experienced a hurricane are inclined to rate these risks higher than others.

Research shows that people tend to underestimate frequently occurring adverse events and illnesses (e.g. diabetes), and overestimate infrequent events (e.g. botulism). Adverse events which achieve intense mass media attention become (usually temporarily) salient events to the general public, and are rated high on perceived risk. If children or other vulnerable individuals are involved in an accident, or exposed to a risk, the perception of the severity of the hazard increases. Similar reactions occur if a victim is identified and presented as a person rather than a statistic. If the consequences of a hazard are seen as irreversible, greater risk is perceived. Risk perceptions are also affected by trust in the regulatory authorities who estimate or mitigate risks. Furthermore, if risks are unequally distributed among individuals, or groups of individuals, the perception of risk is affected; it may be rated high due to the unfairness involved, or differently by different groups according to who is perceived as actually exposed, oneself or someone in the group one feels associated with, or others. This factor is related to perceptions of benefits connected with the risk.

Factors influencing risk perception are interrelated and to some extent situation specific, which makes precise statements disputable and predictions uncertain. Perceptions of hazards and risk ratings must therefore be evaluated in relation to the specific objective or event at hand. In addition, the results of investigations of perceived risk are sensitive to the choice of methodology and study design. Thus, the rating perspective or risk target, i.e. evaluations of risk to oneself or to others, influence the level of the judged risk. Furthermore, the wording of questions, and the factual context in which the questions are presented, are of importance to the outcome. For example, a task involving evaluations of "probabilities" for adverse events differs from a task of judging "risks" of adverse events, because there are differences in the way that people "normally use" the term risk. If they focus on consequences they will give higher risk judgements than if they instead emphasize probabilities. Regarding situation-specific influence, the outcome will differ if the subjects are first asked, e.g., to list all the enjoyable leisure activities they can think of and then proceed to risk ratings, as compared to a setting in which they first are exposed to or made to associate with negative events.

The field of risk issues has become an outstanding example of multifaceted interest and successful multidisciplinary co-operation. It covers technical safety and risk assessments, economic analyses, insurance issues, social development planning, including environmental regulations, and research on risk perception and risk communication. The Society for Risk Analysis, which was founded in the United States at the beginning of the 1980's, has become a forum for the exchange of concerns, ideas and research results for interested parties in industry, academia, the regulatory authorities and private consultants. It has today a European branch, an Asian branch and chapters under development in the CIS. The development of a world-wide, multi-disciplinary association investigating risk issues clearly shows the current importance attached to risk issues, and the magnitude of undertakings.

6. OVERVIEW OF THE MONETARY COSTS OF PROTECTIVE ACTIONS IN THE NORDIC COUNTRIES

A number of different methods of predicting the economic costs connected with accidents have been devised in both Europe and the USA. Some have been reviewed in the report NRPB-R243: "COCO-1: Model Assessing the Cost of Offsite Consequences of Accidental Releases of Radioactivity", 1991.

COCO-1 itself considers two different categories of cost, namely of protective actions and of health effects. The first category, costs in connection with protective actions, is the subject of relevance for our purpose, and to a large extent the concepts of COCO-1 are used as a basis for the calculations presented in full in Appendix V.

In particular we have adopted the idea that *the cost of a protective action is the benefit foregone.* For example with respect to accommodation in the case of relocation, the cost is not that of the emergency accommodation but the benefit foregone, i.e. the cost of the housing abandoned.

We are aware that the approach is somewhat inflexible and has a number of limitations, but these do not invalidate the use of results for comparing the national costs of PAs. If the aim is to study the costs of PAs on particular, defined, limited geographical areas, site-specific information is necessary. Thus for the purpose of national emergency planning, we recommend case studies in greater detail.

The following is an overview of the many results described in detail in Appendix V, except the evacuation costs, which are calculated from the relocation costs in Appendix V for one month by correction to one week.

6.1 Costs Arising from Population Movement

The costs arising from an individual experiencing the countermeasures considered are connected with:

1. Transport away from the area (out and back)
2. Temporary accomodation and food
3. Loss of income from being unable to reach the workplace
4. Lost capital value and investment on land and properety

Other costs are not taken into account here.

6.1.1 Transport, 50 km/person

	private car	rail
DKK	63	70
FIM	42	52
NOK	67	106
SEK	50	

6.1.2 Food and Accommodation Costs

No specific cost for food consumed during evacuation or relocation is calculated because there would have been expenditure on this item by the evacuated or relocated population if the countermeasures had not been implemented.

6.1.3 Lost Income Per Year Per Caput During a Recovery Period of 2.5 Years

During a lengthy period of relocation it is likely that there will be a gradual reduction in income-related costs, as some individuals will find employment again outside the affected area. The loss of income costs can be stopped at some point in time. For the NCs we have chosen a recovery period of 2.5 years:

DKK: 120,830 FIM: 72,107
NOK: 109,904 SEK: 121,551

6.1.4 Lost Capital Services and Investments in Land and Property

The value of lost capital services will decrease with time. The mathematical relationships between value, value of rent and value of rent referred to time 0 (lost capital value) are described in detail in appendix V.
The capital considered lies in:

1) Buildings (excl. dwellings)
2) Dwellings
3) Consumer durables
4) Land
5) Machinery and equipment, etc.
6) Civil engineering works

The lost capital service per average inhabitant in the different Nordic countries per year at time 0 is:

DKK: 104,725 FIM: 83,092
NOK: 95,326 SEK: 97,904

6.2 Calculation of Intervention Costs for Different Scenarios

6.2.1. Sheltering

The efficiency of sheltering decreases with time. It depends on the shielding, the air tightness of the structure, as well as the availability of shelter. The efficiency decreases fairly rapidly with time because of the inflow of radionuclides from the outside air. For our purpose a period of 6 hours has been chosen.

Sheltering for 6 hours per caput

DKK: 125 FIM: 85
NOK: 110 SEK: 120

or expressed in ECU for Denmark, Finland, Norway and Sweden, respectively:
16.5; 13.4; 13.1; 13.2.

6.2.2 Evacuation per Caput for One Week

a) **evacuation from residential areas only**
(calculated from 6.2.3a)

DKK: 875 FIM: 630
NOK: 863 SEK: 816
(In ECU resp.: 115; 99; 103; 90)

b) **evacuation from industrial areas only**
(calculated from 6.2.3 b)

DKK: 3,523 FIM: 2,403
NOK: 3,127 SEK: 3,477
(In ECU resp.: 465; 378; 373; 383)

6.2.3 Relocation per caput per month

a) **Residential areas only, abandoned at time 0:**

DKK: 3,750 FIM: 2,700
NOK: 3,700 SEK: 3,500
(In ECU resp.: 495; 425; 441; 386)

b) **Industrial areas only, abandoned at time 0:**

DKK: 15,100 FIM: 10,300
NOK: 13,400 SEK: 14,900
(In ECU resp.: 1,990; 1,620; 1,600; 1,640)

6.2.4 Repopulation after 5 Years. Capital services saved per person per year

DKK: 76,323 FIM: 63,366
NOK: 75,503 SEK: 82,166
(In ECU resp.: 10,070; 9,960; 9,000; 9,060)

6.3 Comparison of National Expenses

To give another overview besides the ECU calculations above of possible discrepancies in costs, two PAs are compared below with respect to

a) income per caput and
b) differences in currency exchange rates as of february 14th, 1994.

In Appendix V the **Income per caput** was found to be:

133,738 DKK 76,382 FIM
115,447 NOK. 137,230 SEK.

6.3.1 Evacuation Costs for Industrial Areas per Caput for One Wweek:
(from 6.2.2 b)):

DKK: 3,523 FIM: 2,403
NOK: 3,127 SEK: 3,477

(Evacuation b)) x 1000/(income per caput) = (A) is found to be:

DK	FI	NO	SE
26.3	31.5	27.1	25.3

(A) related to US$ (14/2/1994 exchange rate: Danske Nationalbanks officielle notering: US$ 682.70, FIM 121.24, NOK 90.38, SEK 84.70)

DK	FI	NO	SE
179	177	205	204

6.3.2 Repopulation after 5 Years. Capital Services Saved per Person per Year
(from 6.2.4):

DKK:	FIM:	NOK:	SEK:
76,323	63,366	75,503	82,166

Repop. after 5 years/ (income per caput) =
.57 .83 .48 .60
related to US$:
3.89 4.67 3.6 4.8

The statistical economic data were chosen for the year 1990. No differences in taxation policies between the Nordic countries have been taken into account. When making the comparison above now between the Nordic countries, it must be borne in mind that the economic situation has changed since 1990 as regards GNPs as well as currency exchange rates.
However, we conclude:

When the two cost examples above are seen in relation to the income per caput for the four Nordic countries, as well as in relation to the currency exchange rates on february 14th 1994, there are ***by and large*** *no arguments to find for different intervention levels in any of the four countries with respect to the* ***monetary costs of protective actions****.*

6.4 Costs in Connection with Restrictions on Foodstuffs

These costs are already taken into account in regions from which the population is relocated, because the gross income at factor cost (including that of agriculture) was used to calculate the relocation costs. Accordingly no costs should be considered in connection with evacuation or relocation.

During the first period after the banning of foodstuffs (in regions where the population remains) it seems reasonable to calculate retail prices for the foodstuffs lost until supplies of less contaminated raw materials can be acquired by the food industry.

7. INTERNATIONAL RECOMMENDATIONS ON INTERVENTION LEVELS

7.1 Introduction

In the light of the experience gained from the Chernobyl accident, both the ICRP [1] and the IAEA have recently made revisions of their recommendations on Intervention Levels. The revised ICRP recommendations were published as Publication No. 63 (ICRP93). The revised IAEA recommendations (IAEA94) have not yet been published as a final document, but have been circulated worldwide as an IAEA-TEC-DOC for comments from Member States.

7.2 ICRP Publication No. 63

ICRP Publication No. 63 is a revision of Publication No. 40. The following aspects are stressed when applying the basic principles of intervention given in Publication No. 60 (ICRP90).

The first concern is *to keep the exposure to individuals from all pathways below the threshold for serious deterministic effects*. In addition, the unacceptability of a high risk of stochastic effects on individuals may also be a significant factor for introducing intervention. In this case, the *justification of the protective action from the individual's point of view* may become the dominant factor.

Subsequently, consideration should be given to *justifying the protective action from the viewpoint of society* because the costs and benefits will probably not be evenly distributed amongst the same people. Societal considerations may extend the protective action to cover an even larger group of affected people, or they may set limits to the practical or financial feasibility of the action (e.g. evacuation of a large city).

The justification of an intervention should begin by considering the *avertable average individual dose* for the whole of the exposed population to which the intervention would be applied. In some cases the *avertable collective dose* should be used when the exposed population is not easily identified (e.g. food restrictions). If implementation of the protective action is not justified, it should be considered whether there are subgroups in the population whose characteristics differ significantly from the average and for whom the protective action might be justified (e.g. greater radiation risks to be averted or lesser costs). These include *pregnant women* and *small children, hospitalized* or other *institutionalized individuals*. Separate optimisation is needed for workers engaged in the protective measures, and social and psychological costs should be considered when various population groups are treated differently.

Political and wider social factors will necessarily be considered in decision making following radiological emergencies. The authorities responsible for radiation protection should therefore be prepared to provide the radiation protection input (justification and optimisation of the protective actions on radiological grounds) to the decision-making process in a systematic manner, indicating all the radiological factors already considered in the analysis of the protection strategy. *In the decision process both the radiological protection and the political factors should only* *be taken into account once, to avoid the introduction of the same factors at several points in the proces.*

It is of great importance, however, that decision makers inform the public of all aspects of their decisions, especially when the interventions are chosen mainly for political, social, and/or economic reasons, rather than on health protection grounds. Otherwise the public may be misled and radiological protection efforts will be mistrusted. The recommended Intervention Levels (ILs) in the ICRP in Publication 63 are summarised in Table 1 (ICRP93).

Table 1. Summary of the ICRP's recommended Intervention Levels (ILs)

Intervention Levels of avertable dose or avertable concentration (IL)		
Protective measure	Almost always justified IL	Range of optimised ILs
Sheltering (< 1day)	50 mSv [a]	no more than a factor of 10 lower
Iodine prophylaxis	500 mSv [b]	
Evacuation (< 1 week)	500 mSv [a] 5,000 mSv [c]	
Foodstuff restrictions	10 mSv in a year [d]	10 - 100 Bq/kg [e] 1,000 - 10,000 Bq/kg [f]
Relocation	1,000 mSv [a]	5 - 15 mSv/month [a]

(a) averted effective dose
(b) averted equivalent dose to thyroid
(c) averted equivalent dose to skin
(d) averted effective dose committed in a year
(e) α-emitters
(f) β-emitters

7.3 IAEA Safety Series No. 109

The IAEA is at present revising Safety Series No. 81 (IAEA86). The major change will be that the revised document (IAEA94) will be a general document on intervention levels and not specifically on derived intervention levels. The recommended intervention levels would be based on the justification/optimisation principles. ILs will be given for both urgent and later countermeasures. Publication of the revised report in the Agency's Safety Series is planned for 1994 (IAEA94).

The IAEA suggested that the following factors should be considered as radiological protection factors in the optimisation process to determine generic, optimised ILs:

- the avertable individual and collective risks from exposure to radiation for members of the public
- the individual and collective physical risks to the public caused by the countermeasure
- the individual and collective risks to the workers in carrying out the countermeasure

- the monetary cost of the countermeasure
- reassurance of the public and the workers that implementation of the countermeasure provides
- anxiety caused by the implementation of the countermeasure
- individual and social disruption caused by the implementation of the countermeasure

Although the principles for justification and for optimisation are discussed separately and are indeed conceptually separate, it is necessary to consider them together when reaching a decision. In general it is likely that there would be a range of optimised values that give more good than harm for the intervention level for different scenarios. The intervention is then justified over this range of levels, with the selection of the most appropriate one depending on the particular circumstances.

The characteristics of accident sequences postulated for a nuclear installation, the local environmental conditions and national or regional considerations may all influence the choice of intervention level. Clearly, to be most appropriate, intervention levels should be developed specifically for the circumstances of interest. This need for specificity, and the potential varability of intervention levels depending on the prevailing circumstances, inhibit the degree to which broadly applicable quantitative guidance can be established.

Intervention levels for each type of protective action are developed separately because there are differences in the benefits and penalties arising from their application, as well as in the conditions under which they should be applied. Levels for different protective actions have been derived in a consistent manner and are consistent with the recommendations given by the ICRP (ICRP90). The derived values are "generic" in nature, i.e. they should be reasonable for the majority of situations. Deviation would be appropriate when the technical assumptions used for their derivation are not valid for a specific situation, or because of a need to accomodate relevant social or political factors.

The Intervention Levels are expressed as **avertable doses** or **avertable concentrations**, i.e. if the doses or concentrations that could be avoided by a protective action exceed the Intervention Level (IL) this measure should be introduced.

For relocation, a distinction is made between **temporary** and **permanent** relocation. Temporary relocation is the removal of people for an extended but limited period of time, and permanent relocation is removal of people with no expectation of return within their lifetime. The IL values recommended by the IAEA are shown in Tables 2 and 3.

Table 2. IAEA Intervention Levels for foodstuff restrictions (Bq/kg).

Radionuclide Group [(a)]	General consumption	Milk and infants' food
Group 1	1,000	1,000
Group 2	100	100
Group 3	10	1

(a) Group 1: ^{106}Ru, ^{131}I, ^{134}Cs, ^{137}Cs, etc., with a dose per unit activity ingested of ≈ 10^{-8} Sv/Bq
Group 2: ^{90}Sr with a dose per unit activity ingested of ≈ 10^{-7} Sv/Bq
Group 3: ^{238}Pu, ^{239}Pu, ^{241}Am, etc., with a dose per unit activity ingested of ≈ 10^{-6} Sv/Bq

Table 3. IAEA Intervention Levels in terms of avertable dose for sheltering, evacuation, thyroid blocking and relocation.

Protective measure	Intervention Level
Sheltering	10 mSv (up to 2 days)
Evacuation	50 mSv (up to 1 week)
Thyroid blocking	100 mGy
Temporary relocation	30 mSv in first month 10 mSv/month hereafter
Permanent relocation	1 Sv over a long time period

7.4 Other Organisations

Organisations such as the OECD/NEA, the WHO and the CEC have all made recommendations for Intervention Levels, especially for foodstuffs.

The Article 31 Group (EU) has recently adopted a recommendation on relocation having the same numerical levels as those of the ICRP and the IAEA. This publication is issued as a report (CEC93).

The NEA (NEA89) prepared a report for use as the basis for intervention in the event of a nuclear accident. The basic principles are the same as those recommended by the ICRP and IAEA, i.e. justification and optimisation of the protection provided by intervention.

The Codex Alimentarius Commission (CAC) has approved guidelines for foodstuffs (CAC-91). These levels are intended only for radionuclide contamination in foodstuffs being traded internationally and they are considered standards below which the foodstuffs are excempt from any further monitoring and control (non-action levels).

The EU has recommended action levels for foodstuff restrictions that are based on dose limits (CEC 87). These levels are not based on an optimization of protection, and the procedure for their derivation is therefore not in agreement with the basic principles as recommended by the ICRP and IAEA.

The "Nordic Model" (Food Safety after Nuclear Accidents, Nord:1992:33) introduces so-called Emergency DILs which are ten times stricter than the permanent DILs, which apply at any time also under normal conditions. The permanent DILs in the "Nordic Model" are identical to the Guideline Levels laid down by the CAC for foods in international trade. It is important to note that the emergency DILs, which are ten times higher than the CAC levels, *shall not be applied for more than thirty days*, i.e. in the acute phase: the period during which action is taken following the predetermined contingency plans. After thirty days the Emergency DILs should be replaced by ILs adapted to the actual situation.

7.5 Summary

Tables 1, 2 and 3 give the recommended values of generically justified and optimised intervention levels (IL) of the ICRP and IAEA, respectively.

The IL for the urgent protective actions of sheltering and evacuation given by the IAEA are 10 and 50 mSv, respectively. The corresponding ICRP values are no less than 5 and 50 mSv, respectively.

The IL for iodine prophylaxis given by

the IAEA is 100 mGy and that of the ICRP no less than 50 mSv.

The IL for temporary relocation given by the IAEA is 30 mSv for the first month and 10 mSv/month for subsequent months. If the avertable lifetime dose is foreseen to exceed 1 Sv, permanent relocation elsewhere is necessary. The IL for relocation given by the ICRP is 5-15 mSv/month.

For foodstuffs, the IL given by the IAEA for their withdrawal is for β-/γ-emitters in the range 3,000 - 30,000 Bq/kg. If, however, agricultural countermeasures are introduced, the optimised values for β-/γ-emitters would fall in an interval around 1,000 Bq/kg. For other nuclide groups the values are a factor of 10 - 100 times less. The generically optimised intervention levels for the withdrawal of foodstuffs containing β-/γ-emitters given by the ICRP are 1,000 - 10,000 Bq/kg and a factor of 10 lower for α-emitters.

Comparison of the values of generically justified and optimised intervention levels for both urgent and longer-term protective measures given by the IAEA and the ICRP shows good agreement between values.

References

ICRP90 International Commission on Radiological Protection, *1990 Recommendations of the International Commissionon Radiological Protection*, Publication 60, Pergamon Press, Oxford, (1991).

ICRP93 International Commission on Radio logical Protection, *Principles for Intervention for Protection of the Public in a Radiological Emergency*, Publication 63, Pergamon Press, Oxford, (1993).

IAEA86 International Atomic Energy Agency, *Derived Intervention Levels for Application in Controlling Radiation Doses to the Public in the Event of a Nuclear Accident or Radiological Emergency*, Safety Series No. 81, IAEA, Vienna (1986).

IAEA94 International Atomic Energy Agency, *Generic Intervention Levels for Protecting the Public in the Event of a Nuclear Accident or Radiological Emergency*, IAEA Safety Series No. 109, Vienna (to be published in 1994).

CEC93 Commission on the European Com munities, *Radiological Protection Principles for Relocation and Return of People in the Event of Accidental Releases of Radioactive Material*, RADIATION PROTECTION - 64 (1993).

CEC87 Council Regulation (Euratom) No. 3954/87 of 22/12/1987 laying down maximum permitted levels of radioactive contamination of foodstuffs and feedingstuffs following a nuclear accident or any other case of radiological emergency. Official Journal of the European Communities, L146 of 30/12/1987, Luxembourg.

NEA89 Nuclear Energy Agency, *Nuclear Accidents: Intervention Levels for Protection of the Public*, NEA/OECD, Paris (1989).

CAC91 Food and Agricultural Organisation of the United Nations, World Health Organisation, Codex Alimentarius Commission, General Requirements, Section 1, *Guideline Levels for Radionuclides in Foods Following Accidental Nuclear Contamination*, Joint FAO/WHO Food Standards Programme, Rome (1991).

Nord 1992:33 Food Safety after Nuclear Accidents - a Nordic Model for National Response. Nord 1992:33.

I ate mushrooms with 4 000 Be-cquerel !!!	No problem. That's only 0.000 000 1 Curie	I see !

8. INTERVENTION LEVELS BASED ON NORDIC MONETARY COSTS

The intervention levels given below are based on:

1) The monetary costs of the various protective actions in each of the four Nordic countries Denmark, Norway, Finland and Sweden, as calculated in chapter 6.

   As the monetary costs are almost the same in the four countries the average costs in Nordic currencies are converted into rounded US$.

2) With reference to chapter 3, the α-values are found within the range 600 US$ to 250,000 US$ per manSv. The lowest is applied in Sweden in the prevention of lung cancer by reducing the *radon levels in homes*. The highest value is used by the Swedish power company, Vattenfall, in their planning of radiation protection work. Swedish diagnostic radiology lies within the range with 6,000 US$ as also the value of 100,000 US$ recommended generally by the Nordic radiation protection authorities.

   We have chosen to base the calculations presented below on the value of 10,000 US$/manSv found in the pilot study, described in section 3.

The following intervention levels can readily be made to correspond to other values of alpha. A doubling of the alpha value will halve the intervention levels and vice versa.

Only detriments to health caused by radiation exposure and the monetary costs of the protective action are taken into account. The effect of other factors of a psychological or social nature - such as anxiety, reassurance, public relations considerations, etc.- that decision makers might think appropriate to take into account, should be evaluated separately before final decisions are taken.

The background material relating to some of these other factors can be found in chapters 4 and 5.

Sheltering for 6 hours:

The cost is 20 US$/person.

Sheltering should be implemented if a dose of (20x1,000/10,000 =)

2 mSv in 6 hours can be averted.

Evacuation for One Week (7 days):

If evacuation is considered as a means to avoid deterministic effects to individuals, the following should be considered:

In ICRP 63 it is stated: "It has been estimated on a generic basis that evacuation is almost always justified if the projected average individual dose to the whole body is likely to exceed 0.5 Sv within a day or the averted average individual effective dose for the duration of the evacuation is 0.5 Sv or 5 Sv skin dose. It is expected that, for most foreseeable accident situations, an optimised level of averted effective dose for evacuation will be lower but not by more than a factor of 10."

It is therefore recommended to use the ICRP Intervention Level of 500 mSv (projected whole-body dose).

If the level of absorbed dose received during less than one week is below the thresholds for deterministic effects and evacuation is still considered, the costs in the Nordic countries would lead to the following values below:

a) **from residential areas only**
The cost is 100 US$/person.
Evacuation should be implemented if a dose of (100x1,000/10,000 =)
10 mSv in one week can be averted.

b) **from industrial areas only:**
The cost is 500 US$/person.
Evacuation should be implemented if a dose of (500x1,000/10,000 =)
50 mSv in one week can be averted.

Relocation from residential areas lasting one month:

The cost is 500 US$/person at time 0.
Intervention should be implemented if a dose of (500x1,000/10,000 =)
50 mSv in one month can be averted.

Abandoning industrial sites for one month:

The cost is 2000 US$/person at time 0.
Intervention should therefore be implemented if a dose of
(2,000x1,000/10,000 =)
200 mSv in one month can be averted.

Dose levels for the repopulation of residential areas and reuse of industrial areas will depend on the point in time after relocation or abandonment of a site.

As examples are given the appropriate dose levels (dose rates) below which repopulation can take place after 5 years:

Repopulation of residential areas after 5 years:

The economic benefit resulting from return is 4,000 US$/person in the 6th year.
Repopulation can take place if the Maximum dose level (or dose rate) is below (4,000x1,000/(12x10,000) =)
35 mSv per month

Reuse of industrial areas after 5 years:

The economic benefit resulting from reuse of an area is 6,000 US$/person in the 6th year.

Reuse can take place if the Maximum dose level (or dose rate) is below (6,000x1,000/(12x10,000) =)
50 mSv per month

9. CONCLUSIONS

In the table below the generic ILs derived in this study are summarized together with the ILs established by the IAEA (table 3, section 7) and the ICRP (table 1, section 7).

Protective action	**BER-3**	**IAEA**	**ICRP**
Sheltering	2 mSv/6h (~ 0.3 mSv/h)	10 mSv/<2 d (~ 0.2 mSv/h)	50 - 5 mSv/<1 d (~ 2-0.2 mSv/h)
Evacuation			
deterministic:	500 mSv/1 day		500 mSv/<1 d [1]
stochastic: residential	 10 mSv/1 week	 50 mSv/<1 week	500-50 mSv/<1 week
industrial	50 mSv/1 week		
Iodine	100 mSv [2]	100 mGy [2]	> 50 mSv [2]
Relocation		30 mSv/1st month	15 - 5 mSv/ month, prol.
residential	50 mSv/1st month	10 mSv/month thereafter	
industrial	200 mSv/1st month		
		1 Sv long time	1 Sv total
Food		Bq/kg:	10 mSv/a Bq/kg:
beta + gamma		1,000 (1,000) [3]	1,000 - 10,000
beta		100 (100) [3]	
alpha		10 (1) [3]	10 - 100

[1] Projected dose
[2] Equivalent dose to thyroid
[3] The latter figure for infants' food and milk

Sheltering.
Use is made of a six-hour period in our calculations whereas the IAEA gave a value for up to two days and the ICRP for less than one day.

The dose rates seem similar, and the ILs seem consistent.

Evacuation
Because of the threshold for deterministic effects, we have adopted the value of 500 mSv that is internationally recommended. Regarding the derivation of the IL based on optimization, two types of area are considered: residential and industrial. For residential areas, our value is lower than the international values for the same periodof time, one week. The value for industrial areas is the same.

Relocation
For relocation the same two types of area are considered. For the first month our value for residential areas is somewhat higher than the international values.

Repopulation
In practice, after a period of economic recovery the relocated population may not wish to return. Nevertheless a theoretical benefit can be calculated by repopulating the abandoned area. This is now only the capital services that can be saved, and thus repopulation could take place when the capital service saved annually exceeds the value of the dose received annually.

Repopulation of residential/industrial areas could take place after 5 years if the maximum dose rate is below 35 and 50 mSv/month respectively. Appendix II, p. 10, gives a discussion showing that after a temporary relocation from areas that have been contaminated with long-lived radionuclides, there would be an increasing residual dose with increasing effective removal halflife of the deposited radionuclides, compared to an almost constant averted dose per unit time. A ratio of residual to averted dose for a temporary relocation period of, say, one year could be more than a factor of 10.

As indicated in section 7, tables 1 and 3, both the ICRP and the IAEA have adopted an IL of averted dose of 1 Sv for relocation. If the effective removal halflife of radionuclides is greater than about six years, the residual lifetime dose corresponding to a return criterion of, say, 10 mSv/month would be greater than 1 Sv. Therefore, for a contamination with an effective removal halflife greater than 6 years, the relocation would be permanent from areas where the avertable dose is above 10 mSv/month.

Therefore not consider it unlikely that repopulation will be planned at the dose rates derived only from the possible economic gains.
Our calculations based on the economic benefit of return (in the 6th year) show fairly high dose rates of 35 mSv/month for residential areas and 50 mSv/month for industrial areas. However if the effective removal half-life is greater than about six years, the residual lifetime dose corresponding to a return criterion of, say, 10 mSv/month would be greater than one Sv.

This means that repopulation would result in unacceptably high residual doses.

Appendix I
Avertable Doses from Protective Actions

by

Per Hedemann Jensen

I.1 Avertable Doses from Different Exposure Pathways

In a continuous release of airborne material to the atmosphere, the material disperses downwind as a plume. Once the material has reached ground level and is dispersed uniformly throughout a hemisphere several hundred metres in radius with origin at the receptor point, the geometry is referred to as the semi-infinite cloud approximation for γ-radiation, for which the external γ-dose and the external β-dose to skin can be calculated as the product of nuclide-specific dose conversion factors and time-integrated air concentration.

A person immersed in the plume would inhale an amount of radioactive material proportional to the time-integrated air concentration and his/her breathing rate. The committed inhalation dose will therefore be proportional to the time-integrated air concentration and nuclidespecific inhalation dose factors.

Radioactive materials can be deposited on the ground by dry or wet deposition. During deposition and after the material has been deposited, the dose at a receptor point is calculated by integrating the dose rate to an individual from each radionuclide deposited on the ground surface. Removal processes, such as migration into the soil, weathering, radioactive decay, etc., should be included in the time integration of the dose rate. If the surface contamination density within a radius of a few hundred metres is more or less homogeneous, the time-integrated γ-dose rate is proportional to the time-integrated surface contamination density.

Radioactive material deposited on the ground, buildings and vegetation, particularly if the material is relatively insoluble or chemically inactive, may be resuspended into the air, primarily by winds but also by human and animal activity, and thereby cause inhalation doses proportional to the time-integrated surface contamination density.

Based on measurements and suitable theoretical models, the **present** and **future** doses can be predicted. Such an assessment process is an iterative one in which knowledge and appreciation of the radiological situation is being refined, updated and reconstructed. The assessment of future doses leads to **projected doses**, i.e. the doses which, from a specified exposure pathway, would be expected over a specified time period for **normal living conditions** and **without** the introduction of any countermeasures.

The avertable dose is less than or equal to the full projected dose. The efficiency of a protective measure can be defined as the ratio of the avertable dose to the projected dose for the time period during which the protective measure is applied.

I.2 Early Exposure Pathways

The major radiation doses to a population from an accidental release of radioactive material to the atmosphere while the plume is passing will originate from the following pathways:

- inhalation of material in the plume
- external radiation from the plume
- external radiation from deposited activity on ground and structures
- inhalation of resuspended material

The effective doses and the absorbed organ doses from each pathway can be calculated from the time-integrated concentration of activity in outdoor air.

Avertable absorbed doses

The absorbed doses from the plume passage should be compared to the threshold doses for deterministic effects. With plume passage time T the absorbed doses can be calculated for a specific nuclide and all relevant exposure pathways as:

$$D = \sum_{\text{path}} k_{path} \int_0^T C(t)\ dt$$

where k_{path} is a product of factors for the considered pathway.

The avertable absorbed doses over time T can be calculated from the average air concentration $\overline{C}$ over the plume passage time T. The necessary parameters are the following: I is the breathing rate, F is the filtering factor for buildings, d_{inh} is the committed absorbed organ dose per unit activity inhaled, L_{plume} is the location factor for buildings and plume radiation defined as the ratio of dose at a given location (indoor or outdoor) to the dose one meter above the ground surface, $\dot{d}_{plume}$ is the external dose rate (β- or γ-dose rate) per unit plume concentration, L_{ground} is the location factor for buildings and ground radiation, v_d is the dry or wet deposition velocity for particulate activity, $\dot{d}_{ground}$ is the external dose rate (β- or γ-dose rate) per unit surface contamination density, and K is the resuspension factor. The doses can be calculated for each exposure pathway as:

Absorbed inhalation dose:

$$D_{inh} = I \cdot F \cdot d_{inh} \cdot \overline{C} \cdot T$$

Absorbed external submersion dose:

$$D_{plume} = L_{plume} \cdot \dot{d}_{plume} \cdot \overline{C} \cdot T$$

Absorbed external dose from deposited activity:

$$D_{ground} = L_{ground} \cdot \dot{d}_{ground} \cdot v_d \cdot \overline{C} \cdot \frac{T^2}{2}$$

Absorbed inhalation dose from submersion:

$$D_{inh} = K \cdot I \cdot F \cdot d_{inh} \cdot v_d \cdot \overline{C} \cdot \frac{T^2}{2}$$

Avertable effective doses

The avertable effective doses over time Δt should be compared to the Intervention Levels for specific protective actions. The avertable effective doses can be calculated for a specific nuclide and all relevant exposure pathways as:

$$E = \sum_{\text{path}} k_{path} \int_{\tau}^{\tau+\Delta t} C(t)\ dt$$

where k_{path} is a product of factors for the considered pathway. The avertable effective doses over the time interval Δt can be calculated for each exposure pathway as:

Committed effective inhalation dose:

$$E(50) = I \cdot F \cdot e_{inh}(50) \cdot \overline{C} \cdot \Delta t$$

Effective external submersion dose:

$$E_{plume} = L_{plume} \cdot \dot{e}_{plume} \cdot \overline{C} \cdot \Delta t$$

Effective external dose from deposited activity:

$$E_{ground} = L_{ground} \cdot \dot{e}_{ground} \cdot v_d \cdot (\tau + \frac{\Delta t}{2}) \cdot \overline{C} \cdot \Delta t$$

Committed effective inhalation dose from submersion:

$$E(50) = K \cdot I \cdot F \cdot e_{inh}(50) \cdot v_d \cdot (\tau + \frac{\Delta t}{2}) \cdot \overline{C} \cdot \Delta t$$

where $\overline{C}$ is the average air concentration over time Δt, I is the breathing rate, F is the filtering factor for buildings, $e_{inh}(50)$ is the committed effective dose per unit activity inhaled, L_{plume} is the location factor for buildings and plume radiation, $\dot{e}_{plume}$ is the effective external dose rate (β- or γ-dose rate) per unit plume concentration, L_{ground} is the location factor for buildings and ground radiation, v_d is the dry or wet deposition velocity, $\dot{e}_{ground}$ is the external effective dose rate (β- or γ-dose rate) per unit surface contamination density, and K is the resuspension factor.

The avertable doses from the early exposure pathways given in the expressions above are related to the time-integrated air concentration or average concentration over the time interval considered. For the early exposure pathway, radioactive decay for the deposited activity has been neglected for the time intervals considered.

I.3 Late Exposure Pathways

After the release phase of an accident there will be a high probability of the deposited activity being retained on surfaces at and near ground level. Direct external exposure will therefore continue in the post-release phase, from the radioactive material which is now on the ground, on the surfaces of buildings, on trees and vegetation, as well as from ingestion of foodstuffs being contaminated by the deposited material.

The following pathways will dominate the post-release phase:

- external radiation from deposited activity on ground and structure surfaces
- inhalation of resuspended radioactive material
- ingestion of contaminated foodstuffs

The effective doses from each pathway can be calculated from the time-integrated surface contamination density.

Avertable effective doses

The avertable effective doses over time Δt should be compared to the Intervention Levels for specific protective actions. The avertable effective doses can be calculated for a specific nuclide and all relevant exposure pathways as:

$$E = \sum_{path} k_{path} \int_{\tau}^{\tau+\Delta t} Q(t)\, dt$$

where k_{path} is a product of factors for the considered pathway.

The avertable effective doses over the time interval Δt can be calculated for each exposure pathway as:

External effective dose from deposited activity:

$$E_{ground} = \overline{L}_{ground} \cdot \dot{e}_{ground} \cdot \overline{Q} \cdot \Delta t$$

Committed effective inhalation dose from submersion:

$$E(50) = K \cdot I \cdot \overline{F} \cdot e_{inh}(50) \cdot \overline{Q} \cdot \Delta$$

Committed effective ingestion dose per mass of ingested foodstuffs:

$$E(50) = TF \cdot e_{ing}(50) \cdot \overline{Q}$$

where $\overline{Q}$ is the average surface contamination density over time Δt, TF is the transfer factor for a given radionuclide to a specific foodstuff, $e_{inh}(50)$ is the committed effective inhalation dose per unit activity inhaled and $e_{ing}(50)$ is the committed effective ingestion dose per unit activity ingested.

I.4 Avertable Doses from Different Protective Actions

The avertable dose to a specific organ from a specific radionuclide and a specific protective action can be calculated as *the difference between the sum of doses for all exposure pathways to that organ from that nuclide **without** any protective action and the sum of doses for all exposure pathways to the organ **with** the specific protective action implemented.*

As an illustration of the methodology, the avertable committed effective inhalation dose per sheltering time period Δt during the plume passage can be calculated for people inside buildings, and for a single radionuclide, from the equations given above to be:

$$\frac{\Delta E(50)}{\Delta t} = I \cdot e_{inh}(50) \cdot \overline{C} \cdot (1 - F)$$

It is here assumed that sheltering takes place before the arrival of the plume.

Another example is the avertable effective γ-dose per time period Δt from deposited activity of a single radionuclide by relocation after the plume has passed:

$$\frac{\Delta E_{ground}}{\Delta t} = \dot{e}_{ground} \cdot \overline{Q} \cdot \overline{L}_{ground}$$

The avertable effective γ-dose is thus the dose which would otherwise be received from normal residence in the area. $\overline{L}_{ground}$ is here the time-averaged location factor and x is the fraction of time spent indoors. This location factor is given as $\overline{L}_{ground} = L_{out} + x \cdot (L_{in} - L_{out})$. It is assumed that, at the new location, the external γ-dose from the accident is zero.

The avertable doses for early and late exposure are related to the air concentration and the surface contamination density, respectively.

Different radionuclides will often have similar dose conversion factors for given exposure pathways. As an example, the radionuclides of ^{131}I, ^{134}Cs, ^{137}Cs, ^{60}Co and ^{89}Sr, and many others, have similar committed effective inhalation dose factors per unit activity inhaled.

The radionuclides of ^{87}Kr, ^{88}Rb, ^{91}Sr, ^{95}Nb, ^{103}Ru, ^{131}I, ^{133}I, ^{137}Cs and many others have similar submersion dose rate factors per unit activity concentration in air.

It would therefore be possible to place relevant radionuclides in groups having the same dose conversion factors. In the estimation of avertable doses the activity concentration for the radionuclides in the same group could then be added and the dose conversion factor representative for the group used in the dose calculation.

Assuming that each exposure pathway could be represented by, say, three nuclide groups, the avertable doses per unit time of an urgent protective action for a mixture of N nuclides can then be calculated as:

$$\left(\frac{\Delta E}{\Delta t}\right)_{\text{paths}} = \sum_{j=1}^{3} \Delta \dot{e}_{pl,\,j} \sum_{i=1}^{N} C_{ij} +$$

$$\sum_{k=1}^{3} \Delta e_{inh,\,k} \sum_{i=1}^{N} C_{ik} +$$

$$\sum_{l=1}^{3} \Delta \dot{e}_{grd,\,l} \sum_{i=1}^{N} C_{il} +$$

where j, k and l ... are the nuclide grouping for the specific exposure pathway and Δe the avertable doses per unit air concentration and unit time calculated by the above equations for each group and pathway and for the specific accident circumstances, i.e. for site-specific location and filter factors, etc.

Similar equations could be set up for longer-term protective actions in terms of surface contamination density Q.

I.5 Conclusions

Protective actions can be divided into urgent and longer-term countermeasures. These would be introduced after a nuclear or radiological accident where people would be exposed to ionising radiation from different exposure pathways.

The purpose of introducing protective actions is to **avert** radiation doses partly or completely. The introduction of protective actions should, from a radiological protection point of view, be judged in the light of the **avertable doses** from the different exposure pathways which are influenced by these actions and their **costs.**

Protective actions can only influence doses to be received in the future. Accordingly, Intervention Levels for the introduction of protective actions are expressed in terms of avertable doses or surrogates for such doses. If the avertable doses are foreseen to exceed the Intervention Level for a specific protective action, this action should be introduced.

Appendix II
Radiation Protection Principles for Relocation/Return

by

Per Hedemann Jensen

II.1 Introduction

The term **relocation** is used to describe a deliberate, as opposed to emergency, and perhaps time-limited movement of people so as to limit the incidence of any late health effects which might be expected to result from exposure to radiation from deposited or resuspended material.

From the point of view of public authorities and governments, the relocation of a large number of people will require special arrangements if those affected are not to lose, even temporarily, the benefits of certain civil rights and statutory services which they customarily enjoy. Equally, when return is decided upon,it is important that all the services to which they were accustomed (schools, hospitals, cultural facilities, municipal services, policing, etc.) should be available.

Relocation or any other protective actions can only influence doses that may be received in the future. Such doses can be avoided or **averted** by protective actions and they are referred to as **avertable doses.** Only if cumulative doses are likely to exceed the threshold for deterministic effects, past doses (from the accident) are relevant to decisions on the introduction of protective actions. However, past doses may be relevant when determining the need for long-term medical care and surveillance of those affected by the accident.

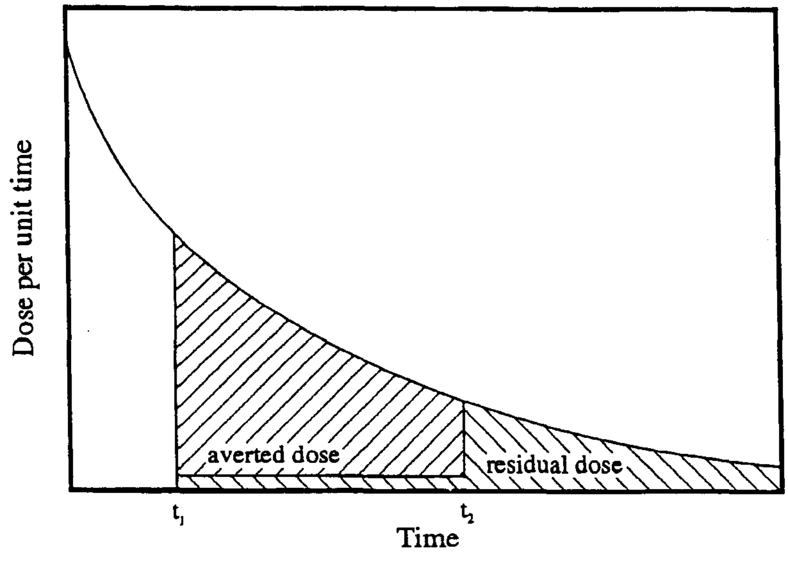

Figure 1.1. Averted and residual individual doses for a protective action which is introduced at time t_1 and terminated at time t_2.

After the termination of a relocation there might still be some contamination of the area which would lead to exposure of the returned population. The dose received after completion of a protection action, e.g. relocation, is called the **residual dose**. The concepts of averted and residual doses are shown in Figure 1.1.

The averted dose is that which would otherwise have been received in the absence of relocation over the relocation period.

II.2 Concept of Relocation

Only those exposure pathways and doses that may be influenced by a protective measure should be taken into account in judging whether it should be implemented and, if so, at what level. For relocation these exposure pathways will, in general, be limited to external exposure from deposited material and internal exposure from inhalation of resuspended material. Where appropriate, the residual foodstuff doses not averted by food restrictions could also be included insofar as these doses would be further reduced by relocation.

II.2.1 General Considerations

It is useful to distinguish the various terms used in connection with population movement after a nuclear accident. Evacuation and relocation have different intents and purposes. Before, during, or even a short time after a release evacuation is the urgent removal of people to avoid the short-term threats from inhalation of radioactive materials and external exposure from the passing plume. Relocation is the term used to refer to the removal of people from the area affected by an accident for a longer period of time (weeks, months or years) to avoid exposure from radioactive material deposited on the ground.

Evacuation and relocation are fundamentally different. In an evacuation the expectation is that people will in general return within a few days, and accommodation will be of a temporary nature, often in schools or other public buildings. In the case of relocation it is not intended that people will return within a short space of time but rather within months or even years. Accommodation should, therefore, be suitable for extended occupancy and new accomodation may need to be built.

The time at which relocation is effected will depend on the circumstances of the accident but decisions on its need should ideally be taken quite rapidly. Inevitably, with the acquisition of further information with time and improvements in the prognosis, initial decisions on relocation may need to be reversed. This should not, however, be allowed to prevent the provision of clear guidance to the affected population on relocation, albeit appropriately qualified.

Judgements on the optimum level of averted dose at which relocation should be implemented would, in general, depend on the period over which the dose was averted and for which the relocation was foreseen. Different judgements could be expected when relocation periods of several years are foreseen compared to a few months. Therefore, a distinction is made between a temporary relocation, when a return to the affected area is foreseen within a reasonable time, and permanent relocation, when return to the area is not expected.

II.2.2 Temporary Relocation and Return

Temporary relocation is the term used to describe the organised and deliberate removal of people from the affected area for an extended but limited period of time. During such periods, people would typically be housed in temporary accomodation.

At the time when the decision on relocation is taken, it is important for social and economic reasons to decide whether the relocation is temporary or permanent.

The economic considerations which may influence decisions on this include the relative costs of temporary relocation (in which case the population will no longer be productive and they will have to be maintained throughout the whole period of relocation), the costs of housing, and the costs of permanent relocation which will necessitate the establishment of a new economic infrastructure, including housing, and where productivity is lost only during transition period.

From the viewpoint of social factors a temporary situation should not be too prolonged. A prolonged transitory period will produce a general sense of malaise, discontent, and an at least partial loss of productivity, all of which can result in social and health detriments. Therefore, the maximum period of relocation will have to take account of all the local conditions.

Social problems may also arise in regions adjacent to those from which people have been relocated. Anxiety and psychological problems may arise from peoples' perception of the risk; social trauma could also emerge from concern for relatives and friends in the relocated population.

II.2.3 Permanent Relocation

Permanent relocation is the term describing the deliberate removal of people from an area with no expectation of return within their lifetime. Relocation would be deemed permanent if its duration was foreseen to exceed a few years. In such cases this should be made clear to those affected at the time that decisions on relocation are taken.

At a future time, when radioactive decay and natural removal processes have reduced the contamination to an appropriate level, the area might be resettled, either by the relocated population or by others.

II.3 Costs of Relocation

II.3.1 Temporary Relocation

The costs arising from the relocation of a population can be categorised as (Ha91):

- transport of people and their belongings
- temporary accommodation
- loss of income from being unable to reach the workplace
- lost capital value and investment in land and property
- control of access to areas, houses, homes, buildings and land

Some of these costs are independent of the duration of relocation (fixed costs), for instance transportation costs. Other costs are continuing, such as accommodation costs and loss of income costs, which are proportional to the period of relocation. Both fixed and continuing costs can be annualized or capitalized for the purpose of evaluating their combination.

The costs of relocation are likely to be approximately proportional to the number of people relocated. The average individual cost can therefore be used in the justification/optimisation process instead of the total cost.

II.3.2 Permanent Relocation

Some of the costs would be the same whether the relocation was temporary or permanent. These include:

- transport of people and their belongings away from the affected area
- loss of income from being unable to reach the workplace
- lost capital value and investment in land and property
- re-routing of major roads and railways

The lost capital value would be greater for permanent relocation because land and property would be completely lost.

For permanent relocation the main costs would be the establishment of new permanent accommodation and its associated infrastructure. If the numbers of people affected were not large, it is possible that they could be re-housed, etc., within the existing infrastructure. Otherwise it might be necessary to construct completely new settlements. These costs would in general fall on society as a whole and not just those directly affected by the accident.

II.3.3 Social Impact

When the duration of relocation exceeds a few weeks or months, anxiety may be felt about the safety of property and continuity of assured sources of income. In addition, people living close to areas from where the population has been relocated, will suffer anxiety. After return to the affected areas, there may be continuing concern about the long-term effects of the radiation to which they have already been exposed, and to which they may be exposed in the future.

In general, there will be strong 'roots' in an original, established home. Farming families may have worked the same land for generations, and there may be attachment to a particular area, whether through ties of tradition or property ownership. These factors may have profound influence on attitudes to relocation.

Mental stress in those who have been relocated can be reduced in a number of ways. These range from designing the layout of new settlements so as to encourage the development of community spirit, through the effectiveness of assistance programmes, to the provision of monetary or other compensation and advisory services.

The relocation of a large number of people will require special arrangements if those affected are not to lose, even temporarily, the benefits of certain civil rights and statutory services which they customarily enjoy. Equally, when return is decided upon, it is important that all the services to which they were accustomed (schools, hospitals, cultural facilities, municipal services, policing etc.) should be available.

Those not wishing to return to their original homes should not be placed in a worse position, financially or otherwise, than those who do. Following temporary relocation there would be pressure from the population to return to 'normality'. There will be a need to explain, particularly to officials, the difference between Intervention Levels and dose limits for a practice.

II.4 Optimisation of Relocation and Return

II.4.1 General Considerations

Given the diversity of circumstances which may be encountered following an accident, there are limits to the extent to which detailed planning for relocation can be made or, indeed, would be sensible. However, after an accident, there will be social pressures for rapid decisions as delay in the provision of information and advice to the public may cause anxiety. This might lead to erroneous or at least less than optimal decisions. To minimise any delay, there is a need for outline guidance in advance of an accident. This may be refined in due course when the detailed circumstances are known and the future sequence of events better predicted.

If the population cannot be advised to resume normal activities, then all the options for reducing doses, their costs and benefits will need to be considered (ICRP90). The use of structured, multi-attribute, decision-aiding techniques may aid the evaluation of the options. Such analyses require some time for consideration and would need to take the prevailing circumstances into account. Prior to an accident, only very general guidance can be prepared on the level of dose at which people may be advised to continue living in a contaminated environment, or return home.

Several decision aiding techniques exist (IAEA94, ICRP83, ICRP89). All methods attempt to achieve the best balance between a number of often conflicting objectives. Cost-benefit analysis is one of the simpler techniques available and is most useful where the relevant attributes can all be expressed in monetary terms. Monetary costs are, of course, only one input to decisions on intervention. The actual costs will be very uncertain and, in practice, decisions on relocation are likely to be strongly influenced by social factors, particularly by public acceptability and perception.

Cost-benefit analysis has been used here to derive Operational Intervention Levels for relocation and return, considered solely on the basis of costs and risks. This limited analysis provides a useful starting point for making decisions on relocation should it ever be needed.

II.4.2 Justification of Relocation

Relocation will involve monetary and social costs in addition to the anxiety and physical risks resulting from its implementation. The benefits, on the other hand, include the doses averted and the reassurance that this might bring. The net benefit in monetary terms is the difference between the cost equivalent of the averted dose and the monetary cost of the relocation. If the net benefit is positive, relocation is justified (ignoring the influence of factors other than averted doses and monetary costs).

The cost of relocation will, to a first approximation, be proportional to the number of people affected. Consequently, the justification and optimisation processes can be applied on the basis of the average individual cost of, and the average individual dose averted by relocation rather than on the total cost and the averted collective dose.

In practice, the average relocation cost per person would be influenced by the total number of people relocated. In addition, the length of the relocation period could also increase the fixed relocation cost per person. If only a small number of people were relocated for a short time, the average cost per person might be considerably less than that where a large number of people were relocated for a long time. In the former case, people could be integrated within an existing community and infrastructure. In the latter, new accommodation and infrastructure would be needed at far greater cost.

If the cost equivalent of the averted dose per unit time is less than the continuing relocation cost per unit time, relocation is never justified. Because fixed relocation costs are greater than zero, relocation is justified only if the cost equivalent of the averted dose exceeds the combination of fixed and continuing costs.

II.4.3 Optimisation of Protection from Temporary Relocation

An Intervention Level, ***IL***, for initiating and ending temporary relocation has been derived from an optimisation (see Annex A) in which consideration was limited to averted dose and monetary costs of relocation. The optimised Intervention Level, expressed in terms of the averted dose per unit time at the time of return, is given by the quotient of the continuing cost of relocation per unit time, ***c***, and the monetary value of the unit collective dose, α:

$$IL = \frac{c}{\alpha}$$

The ***IL*** is the level of effective dose per unit time above which it is worth introducing, and no longer worth continuing, relocation. The costs, *c* and α, will depend on national wealth and thus will vary between countries. However, c/α will, in general, be much less sensitive to geographical location because both will be similarly correlated to national wealth. Representative values of *c* and α, within the EC, are of the order of 300-600 \$/man month and of the order of 20,000-100,000 \$/man Sv, respectively (UN89, HMO92, SB91). Based on these figures the Intervention Level for ending temporary relocation will be in the order of:

$$IL = \frac{\textbf{300-600 \$/man month}}{\textbf{20000-100000 \$/man Sv}}$$

$$= 3 - 30 \textbf{ mSv/month}$$

$$\approx 10 \textbf{ mSv/month}$$

which is in good agreement with the ICRP's recommended value for relocation (ICRP93). Relocation should be ended when the dose averted by its continuation is insufficient to justify its continuation.

The decision maker may wish to relocate people to avoid a substantial increase in the "normal" or "background" cancer risk. An effective dose of about 1 Sv would increase the "background" risk of cancer from about 20% to about 25%; this level of dose was chosen by the ICRP as a level above which relocation would generally be considered justified.

If the effective removal half-life of deposited material was greater than about 6 years, and the averted dose per unit time just below 10 mSv/month at the time of return from temporary relocation, the residual dose (i.e. following return) would be greater than 1 Sv. In these circumstances, the averted residual dose would be a more restrictive criterion than an averted dose of 10 mSv/month.

In summary, if the dose rate exceeds 10 mSv/month, or the dose that would otherwise be accumulated in the absence of relocation exceeds 1 Sv, then relocation is likely to be required.

II.4.4 Sequence of Justification and Optimisation

The principles of justification and optimisation each require consideration of the benefit that would be achieved by the intervention and the harm, in its broadest sense, that would also result from it. Although the two principles are stated separately, and are indeed conceptually separate, it is necessary to consider them together when reaching a decision.

In general it is likely that there is a range of optimised values of the Intervention Level for different scenarios that give more good than harm, so that the intervention is then justified over this range of levels, with the selection of the most appropriate one depending on the particular circumstances. There are, however, some situations where the Intervention Level is optimised but **not** justified because the net benefit is negative.

The monetary cost of relocation has a fixed component of initial cost, C_0, and a running cost component, c, of cost per unit time of relocation. The optimised Intervention Level for relocation is expressed only by the running cost component and the monetary value of the unit collective dose, α.

If the initial cost, C_0, is zero, the optimised Intervention Level is **always** justified. If C_0 is greater than zero the optimised Intervention Level is not necessarily justified. The justification will depend on the length of the optimised relocation time period, τ_{opt}. This time period should at least be equal to a minimum period determined by the two cost components and the effective removal rate constant, λ, of the deposited activity to justify a relocation (see Annex A). The conditions for justification of the optimised Intervention Level are given in Figure 4.1.

II.5 Application of Intervention Levels for relocation

II.5.1 Practical Considerations

In general, the Intervention Level should be applied to a typical member of the group to whom the protective action is to be applied, or to a typical member of a subgroup being considered for inclusion in such a group.

The estimation of the dose averted, or of any quantity to be compared with the Intervention Level, should be realistic. The adoption of conservative assumptions in either the specification of the habits of the group or the dose assessment, will inevitably result in action being taken that is sub-optimal and contrary to the principles and purposes of intervention.

The adoption of a conservative approach in the estimation of dose is often defended as being beneficial to those affected, on the grounds that action will be taken at lower doses than intended and that this is in the best interests of those affected. This view is, however, misguided and ignores the negative features of the protective action itself, which may be considerable.

The assumption of habits typical of more extreme members of the affected group would distort the attempt to find the overall balance between the radiation risk averted and the risk and cost resulting from the protective action; the inevitable outcome of this would be that the overall risk and/or cost to which the affected group would be exposed would be higher than necessary.

If the intervention criterion has been properly evaluated as the best in the prevailing circumstances, the subsequent inclusion of pessimism or optimism in any aspect of its application can only be detrimental and in conflict with the principles of intervention.

The choice of average habits will, however, only remain reasonable provided the variation in risk (both that associated with the exposure and the protective action) within the affected group is not too great. In applying the Intervention Levels to heterogeneous population groups, it is necessary, therefore, to ensure that the variation in overall risk within the affected group is not too great.

Where this variation is large, projected doses to the most sensitive sub-groups, e.g. children, should be used for decisions on intervention because of the potential social problems of introducing protective actions selectively into a general population. This would be particularly important if the decision on relocation was based on averting a dose of 1 Sv in a lifetime.

When implementing relocation issues of equality will arise, in particular between people who are relocated and those remaining in adjacent areas. The identification of areas for which the projected doses are higher than the Intervention Level for relocation should be based on measurements of dose rates and nuclide specific surface contamination density. Natural boundaries, such as rivers, roads, etc., and administrative boundaries should be taken into account in

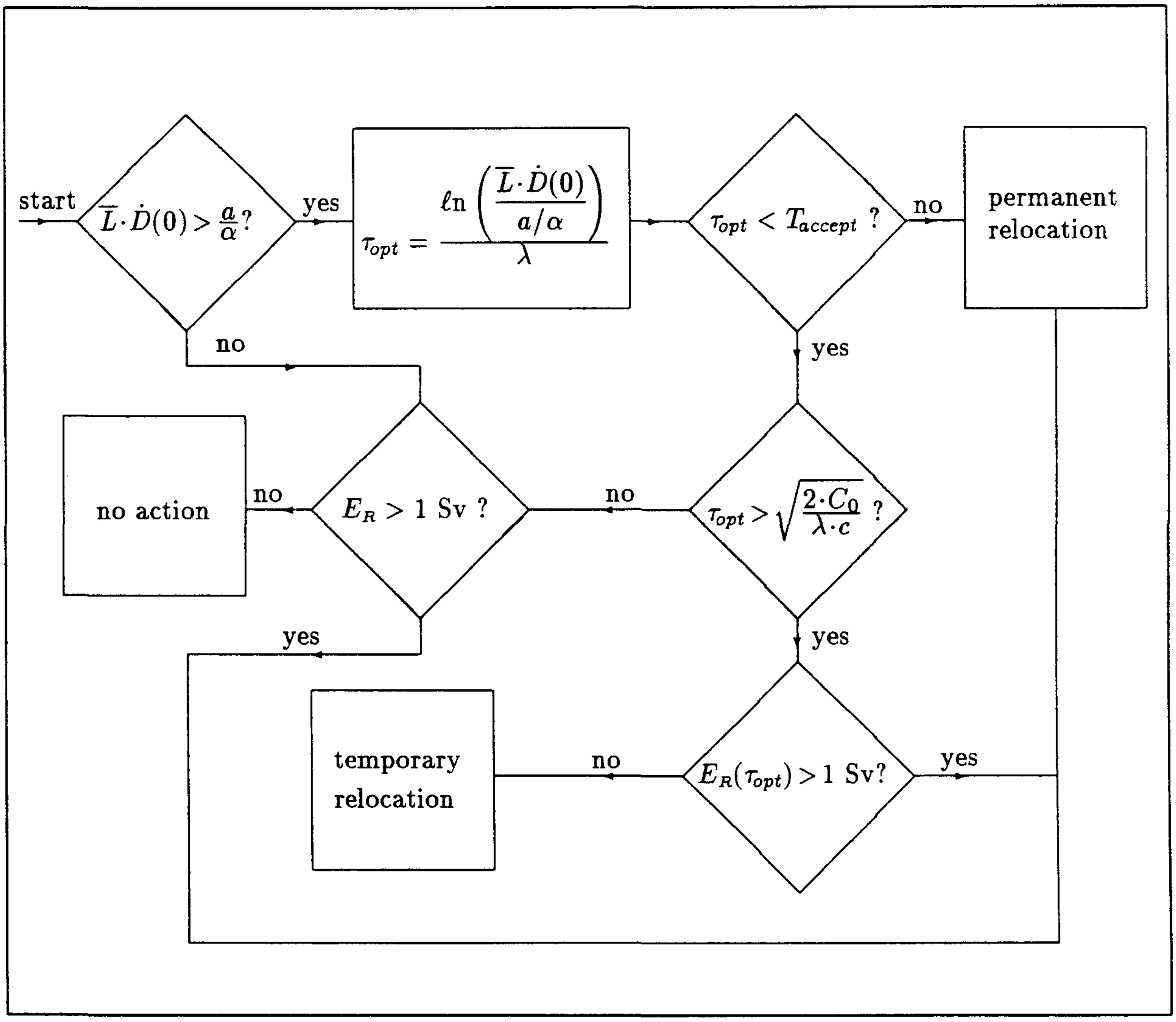

Figure 4.1. Conditions for optimisation/justification of the duration of relocation. The minimum length of relocation time given by $\sqrt{2C_0/\lambda c}$ is valid for $\lambda\tau<1$. The outdoor dose rate at the time of relocation is $\dot{D}(0)$, the time-averaged location factor is $\bar{L}$, the maximum acceptable duration of temporary relocation is T_{accept} and the residual dose after termination of the temporary relocation is $E_R(\tau_{opt})$.

defining areas from which people are to be relocated.

II.5.2 Operational Intervention Levels

Because of the inherent difficulty of forecasting the doses that could be averted by an intervention, there is merit in establishing values for surrogate quantities which can be more readily assessed from conditions prevailing, when decisions need to be made.

The term "Operational Intervention Level (OIL)" (see Annex B) is reserved for these quantities that can be more easily assessed at the time of decision on intervention, such as dose rate, activity concentration, surface contamination density, etc. Operational Intervention Levels are related to the dose that could be averted, and the relationship between these quantities and the averted dose will vary considerably with the circumstances of the accident and nature of contamination, with obvious implications for criteria expressed in these terms. The operational quantities would, therefore, be both accident- and site-specific but would still be inextricably linked to the averted dose.

The *OIL* for relocation can be expressed as an instantaneous outdoor dose rate in open areas when the time-averaged location factor, $\bar{L}$, accounting for shielding and occupancy in that area, is known:

$$OIL = \frac{IL}{\bar{L}} = \frac{c}{\bar{L} \cdot \alpha}$$

where c is the continuing cost of relocation per unit time of relocation and α is the cost of the unit collective dose.

II.6 Conclusions

The use of dose limits, or of any pre-determined dose limits, as the basis for deciding on relocation might involve costs that would be out of all proportion to the benefit obtained and conflict with the principle of justification for an intervention. Therefore, the ICRP (ICRP90) recommends against the application of dose limits for deciding on the need for, or scope of, intervention.

The radiation protection criteria needed for the introduction of relocation should be prepared in advance of an accident in terms of Intervention Levels or Operational Intervention Levels expressing the doses that could be averted by relocation. At the time of the accident, the decision maker will need this guidance as one input together with inputs from other experts to reach a final decision on relocation.

Indicative Intervention Levels for relocation are derived in this report from an optimisation which only includes risk (dose) reduction and the monetary costs of relocation. Based on these two factors, we find an almost always justified intervention level of averted dose over a longer time period of **1 Sv.** An optimised Intervention Level for temporary relocation of the order of **10 mSv/month** has also been determined. Clearly, when other relevant factors are taken into account, these numerical values may be modified. However, it is considered that these indicative criteria form a useful starting point for more detailed exploration of the relocation problem.

Some important issues should be taken into consideration after an accident where relocation is needed.

Firstly, to avoid stress and anxiety building up among the population in affected areas, the decision on relocation should not be unduly delayed. This decision period should be limited to maybe as little as 1 month. Another important aspect is the distinction between temporary and permanent relocation. At the time of the decision it should be made clear to the population if the relocation is to be permanent or only temporary, and in the latter case for what length of time.

Secondly, from a practical, economic and social point of view it should be recognised that relocation lasting more than a few years would become permanent. If the period becomes too long a new infrastructure will inevitably emerge in new localities. Return would thus become less likely as time goes by. A few years seems here to be a reasonable estimation for a maximum acceptable time period for temporary relocation. However, areas from which people have been permantly relocated might be repopulated in the distant future.

Thirdly, after a temporary relocation from areas that have been contaminated with long-lived radionuclides, there would be an increasing residual dose with increasing effective removal half-life of the deposited radionuclides compared to a nearly constant averted dose per unit time. The ratio of residual to averted dose for a temporary relocation period of, say, 1 year could be more than a factor of 10.

If the effective removal half-life is greater than about 6 years, the residual life-time dose, corresponding to a return criterion of 10 mSv/month, would be greater than 1 Sv. Therefore, for a contamination with an effective removal half-life greater than 6 years, relocation would be permanent from areas where the avertable dose is above 10 mSv/month.

Annex A
Justification/Optimisation of the Protection Afforded by Relocation

Justification of Relocation

The harm inherent in relocation includes monetary and social costs and the anxiety and physical risks. The benefits, on the other hand, include the doses averted and reassurance. The net benefit, B, achieved by a protective measure can be expressed as (IAEA94, ICRP3):

$$B = (Y_0 - Y_I) - C$$

$$= \Delta Y - C$$

where

- Y_0 is the cost equivalent of the radiation detriment if the protective measure is not taken
- Y_I is the cost equivalent of the remaining detriment if the protective measure is carried out
- C is the monetary cost of implementing the protective measure

The cost equivalent of the averted radiation detriment, ΔY, can be calculated from the monetary value of the unit collective dose, α, as:

$$\Delta Y = \alpha \cdot \Delta S$$

where ΔS is the averted collective dose afforded by the protective measure.

The net benefit, $B(t)$, of a relocation of duration, t, is given as:

$$B(t) = \Delta Y(t) - C(t)$$

The cost of the relocation will as a first approximation be proportional to the number of people affected. Consequently, the justification/optimisation process can be applied on the basis of average individual cost of relocation and the average individual dose averted by the relocation rather than on the total cost and the averted collective dose:

$$\Delta Y(t) = \alpha \cdot \Delta E(t)$$

The cost of relocation can be assumed to comprise fixed and continuing costs:

$$C(t) = C_0 + c \cdot t$$

where C_0 is the fixed cost component and c is the continuing cost component per unit time of relocation. Therefore, the net benefit can be expressed as:

$$B(t) = \alpha \cdot \Delta E(t) - (C_0 + c \cdot t)$$

Let τ be the period of relocation:

$$\tau = t_2 - t_1$$

where t_1 is a constant, set at the time when relocation started and t_2 is the time when relocation ended.

The averted dose is given by the integral of dose rate during the period of relocation (see Figure 1.1 in Section 1):

$$\Delta E(\tau) = \int_{t_1}^{t_2} \dot{E}(t)\, dt = E(t_2) - E(t_1)$$

The net benefit is then:

$$B(\tau) = \alpha \cdot E(t_1+\tau) - (\alpha \cdot E(t_1) + C_0 + c \cdot \tau)$$

$B(\tau)$ must be positive for the relocation to be justified.

Optimisation of Protection from Relocation

The optimum level of protection from relocation is given by the maximum of $B(\tau)$, when $dB(\tau)/d\tau$ is zero. If t_1 is fixed, the optimum is given by:

$$\frac{dB(\tau)}{d\tau} = \alpha \cdot \dot{E}(t_1+\tau) - c = 0$$

Thus:

$$\dot{E}(t_1+\tau) = \frac{c}{\alpha}$$

and the Intervention Level is given as the dose per unit time, $\dot{E}(t_2)$, at which relocation should be ended:

$$IL = \dot{E}(t_2) = \frac{c}{\alpha}$$

The dose per unit time, $\dot{E}(t_2)$, at the time of return, t_2, can be expressed by the instantaneous dose rate in air over open country as:

$$\dot{E}(t_2) = \bar{L} \cdot \dot{D}(t_2)$$

where $\bar{L}$ is the time-averaged location factor allowing for occupancy and shielding. In principle, $\bar{L}$ may be a function of both the photon energy and time, but it will usually be sufficient to adopt a single value for typical energies and time periods.

The conditions for $B(t)$ at the point of maximum to be positive is:

$$\alpha \cdot \Delta E(t) > C_0 + c \cdot t$$

This expression cannot be evaluated from the values of dose rate and the cost parameters α and c alone. Both the averted dose and the fixed cost component, C_0, have to be estimated. If the condition is not met, the benefit at the maximum is negative and relocation is not justified.

If it is assumed that the time variation of the dose rate can be expressed by an exponential decay function including the environmental removal rate, the conditions can be found from the following calculations:

$$B(\tau) = \alpha \cdot \frac{\bar{L} \cdot \dot{D}(0)}{\lambda} \cdot (1 - e^{-\lambda\tau}) - (C_0 + c \cdot \tau)$$

and:

$$\bar{L} \cdot \dot{D}(0) \cdot e^{-\lambda\tau} = \frac{c}{\alpha}$$

$$\Rightarrow \bar{L} \cdot \dot{D}(0) = \frac{c}{\alpha} \cdot e^{\lambda\tau}$$

which gives the following relation between the relocation time period, τ, the effective removal rate constant, λ, and the relocation costs, C_0 and c:

$$e^{\lambda\tau} - (1 + \lambda\tau) > \frac{\lambda \cdot C_0}{c}$$

For values of $\lambda\tau < 1$ the following approximation can be used:

$$e^{\lambda\tau} \approx 1 + \lambda\tau + \frac{(\lambda\tau)^2}{2}$$

which gives the condition for the minimum value of a justified relocation time period, τ, for nuclides with $\lambda < 1/\tau$ in terms of the relocation costs C_0 and c:

$$\tau_{min} > \sqrt{\frac{2 \cdot C_0}{\lambda \cdot c}}$$

Consequently, if the initial relocation cost $C_0 = 0$, the optimised value of the return time is always justified. If $C_0 > 0$, the optimised return time is only justified if $\tau_{opt} > \tau_{min}$. These conditions for the optimisation/justification of the relocation time are shown in Figure 4.1 in Section 4.

The value of the Intervention Level, $IL = c/\alpha$, is likely to show less variation geographically than either c or α alone. The value of the Intervention Level, IL, calculated from representative cost parameters in Nordic countries, is of the order of:

$$IL = \frac{300 - 600 \text{ \$/man month}}{20{,}000 - 100{,}000 \text{ \$/man Sv}}$$

$$= 3 - 30 \text{ mSv/month}$$

$$\approx 10 \text{ mSv/month}$$

Time of Return

The optimised time of return, t_2, without decontamination of the area, is calculated from the optimised Intervention Level of averted effective dose per unit time as:

$$\bar{L} \cdot \dot{D}(0) \cdot e^{-\lambda t_2} = \frac{c}{\alpha}$$

which leads to:

$$t_2 = \frac{1}{\lambda} \cdot \ln\left(\frac{\alpha\, \dot{D}(0)\, \bar{L}}{c}\right)$$

The condition for this expression is that $\bar{L}\dot{D}(0) > c/\alpha$.

The residual dose, E_R, after return to the area at time t_2 is given by:

$$E_R = \int_{t_2}^{\infty} \dot{E}(t)\, dt$$

Effect of Decontamination on Accelerated Return

If relocation is followed by a decontamination of the contaminated areas, the return time could be accelerated. With a decontamination factor of f (f>1), the external dose per unit time before the decontamination can be expressed as:

$$\dot{E}_1(t) = \dot{D}(0) \cdot \bar{L} \cdot e^{-\lambda t}$$

and after decontamination as:

$$\dot{E}_2(t) = \frac{1}{f} \cdot \dot{D}(0) \cdot \bar{L} \cdot e^{-\lambda t}$$

The external dose per unit time at the return time will be equal in both situations because of the balance between relocation costs and averted dose per unit time. Consequently, the time of return, τ_2, after decontamination will be less than the time of return without decontamination, τ_1. Decontamination should be justified on its own merits. The benefit of a decontamination is the accelerated return time and the costs comprise the decontamination costs plus the monetary value of the doses to the decontamination workers.

The difference, $\tau_1 - \tau_2$, will depend on the effective removal half-life of the deposited radionuclides and the effectiveness of the decontamination. From the equation:

$$\dot{D}(0) \cdot \bar{L} \cdot e^{-\lambda\tau_1} = \frac{\dot{D}(0) \cdot \bar{L}}{f} \cdot e^{-\lambda\tau_2}$$

the accelerated return $\tau_1 - \tau_2$ is found to be:

$$\tau_1 - \tau_2 = \frac{\ln(f)}{\lambda}$$

The accelerated return, $\tau_1 - \tau_2$, for a given decontamination factor, f, will increase with increasing half-life of the deposited radionuclides.

If the decontamination factor, f, is of the order of 1.5 - 2 and the effective half-life is of the order of a few years, the return time could be accelerated by about 1 year.

The optimized time of return, τ_2, after a decontamination with the factor, f, calculated from the accelerated return, $\tau_1 - \tau_2$, is:

$$\tau_2 = \frac{1}{\lambda} \cdot \ln\left(\frac{\alpha\ \dot{D}(0)\ \bar{L}}{c\ f}\right)$$

Decontamination of areas from which people have been relocated would be justified if the decontamination costs, C_{decon}, which include the monetary value of the collective dose to the decontamination workers, are less than the saved relocation costs for the accelerated time of return, $\tau_1 - \tau_2$:

$$c \cdot \frac{\ln(f)}{\lambda} > C_{decon} \Rightarrow \textbf{decontamination}$$

Decontamination could be justified also in areas from which people have not been relocated if the decontamination costs are less than the monetary value of the averted collective dose otherwise received by the population.

In general, if return to the area takes place within a maximum acceptable relocation time period, T_{accept}, the ambient dose equivalent rate at the time of relocation should be less than:

$$\dot{D}(0)_{max} = \frac{f}{\bar{L}} \cdot \frac{c}{\alpha} \cdot e^{\lambda T_{accept}}$$

Experience from different research programmes on decontamination and from the Chernobyl accident seems to indicate that a large-scale decontamination would not result in reduction factors greater than 2 - 3.

Annex B
Operational Intervention Levels for Relocation

General

Quantities such as dose rate and surface contamination density would be needed as Operational Intervention Levels because these quantities can be easily measured and applied as surrogates for the Intervention Level of averted dose. However, such operational quantities should be carefully derived from the Intervention Level, the local conditions and the circumstances of the accident, which include the environmental half-lives of the deposited radionuclides and location factors for housing conditions in the affected areas accounting for occupancy and shielding.

(a) Dose rate

Single radionuclides

The ratio of the accumulated external dose over a given time period, (t_1, t_2), to the external dose accumulated per unit time at time t_3 $(t_3 > t_1)$ after the plume passage, is calculated for a given radionuclide as:

$$\frac{IL_{temp}}{OIL_{temp}} = \frac{\Delta E(t_1,t_2)}{\dot{D}(t_3)}$$

$$= \frac{\int_{t_1}^{t_2} \bar{L} \cdot \dot{D}(0) \cdot e^{-\lambda t} dt}{\dot{D}(0) \cdot e^{-\lambda t_3}}$$

$$= \frac{\bar{L}\,(e^{-\lambda t_1} - e^{-\lambda t_2})}{\lambda \cdot e^{-\lambda t_3}}$$

The Operational Intervention Level expressed as an instantaneous dose rate and corresponding to the Intervention Level for temporary relocation, IL_{temp}, is calculated as:

$$OIL_{temp} = \frac{IL_{temp}}{\Delta E(t_1,t_2)/\dot{D}(t_3)}$$

$$= \frac{a}{\alpha} \cdot \frac{\lambda \cdot e^{-\lambda t_3}}{\bar{L} \cdot (e^{-\lambda t_1} - e^{-\lambda t_2})}$$

where $\bar{L}$ is the time-averaged location factor for the area.

In Table B1 values of the ratio $\Delta E(t_1, t_2)/\dot{D}(t_3)$ are calculated for radionuclides with different values of the effective removal half-life and for a value of $\bar{L}$ of 1.0.

Mixture of fission products

Another approach is to consider a release of a mixture of fission products. The dose rate from deposited fission products has a time dependence of the type t^{a}, where a is in the range of 0.2 - 0.8 for the first few months after the release, depending on nuclide composition, and t is the time in days.

The ratio of the accumulated dose over a given time interval, (t_1, t_2), to the dose accumulated per unit time at different times, t_3 $(t_3 < t_1)$, after the plume passage is calculated from:

$$\frac{IL_{temp}}{OIL_{temp}} = \frac{\Delta E(t_1,t_2)}{\dot{D}(t_3)}$$

$$= (t_3)^{a} \int_{t_1}^{t_2} \bar{L}\, t^{-a}\, dt$$

$$= \frac{\bar{L}\,((t_2)^{1-a} - (t_1)^{1-a})}{(t_3)^{-a}\,(1 - a)}$$

Table B1. Values of $\Delta E(t_1, t_2)/\dot{D}(t_3)$ for radionuclides with different effective removal half-lives for monthly periods following the reference time for dose-rate measurement, t_3. The value of $\bar{L}$ is 1.0.

$\Delta E(t_1, t_2)/\dot{D}(t_3)$ (mSv/mSv·h^{-1})					
Effective removal half-life (years)	Monthly periods (t_1, t_2) following the measurement time, t_3				
	1st month	2nd month	3rd month	6th month	12th month
0.1	549	310	176	32	1
0.5	680	607	542	385	194
1.0	700	661	625	526	374
5.0	716	708	700	676	632
10.0	718	714	710	698	674

The Operational Intervention Level corresponding to the Intervention Level for relocation, IL_{temp}, is calculated as:

$$OIL_{temp} = \frac{IL_{temp}}{\Delta E(t_1,t_2)/\dot{D}(t_3)}$$

$$= \frac{a}{\alpha} \cdot \frac{(t_3)^{-a}\,(1 - a)}{\bar{L} \cdot (\,(t_2)^{1-a} - (t_1)^{1-a}\,)}$$

In Table B2 values of $\Delta E(t_1, t_2)/\dot{D}(t_3)$ have been calculated for different values of t_3 and for a value of the parameter a of 0.8, which is valid for contamination by a mixture of all the radionuclides of caesium and iodine in the same proportion as in a reactor core. The value of $\bar{L}$ is 1.0.

The reference time, t_3, is always smaller than t_1, i.e. the decision on relocation will be taken after measurements of the dose rate. The ratio $\Delta E(t_1, t_2)/\dot{D}(t_3)$ is independent of the values of t_3, because of the assumed exponential removal rate.

For an IL_{temp} of 10 mSv/month and a contamination with an effective removal half-life of 1 year, the OIL_{temp} for triggering a relocation for at least 6 months after the measurement, is calculated from the values in Table B.1 as an instantaneous dose rate at time t_3 of:

$$OIL_{temp} = \frac{10}{0.2 \cdot 526} = 0.1 \text{ mSv/h}$$

assuming that the time-averaged location factor is 0.2.

If the effective removal half-life had been 0.1 year, the corresponding OIL would have been an instantaneous dose rate at time t_3 of 1.6 mSv/h to trigger a relocation for 6 months.

Table B2. Values of $\Delta E(t_1, t_2)/\dot{D}(t_3)$ for mixtures of radionuclides for monthly periods following the reference time for dose-rate measurement, t_3. The value of the decay parameter a is 0.8. The value of $\bar{L}$ is 1.0.

$\Delta E(t_1, t_2)/\dot{D}(t_3)$ (mSv/mSv·h^{-1})					
Value of reference time t_3 (days)	Monthly periods (t_1, t_2) following the measurement time, t_3				
	1st month	2nd month	3rd month	6th month	12th month
1	118	35	23	12	7
2	178	59	39	21	12
3	222	80	54	29	16
7	332	148	101	56	31
14	432	231	165	94	54

For an IL_{temp} of 10 mSv/month and a contamination with a decay parameter a of 0.8, the OIL_{temp} for triggering a relocation for at least 6 months after the measurement is calculated from the values in Table B.2 as an instantaneous dose rate at time t_3 = 7 days of:

$$OIL_{temp} = \frac{10}{0.2 \cdot 56} = 0.9 \text{ mSv/h}$$

assuming that the time-averaged location factor is 0.2.

If the measurement had been made at time t_3 = 1 day, the corresponding OIL would have been an instantaneous dose of 4 mSv/h to trigger a relocation for 6 months.

The Operational Intervention Level for permanent relocation, OIL_{perm}, is based on two conditions, namely (a) the avertable lifetime dose should be 1 Sv or more, and (b) the duration of a temporary relocation should be less than a few years, which in this report is taken to be 2 years. The OIL_{perm} for permanent relocation for specified radionuclides is therefore calculated from the two conditions (a) and (b) as:

Condition (a):

$$\bar{L}\ \dot{D}(0) \int_0^{70 \text{ years}} e^{-\lambda t}\, dt < 1 \text{ Sv}$$

Condition (b):

$$\bar{L}\ \dot{D}(2 \text{ years}) = \bar{L}\ \dot{D}(0)\ e^{-\lambda\ 2 \text{ years}}$$

$$< 10 \text{ mSv/month}$$

The OIL_{perm} is here the instantaneous dose rate in outdoor air, $\dot{D}(0)$, at the time of decision of permanent relocation which is shown in Table B.3 for three different radionuclides.

If the outdoor external dose rate from a contamination with ^{106}Ru at the time of decision for relocation is above $60/\bar{L}$ μSv/h, the avertable external dose after 2 years would still be greater then 10 mSv per month and permanent relocation therefore mandatory. Similarly, for ^{137}Cs, permanent relocation should be introduced if the outdoor dose

Table B.3. Operational Intervention Levels, OIL_{perm}, for permanent relocation corresponding to an Intervention Level, IL_{perm}, of averted external dose of either 10 mSv/month beyond 2 years or an avertable external dose of 1 Sv. For illustrative purposes the values are calculated for a maximum acceptable relocation period of 2 years and for an environmental half-life of 15 years.

Operational Intervention Levels for permanent relocation, *OIL*		
Radionuclide	Outdoor external dose rate at time of relocation (μSv/h)	
	10 mSv/month for more than 2 years	1 Sv for a lifetime
^{106}Ru	$60/\bar{L}$	$80/\bar{L}$
^{134}Cs	$30/\bar{L}$	$40/\bar{L}$
^{137}Cs	$15/\bar{L}$	$8/\bar{L}$

rate is greater than $15/\bar{L}$ μSv/h.

Table B.3 shows that for a ^{137}Cs-contamination with an effective removal half-life of about 10 years, corresponding to an environmental half-life of 15 years, the 1 Sv criterion for permanent relocation will be the most restrictive of the two criteria. The value of the effective removal half-life that would make the two criteria equally restrictive is about 6 years. For an effective removal half-life lower than this, the criterion of 10 mSv per month for 2 years will be the most restrictive, and the residual dose after return after 2 years of temporary relocation would be less than 1 Sv.

(b) Surface contamination density

The external dose rate will depend on the contamination density, Q, of the deposited radionuclides. In an unshielded position out of doors, having no buildings within a few hundred metres around the measuring point, the surface contamination density is expressed as:

$$Q = q \cdot \dot{D}$$

where q is the surface contamination density per unit dose rate.

This conversion factor is nuclide specific and also depends on the roughness of the surface on which the radionuclides are deposited. Normally, the surface roughness of a lawn is used as reference for the calculation of conversion factors for deposited nuclides. Values of the conversion factor, q, are illustrated in Table B.4 for the radionuclides of ^{134}Cs, ^{137}Cs and ^{106}Ru.

An accumulated external dose of 10 mSv per month for long-lived nuclides corresponds to an accumulated dose per unit time of $10/30 \cdot 24$ = 0.014 mSv/h. If the time-averaged location factor for the area is 0.2, this is equivalent to an instantaneous outdoor dose rate of 0.014/0.2 = 0.07 mSv/h. The figures in Table B.4 show that an external dose rate of 0.07 mSv/h would result from a surface contamination density of ^{137}Cs of approximately 50 MBq/m^2.

A surface contamination density of 50 MBq/m^2 ^{137}Cs is therefore the Operational Intervention Level for relocation of that area, because surface contamination densities above that value would cause an effective dose of more than 10 mSv for anyone living a normal life in the area for one month. For ^{106}Ru the corresponding *OIL* would be 140 MBq/m^2.

Table B.5 gives examples of Operational Intervention Levels for temporary relocation corresponding to an Intervention Level of avertable external dose of 10 mSv/month and Operational Intervention Levels for permanent relocation corresponding to an Intervention Level of avertable life-time dose of 1 Sv, or a duration of temporary relocation greater than 2 years, for different radionuclides, expressed as surface contamination density.

Table B.4. Surface contamination density per unit external outdoor dose rate 1 m above an infinite plane surface source with a surface roughness corresponding to an effective depth of the source in the soil of 3 mm.

Nuclide	q (MBq·m^{-2}/mSv·h^{-1})
^{106}Ru	2000
^{134}Cs	300
^{137}Cs	700

Table B.5. *OILs* for temporary relocation corresponding to an Intervention Level of averted external dose of 10 mSv/month, and *OILs* for permanent relocation corresponding to an averted life-time dose of 1 Sv or a temporary relocation period of more than 2 years. The time-averaged location factor for the area is $\bar{L}$.

Operational Intervention Level for temporary relocation, *OIL*			
Radionuclide	Surface contamination density at time of relocation (MBq/m^2)		
	OIL_{temp}	OIL_{perm} (> 2 years)	OIL_{perm} (> 1 Sv)
^{106}Ru	$28/\bar{L}$	$120/\bar{L}$	$160/\bar{L}$
^{134}Cs	$3.9/\bar{L}$	$8.4/\bar{L}$	$11/\bar{L}$
^{137}Cs	$10/\bar{L}$	$11/\bar{L}$	$5.7/\bar{L}$

For comparison with the external dose factors shown in Table B.4, calculations have been made of the corresponding dose factors for resuspension and ingestion doses to small children playing outside for 8 hours a day.

These calculations are made under the assumptions that the resuspension factor is 10^{-5} m^{-1}, that 0.2 g soil is ingested per day (MIL90), and that the inhalation and ingestion dose conversion factors both are 10^{-8} Sv/Bq (radionuclides of caesium, ruthenium, etc.).

The results are shown in Table B.6. For α-emitters the values of q would be a factor of 100 lower because of a dose per unit intake that is 100 times higher.

Table B.6. Surface contamination density per unit resuspension and ingestion doses per unit time for small children. The resuspension and ingestion doses are representative of radionuclides having dose conversion factors of the order of 10^{-8} Sv/Bq.

Exposure pathway	q ($MBq \cdot m^{-2}/mSv \cdot h^{-1}$)
Resuspension	40000
Ingestion of soil	400000

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Appendix III
Decision Making and Decision-Aiding Techniques

by

Kari Sinkko

1 Introduction

Decisions concerning protective actions involve *multiple objectives* such as minimizing the dose, monetary costs and social disruption. No course of action achieves all these objectives. Factors affecting decisions usually conflict with one another, and some are more important than others. Thus, there is a need to consider *trade-offs* between the benefits and drawbacks connected to various factors. The problems also involve *uncertainties*. For example, the dose and the costs of an individual can only be predicted at the moment of the decision, and large variations are possible. So, the *attitude to risk* held by the decision maker(s) will affect the choice of an alternative. Decisions on protective actions are *sequential*. If an action is taken, it may call for a second action. Finally, protective actions, as concerning society, are *group decisions*. Multiple stakeholders may have different views on the problem and alternative sets of objectives.

Research over the past 30 years has transformed the abstract mathematical discipline of decision theory to a potentially useful technology known as *decision analysis*, which may assist decision makers in handling large and complex problems and the attendant flows of information. Decision analysis is not intended to solve problems directly. Its purpose is to produce insight and understanding, so that the decision maker can make better decisions. Those interested in the theory of decision analysis may consult the literature (French 1988, Goodwin et al. 1992, Keeney et al. 1976, Winterfeldt et al. 1986).

There are numerous ways in which the process of making decisions can go wrong, usually without our knowing it. This appendix explains the importance and practical relevance of decision analysis. In particular, a dicussion is given how the analysis guides a decision maker and how qualitative verbal descriptions of a system can be translated into a well-defined mathematical model.

2 Decision Analysis for Management of Information

In decision theory it is implicitly assumed that the actual decision maker has need of the support and guidance of some form of structured decision analysis. Where this is not the case, it might seem simpler, more efficient and more acceptable to allow the decision maker to study carefully the complete list of alternatives and to choose intuitively without recourse to any formal analysis.

Studies indicate that, when left to their own devices, people easily form and hold many kinds of inconsistent beliefs and preferences. This view is supported by research, which indicates 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 gets larger (Winterfeldt et al. 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 will lead to irrationality (Kahneman et al. 1981).

The essence of decision analysis is to break down complicated decisions into small pieces that can be dealt with individually and then recombined logically. Most important, decision analysis makes a clear distinction between the choices that can be made (*alternatives*), the characteristics of the alternatives (*attributes*) and the relative desirability of different sets of characteristics (*preferences*).

The process of breaking something down into its constituent parts refers to the process of developing an overall analytic structure. The formulation of the problem is *to identify what can be done and what might happen as a consequence*. In this process the construction of a decision table or *decision tree* is very helpful. Figure 1 shows, as an example, a decision tree for primary protective actions. Problem formulation is a major part of any decision analysis.

Structuring the problem and identifying options and objectives are the difficult parts of most problems. However, model building is important because, as initially presented, many decision models do not capture the essential views for choice among the options. The model will be improved by running through rough calculations and with the help of clarifying discussions. It is an iterative process and creative exercise. If the model is not restructured at least once or twice, then one should worry whether the problem has been considered carefully enough (Winterfeldt et al. 1986). The initial structuring depends on the problem at hand. One might start building the model by identifying the actions or the attributes, sometimes the key uncertainties.

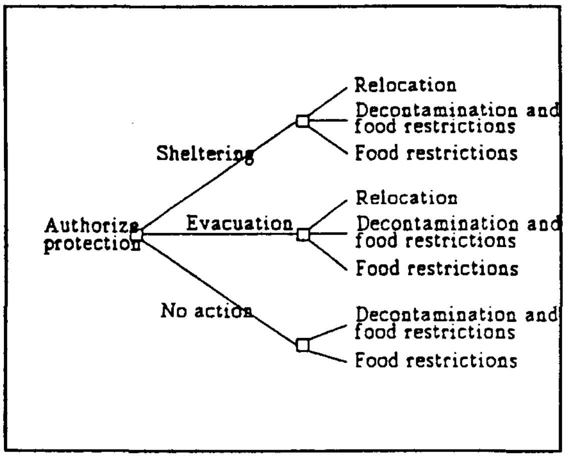

Figure 1. A sequential decision tree for primary protective actions.

Before any formal or informal analysis, it is necessary to identify the decision to be made, the stakeholders and the deciding organization - the real decision maker(s) - and the purpose of the analysis. The analysis may well serve other purposes rather than leading to prompt decisions. The advance planning of protective actions is a common example.

3 Action Alternatives

One main stage in the analysis is to identify the alternative courses of action. In considering an intervention, all feasible actions are defined - including no action at all - which might be implemented to control a certain pathway. One should also define the population group to be protected and which group is reached by the action. In defining the action its feasibility should be considered; can it be implemented in practice as has been planned? Society is by no means indifferent to the choice of action. Public opinion and perception of risk can reduce the benefit of an action or make its implementation impossible. For example, in a limited accident the population might not wish to comsume cheese or butter if these were made from milk produced in a contaminated area although, e.g., cesium and iodine could be removed very efficiently during manufacturing processes. It is difficult to make people to follow recommendations, that are against their wishes and psychological needs.

4 Objectives and Attributes

Having identified possible courses of action, the next main step is to identify all the attributes relevant to the decision problem. Although one might have identified alternatives first, it is useful to iterate between articulating values and creating alternatives. *Alternatives are relevant only because they are means to achieve values.*

One technique for identifying an operational set of attributes is to start by listing all important objectives, such as the reduction of health detriment, the monetary costs and social disruption. The objectives can be divided into general categories: health, safety, social, political, psychological and economical effects. Since environmental values are multidimensional, many of these objectives will necessarily be involved in any decision following radiological emergencies. Some of the objectives might be directly measured on a numerical scale and some should be further divided into sub-objectives in order to be measurable. This kind of numerical variable is called an attribute, and it is used to measure the performance of actions in relation to an objective. Natural attributes are, e.g., immediate deaths, cases of cancer or reductions in the length of life. Using either radiation dose or ultimate health effects, such as cancer as an attribute may have much impact on the final outcome of the analysis. An *attribute hierarchy* (*value tree*) can be useful in defining attributes and objectives. Figure 2 shows a value tree for a radiation protection problem.

The top layer of the tree contains very general, and sometimes vague values. The values become more specific lower down the tree. The building of the objective hierarchy is continued until such objectives are found that are measurable, operational or easy to assess judgementally. Keeney and Raiffa (1976) propose the following criteria for examining the attributes: *completeness, operationality, decomposability, absence of redundancy and minimum size*. See also Keeney, R. (1992) 'Value focused thinking' for advice on building attribute/value trees. To make the tree operational, it may be necessary to increase its size or prune it. For example, in some decisions only dose averted and monetary costs may turn out to impact significantly on the decision.

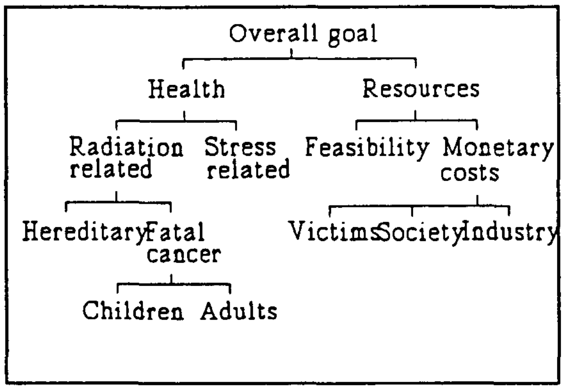

Figure 2. A value tree for a radiation protection problem.

The quality of a tree may only become clear after assessment of the numerical values and weights. However, the analyst should be relatively certain that the current structure is reasonably acceptable before eliciting numbers in detail. Only a well-defined and acceptable structure will provide a feeling for what numbers are important and require refined assessment. A good way of checking an initial structure is to make a few preliminary numerical assessments and run through some rough calculations (see below for the form of assessment and calculations).

The hierarchy of objectives facilitates the process of ensuring that the final set of attributes actually captures all the relevant and useful values. All important factors affecting the decision have to be taken into account. If crucial objectives are omitted from the list, the value of the analysis as a tool for communication and the consideration of alternatives diminishes. In addition, the consideration of political issues and being open and explicit about selfish values and motives helps the decision maker to benefit from the process. If these subconscious and social issues are ignored, the decision maker may be disappointed after the decision is made (Winterfeldt et al. 1986).

5 How Options Perform on Each Attribute

The consequences of the actions can now be assessed, i.e., how well do the different actions perform on each of the lowest-level attributes in the value tree. The consequences are the values of attributes in various actions, e.g., the assessed dose if the action is taken and its monetary costs. The measurement of these attributes is easy, because we can identify the variables representing them. However, for attributes such as stress and anxiety, it will be more difficult to find a variable that can be quantified. The techniques, that can be used to express the preferences over the values of an attribute, are *direct rating* and the use of *value functions*.

Direct rating can be used with attributes which cannot be represented by easily quantifiable variables. In this technique, the most preferred option for, e.g., anxiety, 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 strength of preference for one option over another in terms of anxiety. Although this technique seems robust, it should be emphasized that there are methods of checking the consistency of the numbers elicited. Also, numbers do not need to be precise. As will be pointed out later when discussing sensitivity analysis, the choice of action is generally fairly robust, and substantial changes in the figures are often required before another option is preferred. Application of this method can be found in French et al. (1993).

The preferences over values of an attribute can be changed numerically also by a value function. As in direct rating a value of 100 (or one) is given to the most preferred option for an attribute, and the value of zero to the least preferred option. There are several methods that can be used to elicit the intermediate values to form a continuous value function. Figure 3 shows a value function for dose.

The values of attributes should be assessed realistically, without overestimation. Conservatism in assessment may cause overestimation of the benefit of an action, excess of monetary resources and increase of unnecessary stress in the population. The consequences for the rest of the population should also be taken into account. The assessment of values could be based on radiological and economical consequence models and on predictions of the course of an accident.

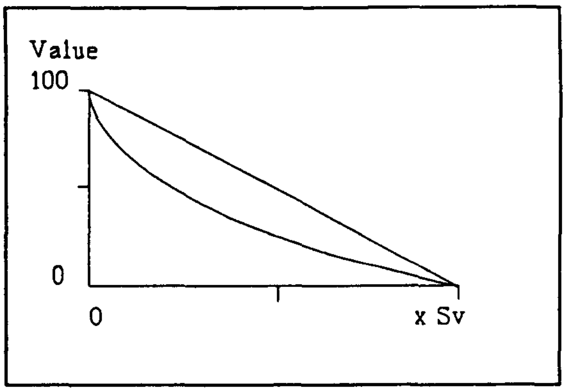

Figure 3. A linear and convex value function for dose.

6 Trade-offs - Least Secure and Most Uncomfortable to Make

Before we can combine the values for different attributes in order to obtain a view of the overall benefits offered by each action, we have to assess the weights on attributes. They represent the judgement of the decision maker on the relative importance of the levels of attributes. For example, how much he/she is ready to invest to avoid a certain dose. When assessing a trade-off value, it should be noted that 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 cases of cancer. Here the range means the difference in values in various actions, e.g., the difference in dose when the action is taken or not taken. The significance of determining and expressing the trade-off value is enhanced for low radiation dose levels when it has to be decided whether to take an action or not, or when assessing intervention levels.

There are different preferences connected to the values of attributes. Therefore, *the trade-off values are subjective*, not objective. Expressing the value may be both unpleasant and difficult, but often it is very crucial when assessing an intervention level. Decision analysis does not require an accurate trade-off value but a range; the minimum and the maximum values. A rough mean value could be used in the analysis and the effect of its uncertainty studied afterwards in a comprehensive sensitivity analysis. The demand for a relatively narrow range of trade-off value relates to the fact that the decision maker is striving to find a decision.

As the trade-off values are subjective, there are no universal values. The values are related to a specific problem, and in addition they change according to opinions and resources. There are methods and studies which make it possible to estimate the trade-off value and give more insight and understanding of the values. However, these methods, such as *contingent valuation* and investment studies, carried out to prevent harm, have been criticized. 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' (see, for example, Gregory et al. 1993). The results of investment studies are no more useful, because these problems are usually poorly structured and do not indicate multidimensional values behind decisions. Environmental values are multidimensional and people have strong feelings and beliefs about these values, which typically are not numerically quantified and *do not exist in monetary form*. 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. So it does not seem reasonable to assess trade-off values using different studies. Indeed, a proposal has been made to adopt the multiattribute value/utility theory in contingent valuation studies (Gregory et al. 1993).

The value of an attribute, such as the costs of the protective action, may be small, indirect or not easily discernible. The trade-off value should not, however, be established on the apparent insignificance because it can lead to irrationality between other protective actions when values of factors in other actions are great and actual. There should be coherence between actions so that people are equitable protected at different times after the accident.

Swing weighting is recommended as an assessment method for scaling constants, i.e., the trade-offs. The decision maker is asked to compare a pair of hypothetical actions which differ only in their values along two attribute scales. In this method a set of hypothetical options is given to the decision maker until an indifferent pair of options is found. For example:

Option A: The individual dose is 5 mSv and the monetary costs are 0 USD.

Option B: The individual dose is 4 mSv and the monetary costs are 20 USD.

If the decision maker is indifferent to options A and B, it can be seen that he/she is willing to invest 20 USD to reduce the individual dose by 1 mSv, i.e., the trade-off value - 'α-value', in radiological protection terminology - is 20,000 USD/manSv.

7 Aggregating the Benefits

At this stage we are in a position to aggregate the values to find out how well each action performs overall. We can use an *additive model* simply to add together the weighted value scores of an action (weighted attribute values on each action) to obtain the overall benefit:

$$v(a) = \Sigma_i k_i v_i(a_i),$$

where $v_i(a_i)$ are single-attribute value functions and k_i are weighting factors. A sufficient condition for an additive decomposition of multi-attribute value function is mutual preferential independence of the attributes. An attribute X is preferentially independent of attribute Y, if the two preference values of attribute X do not depend on the value of Y. The existence of preferential independence is normally verified during the analysis - and should, in principle, be verified. If the conditions for an additive function exist, the weights are assessed by making trade-offs between attributes as described earlier.

Cost benefit analysis is also an additive model commonly based on linear value functions (i.e., $v_i(a_i) = a_i$). The distinguishing feature is that every attribute of an alternative is transformed by a conversion factor k_i to a financial value, positive or negative. Alternatives are compared according to their total financial value. Applications of cost benefit analysis in radiation protection can be found in Gjörup et al. (1992).

Additive models are widely used and have been found to be useful in decision conferences, where a group of decision makers meet to consider a decision problem (French et al. 1993). The cost of its simplicity is that the method may not capture all the details and complexities of the real problem. In practice, the approach has been found to be robust, although not suitable in all circumstances. For example, it is inappropriate if major uncertainties are connected to the decision.

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 higher or lower doses than estimated will result, or it is not known how successful the action will be. Facing these uncertainties, the attitude to risk of the decision maker will affect the choice of action. This attitude can be assessed by eliciting a *utility function.* This is to be distinguished from the value functions, which are used in decisions where uncertainty is not a major concern. Value functions do not involve any consideration of risk attitudes.

As in the additive model, for each course of action a numerical score is derived to measure its attractiveness to the decision maker. In utility analysis this score is termed the *expected utility* of the course of an action (additive form):

$$u(a) = \Sigma_{ij} k_j p(a_i) u_j(a_{ij}),$$

where the probability $p(a_i)$ is the occurrence of a certain attribute j level i, and $\Sigma_i p(a_i) = 1$, by definition.

There are many approaches which can be adopted to elicit the utility functions. The common methods are based on reference experiments, where the decision maker is offered a series of choices between receiving certain outcomes or entering hypothetical lotteries. If the elicited function is concave, it indicates a risk aversion attitude, a linear utility function demonstrates a risk neutral, and a convex one a risk-seeking attitude.

In solving problems which do involve *uncertainty* and *risk*, utility has a valuable role to play. The utility function is designed to allow both of these factors to be taken into account. However, in circumstances where the decision maker only requires an outlined guidance from the model, it is not worth going to the trouble of asking a series of potentially difficult questions. A less sophisticated approach may be sufficient, e.g., based on values rather than utilities. Sensitivity analysis will provide useful guidance on the robustness of the applied model.

8 Sensitivity Analysis

It is wise to be sceptical about the ranking of the actions, if the variation of the figures used in the analysis is not analyzed by means of a sensitivity analysis. We have to examine the robustness of the choice of an alternative in the light of changes in the figures. In many cases sensitivity analysis also shows that the data need not be accurate. Large changes in these figures are often required before one action becomes more attractive than another. If this is the case, then it would be a waste of effort and time to elicit the numbers more accurately.

There are several techniques described in the literature for performing a sensitivity analysis. The most straightforward analysis currently used examines the effects of varying one parameter at a time. Although the method is simple, it clearly indicates which factors are important and require refined assessment. In some circumstances the additional use of a spreadsheet package can make sensitivity analysis easy, allowing a large number of 'what if' situations to be analyzed in a few minutes.

9 Group Decisions and Decision Conferencing

The decision analysis discussed above is based on the preference model of a single decision maker. However, in reality, the decision maker is not always a single person, but often a group in which opinions differ. Decisions involving societal issues such as protective actions are often group decisions, which may be affected by various markets and those controlling various interests. It is more complex to develop a mathematical model for rational group decisions than a mathematical preference model for an individual decision maker. 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. Nevertheless, it is possible to analyze decision problems for groups of decision makers in a manner that can be characterized as useful and informative (See, for example, French 88).

The values or the expected utilities of a group cannot be constructed by individual value or utility functions. Therefore, democracy does not exist in a simple form. A fair and just solution to a group decision problem can be found only if each member of the group behaves rationally and equitably.

Technically, group decisions can be made with the help of a decision analysis by treating the group as an individual, and by constructing the problem and the solution as explained above. In group decisions as well as in individual decisions, decision analysis aids decision makers in 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 in a discussion for jumping from one issue to another without direction or progress. The internal confidence of a group makes the role of the analyst more important in group decisions than in decisions involving only one person. When necessary, the analyst can discuss with the group collectively, or with individuals or subgroups that have special technical expertise.

If a mutual understanding is reached in a group analysis, then consensus values are chosen. In the case of disagreement, rough averages are used. But as stated before, it is fruitless to form a group's subjective probabilities or expected utilities on the basis of mean values. The aim is only to construct a rough skeleton of the decision analysis which can be modified using the views of the members, discussing with them, and using a comprehensive sensitivity analysis. *Decision conferencing*, discussed next, is a socially interactive approach to group decision making in order to generate a shared understanding of the problem and to produce a commitment to action.

Decision conferencing brings together decision analysis, group processes and information technology over an intensive, generally two- or three-day session attended by decision makers, e.g., stakeholders with different fields of expertise. A small group wishing to resolve a problem, and having an input to the decision, is seated in a semicircle to discuss the problem through a *facilitator*, who aids the group's discussion and knowledge sharing. In the background an *analyst*, using decision-aiding technology, models the group views.

The objective of decision conferencing is to provide a shared understanding of the problem and views generated with the aid of decision-analytic techniques and social facilitation. Phillips (1984) argued that decision conferencing produces conditions for creative and effective decision making. Participants are not on home ground. Usually sessions take place in hotels, or an especially designed room on the facilitator's premises. The group is carefully composed of problem owners representing all perspectives on the issue to be resolved. The facilitator is a neutral outsider.

To date, well over 500 decision conferences have been held worldwide. In the field of radiation protection at least seven have been organized so far, five of which in Soviet Uninon (IAEA 91), and one by the BER-3 committee of the NKS BER programme, in Denmark in 1992. It was attended by local government officials, emergency planners and members of the radiation protection community in the Nordic countries (French et al. 1993).

10 Summary

The planning of protective actions aims to find, based on the available information and the preferences of the decision maker(s), the best course of action. It is worth noting, that protective actions are social choices, in which - at least in a democracy - the decision maker(s) represents the population, on behalf of which the decision is made, and its preferences which are considered in a fair and just solution. Thus, an action should be based on preferences of the population. However, these preferences are ill-defined or difficult to elicit, and the decision maker has to decide on behalf of the population. The preferences and beliefs of the decision maker should be no different in this situation whether he decides by himself or on behalf of the population. In addition, his/her preferences should not be selfish; they should describe what he/she feels is best for those for whom he/she is responsible. The decision maker should imagine himself in the position of each member of the population and form a family of preferences representing those of each member of the population. This type of altruism meets the criterion of a fair and just solution.

In order to obtain the planned benefit, *the protective actions and their basis should be transparent and understandable to the population*. The planning of protective actions with the assistance of decision analysis helps to clarify the importance of the factors involved and to elicit the preferences.

At the beginning of this annex I referred to psychological experiments that indicate the biases in human judgement. However, many of these studies were carried out in laboratories and they have been criticized for not describing the real world. Research indicates that real world judgements are more accurate when more information is provided. Adequate information, and the way in which the data are presented, is essential for an understanding of the problem's underlying structure.

The objective of this annex has been to give an illustration of decision analysis and its application when planning countermeasures in order to mitigate the consequences of a nuclear accident. The basic principle in planning protective action is that intervention should be justified and optimized, i.e., the introduction of a protective measure should achieve more good than harm and the net benefit should be maximized. As we have seen, decision analysis can guide the decision maker in many ways in solving societal problems of this type. There are, however, many other techniques which can be adopted. Generally, the method chosen should depend on the problem and its complexity, the people involved, and the time available.

ACKNOWLEGEMENT

I should like to thank Professor Simon French for his advice and invaluable comments on this appendix.

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Appendix IV
Risk Perception and Risk Communication

by

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Abstract

Such issues as risk analysis, risk perception, and risk communication have become increasingly important and debated during the last 20-25 years. In our highly complex society, which requires sophisticated and sometimes large-scale technological solutions to current, and future, human needs, the risk aspects cannot be disregarded. Neither can they be fully described or totally controlled; this may create feelings of frustration, vulnerability and distrust in the general public. Risks are analyzed to foresee and minimize adverse events, if not to prevent them. Risk perceptions refer to intuitive judgements of risk. The development of and interest in the risk area have increased the number of people involved, revealed the multidimensionality of the important factors to consider, and pointed out the importance of, as well as the difficulties associated with, risk information and risk communication. Public awareness of risk, including concern about possible catastrophes and long-term health effects, calls for valid information and adequate safety standards. Leaders of society, authorities and professional risk managers face the challenge of meeting the requirements correctly and comprehensively. This paper discusses some areas of risk perception and risk communication. It is argued that an enhanced understanding of perceptions of risk demands a broader perspective and more intensive research collaboration between traditionally separated research areas than is currently the case. It is also argued that risk communication research would benefit from intensified research efforts on the establishment of effective communication networks. It is finally argued that public perceptions of risk will continue to increase until powerful positive alternatives of future scenarios are presented.

* The author wants to thank professor Lennart Sjöberg and professor Ole Walmod-Larsen for comments on the previous manuscript.

Introduction

The world is filled with pain. Frustration, stress and bereavement are normal human experiences in life. Joy and success are positive contrasts to normal life, and satisfaction and contentment are mental states accepting what life has become and what it may involve. The sharp contrast between one's personal goals in life and the reality encountered may result in feelings of inadequacy, discontentment and alienation. It seems as if the more healthy and safe a population becomes, measured in terms of, e.g., standard of living or life expectancy, the more intensely expressed are feelings of vulnerability, and demands for increased safety or health standards. The current rapid internationalization, the ever increasing complexity of society, and the decreasing time for contemplation and considered decision-making, sensitize people to risks. These may concern experiences of risk related to global financial speculation, environmental pollution, armed conflict or unstable nuclear installations. There is a new understanding among world leaders and the public that events which are beyond one's direct control or influence may nonetheless severely affect one´s country or personal life.

The rapid transmission of adverse events, presented by local and global media and information networks, provides a fragmented, but non-fictitious, picture of immense numbers of actual and possible evils. Such images are replaced only by vivid displays of even worse scenarios of violence, death and destruction. The increased physical and mental distance to the power centers of the world, enhance feelings of national and personal vulnerability. People in the last decade of the twentieth century face environmental threats which might suffocate human life, an increasing global inability to meet basic human needs, and systematic insanity in the treatment of fellow human beings in war areas; all this combined with the lack of a powerful vision of a positive alternative. Fiction and non-fiction seldom form a harmonious whole. Discrepancies and disharmonies between personal dreams and ideals on the one hand, and uncertainties, fears and frustrations on the other, create instead a fertile basis for extremism in one form or another, for fear and avoidance reactions, and risk perceptions.

This paper presents some research results dealing with risk perception and risk communication. It also aims at broadening the framework within which the research is conducted, and points to the feasibility of expanding the research areas.

Risk Perception Research

Risk perception research is often motivated as aiming to guide policy and decision making by studying how people evaluate and judge hazardous activities and technologies (Slovic, 1987). It may also serve as a basis for the study of risk communication processes, although the rapid development of the latter area has created a specialized field of its own. Risk perception research is historically rooted in the discrepancy between estimated, or expected, risk levels for novel technologies in particular, and the public perception of risks. Starr (1969) set out to answer the question "How safe is safe enough?" and examined the relationship between technological risks and social benefits in a "revealed preference" approach. He pointed to the importance of voluntariness and the magnitude of consequences in risk acceptance. The risk perception literature has since then developed both in scope and depth. Numerous risk dimensions have been identified, and a number of factors, social as well as individual and intrapsychic, have been shown to be related to perceived risk. These factors are discussed in detail below.

Although risk and danger have always been parts of life, risk analysis has not. Covello and Mumpower (1985) traced the first simple form of human systematic risk analysis to the Asipu group of the Tigris-Euphrates valley about 3200 B.C. These people provided consultant services regarding "risky, uncertain, or difficult decisions" (p. 103). Input data concerning likely outcomes were made available by signs from the gods, and analyses and interpretations yielded predictions about the risky future venture in the form of recommendations. A final report "etched upon a clay tablet" (p. 103) was also provided for the customer.

Risk analyses of today are conducted on the basis of more reliable data, gained by the utilization of scientific methodology and accumulated knowledge. Different approaches to a problem may nevertheless yield different results or recommendations, and different considerations relative to a specified hazard may manifest themselves in opposing points of view in debates. It is not always obvious what approach results in the "true" description of, or best solution to, a problem. Neither is it possible to foresee all possible consequences of specific decisions or interventions. Disparate risk estimates and different opinions may always have been at hand throughout history, but today they might create problems of greater magnitude, due to the potential impact of large-scale industrial or technological accidents, and because decisions of great importance to many, and with implications for long periods of time, must be taken. Perhaps, however, a more important difference between the present day and ancient times lies in the fact that scientific knowledge is not absolute and static, but subjected to continuous development and re-evaluation, and hence, on these grounds, results and recommendations can be changed, disputed and distrusted. Scientific progress often highlights our ignorance in the sense that we increasingly know better what we do not yet know. It is in relation to this constant development of knowledge, including the awareness of uncertainties, that factual risk, risk awareness and risk communication continue to be research areas of great interest and importance.

Objective and Subjective Risk

Risk perception research does not challenge the fact that there exist real dangers to consider, and it does not attempt to counter such factual risks by suggesting, e.g., psychological solutions. On the contrary, an improved understanding of subjective experiences of risk is aimed at facilitating the design and presentation of information, to increase the ability to respond appropriately to risk reactions, and to develop predictive models of human behavior in a context of hazards. In sum, to understand and to calibrate the sometimes huge discrepancies concerning what is actually dangerous to life or health, and what is mistakenly perceived as dangerous or safe.

Perhaps one of the more interesting questions in risk perception research is the relationship between perceived risk and objective, or estimated, risk level. Most risk perception research is cross-sectional, and thus provides "snap-shot" overall pictures of a situation at a given point in time. This kind of data can be used to point out under- or overestimation of factual risks, e.g., as based on historic frequency data. Loewenstein and Mather (1990), however, presented time series data on public concern about a number of phenomena or events, *viz.* the AIDS disease, crime, inflation, suicide, etc. They studied, among other aspects, how accurately risk perceptions corresponded to actual levels and changes over time. They found that "concern" (in their terminology) and actual problem levels were quite highly correlated[1], whereas correlations between change variables ("period-by-period") were much lower[2]. The results indicated that risk perceptions, as measured in opinion polls, were more in accordance with overall levels than with changes measured at separate time periods.

Another example can be found in an article by Hohenemser and Renn (1989), who compared reactions to the Chernobyl accident in several countries. They reported, firstly, that opinions in different countries were by no means uniform before the accident and, secondly, that opinions on nuclear power immediately after the accident varied greatly in magnitude across countries. People in countries like Finland, Greece and Yugoslavia experienced an increase in opposition to nuclear power of about 30%, whereas in France and the USA there was an increase in opposition of 12% and 6%, respectively. In the case of Yugoslavia, opposition increased from 42% to 78% three months after the accident. A year later the level was still 24% higher than before the accident. In their attempt to explain these data, the authors hypothesized that countries with a larger undecided population before the accident would demonstrate the largest initial increase in opposition to nuclear power and, conversely, that countries which already prior to the accident had a large proportion of highly committed citizens would show the largest return toward pre-accident opinion levels. They found both suggestions to conform with available data (see also Renn, 1990).

These authors also studied the relationship between estimated radiation exposure and public opinion, and found a positive relationship between the average radiation dose in a country and the observed shift in public opinion. Although data showed a considerable scatter, the relationship was statistically significant. They concluded that:

> "The high correlation at a national level between increased opposition to nuclear power and the actual average radiation dose following the Chernobyl accident indicates that, in spite of the confusion and the controversy about the seriousness of the threat, most citizens were capable of forming relatively accurate assessments, which were in part expressed in public opinion shifts. In saying this, it is not implied that people reacted directly to fallout levels but rather processed information from different sources and took into account expected biases" (p. 10).

The examples above indicate that subjective perceptions of risk can reflect fairly well the objective severity level of a problem or event, but that the overall correspondence is better measured over longer periods of time than at specific moments in time on the basis of cross-sectional data. One should also expect a large variation of responses on the individual level.

Certain risks achieve greater emphasis than others, and may come to dominate the media or public awareness during a specific length of time. The reasons for this are not fully understood, but seem to include voluminous information about the risk, as well as unclear or disputed information, and rumours. An attempt to shed light on the phenomenon is the "theory of the social amplification of risk" (Kasperson, Renn, Slovic, Brown, Emel, Goble, Kasperson

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[1] r=0.55 on average over nine different problems, all but two with correlations exceeding 0.38.

[2] r=0.25 on average, with only unemployment and inflation rates yielding high correlations, 0.72 and 0.59, respectively.

& Ratick, 1988; Kasperson, Emel, Goble, Hohenemser, Kasperson & Renn, 1989). It is suggested that social amplification is brought about by the transfer of information on the risk through individual and social "amplification stations", and by social response mechanisms. It may result in behavioral changes and further social impact, e.g., the creation of new social groups, and stigmatization of certain geographical areas. As can readily be understood, the phenomenon may lead to a distorted representation of public risk awareness if the perception of a specific hazard is measured at only one point in time. The continuous monitoring of phenomena of interest is therefore a more reliable approach to the test of concordance between statistically estimated risks, or expert judgements of risk, and public subjective risk perceptions.

Risk Dimensions

A large number of factors or dimensions have been related to perceived risk in the literature. For example, if a hazard or hazardous activity is seen as unfamiliar, scientifically unknown or involuntary, the risk is perceived as larger than in the opposite situation. If children are involved, the risk is unequally distributed, or if the effects are seen as irreversible, the perceived risk increases. There are correlations between the suggested risk dimensions, however, and an early strategy in the study of perceived risk involved the development of a taxonomy of hazards, i.e. the psychometric paradigm (see e.g. Fischhoff, Slovic, Lichtenstein, Read & Combs, 1978; Slovic, Fischhoff & Lichtenstein, 1985; Slovic, 1987). The approach showed that three higher level factors could be extracted from a number of single dimensions through factor analysis; i.e. the "dread risk" factor (involving catastrophic potential, dread, lack of control), the "unknown risk" factor (involving new, non-observable, unknown hazards), and the "number of exposed to risk" factor. The psychometric approach has had an important role in risk perception research.

Risk Target

Apart from risk taxonomies there are methodological factors and design aspects which influence the level of reported risk in risk studies. Weinstein (1989) reported on the "consistent, optimistic bias that exists concerning personal risks" (p. 1232). He asserted that the bias also includes positive events (e.g. financial success, long life, etc.) and that pessimistic biases are rare. The optimistic bias, with respect to personal risk, has often been observed in several contexts, e.g., traffic research (DeJoy, 1989; Sivak, Soler & Tränkle, 1989). Thus, subjects often rate themselves as better drivers, and less likely to be involved in a traffic accident, in comparison to an average driver. For risk perception research, this phenomenon has the consequence that people differ with respect to how they rate risks to themselves and risks to others. Thus, it matters if people are asked to rate the risk for their own person or for someone else, e.g., for people in general, for society, or for the world at large (see Fig. 1). The figure is based on six different rating instructions regarding risk target, (e.g. personal risk, risk to family and friends, etc), in six independent groups of respondents, randomly assigned to the respective groups. The data shown here are based on the average mean rating over a number of hazards within each group of respondents. Note the difference between ratings of personal risk and risk for *a single* other person, "any one Swede", indicating that the effect is not due to the number of people imagined during the rating task (Drottz-Sjöberg, 1991b).

Figure 2 shows data from a Swedish national sample regarding the AIDS disease carried out in 1990 (Sjöberg, 1991a), where the respondents, aged 30-45 years, rated the same 12 "everyday" hazards with respect to both personal risk and risk to people in general. The following figure 3 is based on Russian data collected in 1992 in Novozybkov (Drottz-Sjöberg, Rumyantseva & Martyushov, 1993), where the respondents similarly were asked to rate the health risk to themselves, as well as for people living in the same geographic area.

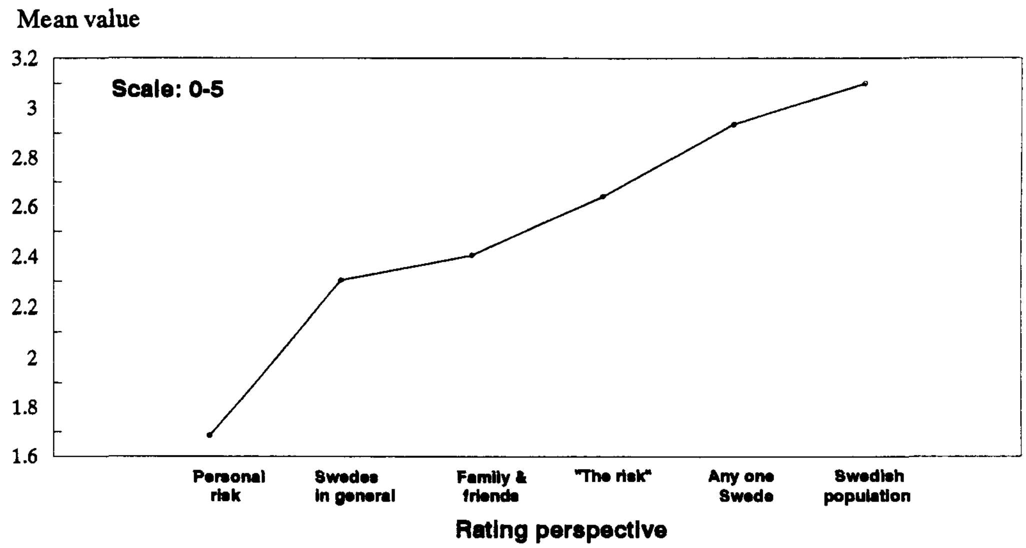

Figure 1. Mean values of rated risk supplied by six independent groups of subjects using different rating perspectives.

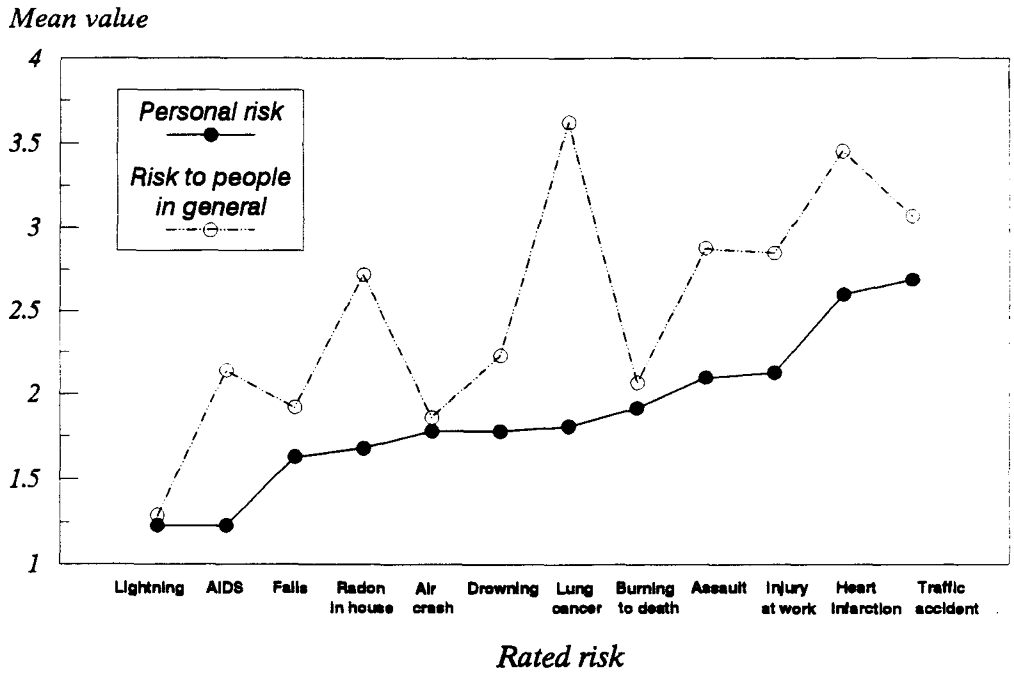

Figure 2 Ratings of 12 everyday hazards regarding personal risk and risk to people in general, Swedish subjects.

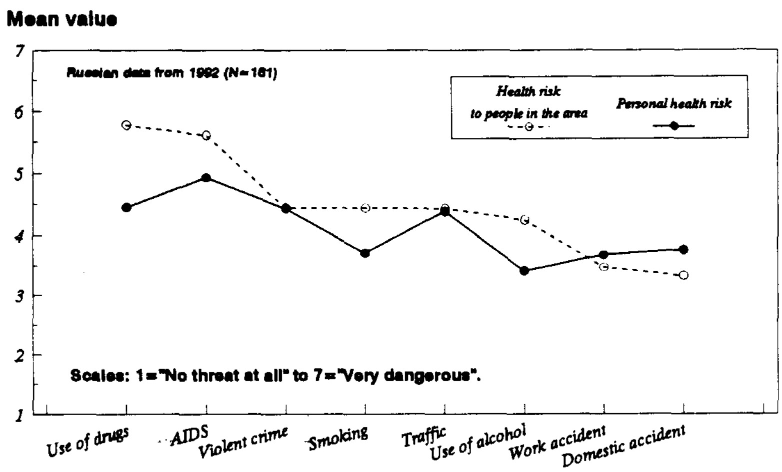

Figure 3 Ratings of personal health risk and health risk for people living in the same area, Russian subjects.

Risk Levels

It may be of interest to relate different risks to one another using the same rating scale to investigate the relative ranking of the hazards included, or their estimated threat to some specified risk target. Keeping in mind that only the set of hazards included in the rating task will be involved in the output, the results indicate both to what degree the respondents perceive specific hazards as troublesome in some respect, and the relative ranking of hazards. Figure 4 gives an example. It is based on data from a representative Swedish sample from 1993 (Drottz-Sjöberg, in preparation). The subjects were asked to rate the threat from eight hazards to "Swedish society". As can be seen in the figure, the risk posed by "environmental pollution" was perceived as the most serious threat to society among the items listed, and it was rated high on the 6-point scale.

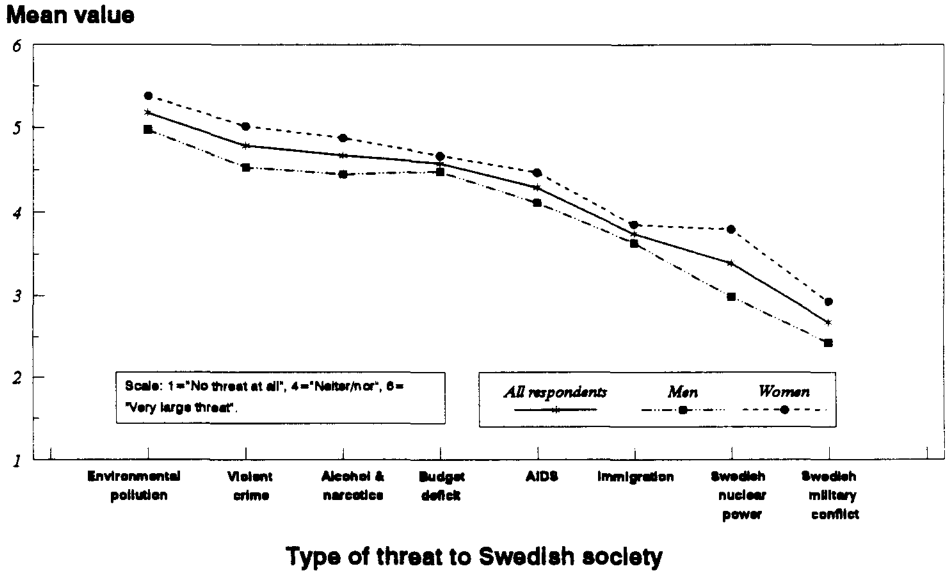

Figure 4 Ratings, given by men and women, of the perceived threat from 8 hazards to Swedish society.

Comparisons of risk levels are also of great interest in cross-cultural research. Figure 5 shows data collected in Sweden and Poland in 1992. The respondents in each country were asked to rate "everyday" risks as those shown in the figure, as well as risks related to different industrial activities. The results showed that Poles rated those "normal" risks higher than did the Swedes. This finding may be related to higher factual risk levels with respect to some of the hazards, e.g., injuries at work and traffic accidents, but this could hardly be the explanation of all rating differences. Regarding the risk of being "struck by lightning", one could perhaps expect the same factual risk in the two countries, and the difference could be hypothesized to be an effect of a generally increased sensitivity to risk in Poland.

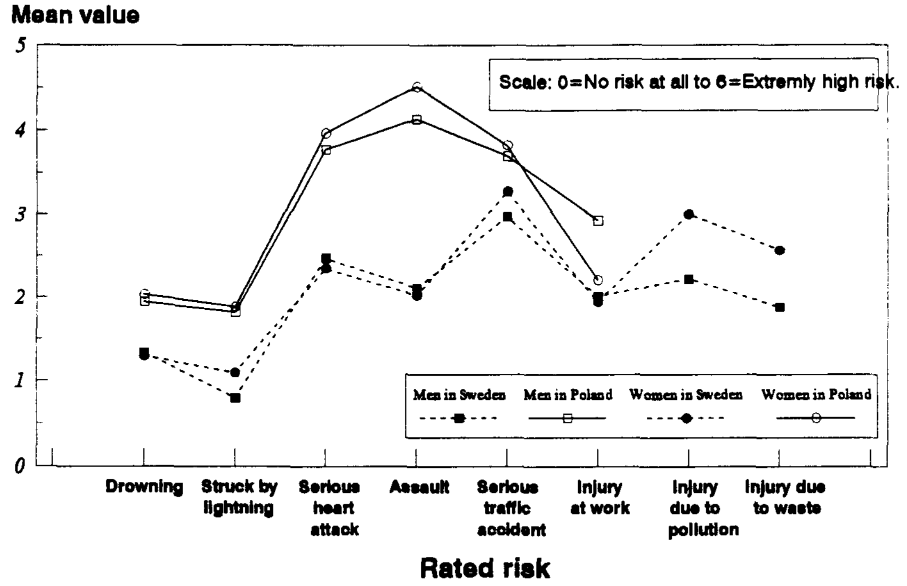

Figure 5 Ratings, given by men and women in Sweden and Poland, of everyday hazards.

Individual Differences and Background Factors

De Man, Simpson-Housley and Curtis (1984) investigated the relationship between trait-anxiety (anxiety as a personality trait), state-anxiety (temporary anxiety), and perceptions of potential nuclear disaster. They found that only state-anxiety was related to the expectation of an accident and estimation of damage. Thus, there was no strong relationship between high scores on a trait-anxiety test and strong beliefs in the likelihood of future nuclear accidents, or regarding anticipated damage in case of an accident. State-anxiety effects were indeed 3-4 times greater than trait-anxiety effects. The previously discussed papers on the relationship between perceived and estimated objective risk likewise support the notion that increased levels of concern, worry, or perceived risk, correspond to changes in the real world. People do differ, however, with respect to both risk perception and risk taking, and radiation seems to be a source of somewhat peculiar apprehension, specifically when associated with nuclear energy.

It is well known that an individual may be a risk taker with respect to a certain activity, but that there is no personality trait which distinguishes between individuals who take risks and those who do not, regarding all kinds of situations. Levenson (1990) suggested that there are many kinds of risk taking and that these may have very different sources and consequences. He used measures of substance abuse inclination, emotional arousability, conformity, moral reasoning, empathy, sensation seeking and psychopathology to investigate risk taking in subjects of three all-male groups: (1) antisocial risk takers (criminal long-term drug abusers committed to treatment), (2) adventurous risk takers (rock climbers), and (3) heroes or pro-social risk takers (policemen and firemen decorated for bravery). He found that the drug-unit sample scored higher than others on measures of psychopathology and antisocial behavior (e.g., emotionality, disinhibition, depression, substance abuse inclination, etc.) and had lower empathy scores. Rock climbers scored higher on adventure and experience seeking and thrill than heroes, but these groups did not differ with respect to moral reasoning or independence/conformity measures. Heroes differed from others primarily on the basis of low scores for sensation seeking. Concerning the "Anti-social" and "Anti-structural"[3] dimensions, the drug-unit sample was found to be low on the anti-structural dimension and high on the anti-social dimension, whereas rock climbers exhibited the reverse pattern and heroes were found low on both. With respect to the latter group, the author noted: "The fact that the heroes, although they literally risked their lives in the performance of their duties, were not characterized by either dimension, suggests that the reason for pro-social risk taking may be very different from those for risk or sensation seeking" (p. 1079). And he suggested altruism as one such motive. Levenson also distinguished between different types of social risk taking, i.e. the violation of norms for personal gain and in the service of positive social change.

The example suggests that the concepts of "risk taking" and "risk takers" should be further divided into more precisely defined characteristics. The most interesting aspect of the example is, however, that it points to the importance of moral norms, social attitude and the influence of self-interest on the characterization of different risk taking groups. Concerning risk ratings that include others, this implies that other considerations are involved than those related to personal risk (see also Sjöberg & Winroth, 1986). In relation to the optimistic bias discussed above, the example also shows the relevance of different estimations of risk for oneself and for others, if the rated risk involves aspects of skill and knowledge. A rock climber, for example, would certainly agree to a certain personal risk involved in the activity, but asked about "people in general" climbing the same rock, he or she would probably perceive an average risk level of a completely different magnitude. It would be difficult to refer such a difference in ratings purely to an optimistic bias. Policemen and firemen are similarly trained, and equipped, to deal with dangerous situations in their work. They may still experience risk, and worry about some scenarios, but they know, and rightly so, that they are better prepared than others to deal with the situations (see also Brewer, 1990).

The gender difference is well documented in the risk perception literature, and women usually rate risks higher than men do. We have found, however, that the effect is stronger if subjects rate the risk to "people in general" than when ratings are related to personal risk (Drottz-Sjöberg, 1991a). An example would be the study by Bord and O'Connor (1990), who investigated women's reactions to food irradiation. They measured the extent to which their respondents intended to try irradiated food in the home, their comfort in serving it to family members, and their reaction to a hypothetically suggested ban on irradiated food. The results showed that the women rather ate irradiated food themselves than served it to members of their families.

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[3] Explained as "a tendency to regard conventional norms as provisional not because of an antisocial posture but because of experience seeking or developmental aspirations toward self-actualization".

Studies made in Sweden of risk perception related to the Chernobyl accident (Sjöberg & Drottz, 1987; Drottz-Sjöberg & Sjöberg, 1990) showed that worry was overall high in Sweden after the accident, but that women reported more worry than men did. Among the specifically chosen groups in one study, farmers, pregnant women and parents were more worried than adolescents and men without children of their own. Thus, the results indicated that people having some responsibility for others gave higher worry ratings.

Worry, as well as risk perception, is often strongly related to perceived personal control. Personal control, in turn, is positively related to mood (Sjöberg & Magneberg, 1990) and negatively related to perceived helplessness (Seligman, 1975). It is generally the case that strong emotions have a relatively short duration (Wallbott & Scherer, 1986), and that everyday mood is usually experienced in a mildly positive direction (Sjöberg, 1981,1989). Negative expectations and perceived lack of control seem to play an important role in affecting the mood state in a negative direction. Sjöberg and Magneberg (1990) found that women, on average, experienced a more positive mood state than men, and Sjöberg, Olsson and Salay (1983) showed that they displayed greater variations in mood than do men. Sjöberg (1993) also showed that women tolerated risks considerably less than men did. Thus gender differences with respect to risk perception and ratings of risk and worry may be related to emotional and mood factors, as well as to differences regarding risk tolerance, perceived personal control and responsibilities as discussed above.

In this context it is important to note that considerable research related to emotion and stress indicates that positive affect (e.g. level of energy and enthusiasm) and negative affect (e.g. subjective distress, including a variety of aversive mood states) are two *independent* psychological dimensions. Watson and Pennebaker (1989) extended the negative affect factor to cover "a more general trait of somatopsychic distress" (p. 248), which is related to a broad range of somatic health complaints and negative emotional states, including perceived stress. More importantly, however, they pointed out that there was no consistent relationship between negative affect and long-term *objective* health status. Regarding positive affect they found no relationship to somatic complaints. Positive affect was instead related to, e.g., social activities and other specific events.

Awareness or experience of little personal control and perceived helplessness in the wake of the Chernobyl accident seemed to express itself in experiences of worry and in high risk ratings. The worry focused on radiation from nuclear power sources (worry was not related to the perceived risk of non-nuclear sources of radiation), and the possibility of radioactive contamination. This is not very surprising because nuclear radiation involves the aspects of catastrophic potential and *dread* (Fischhoff, Slovic, Lichtenstein, Read and Combs, 1978), e.g. a relatively new and unknown phenomenon, undetectable by human senses. In a recent study on nuclear waste, the perceived risk of background radiation was one of the main predictors of perceived risk of nuclear waste (Sjöberg & Drottz-Sjöberg, 1993). The result deserves more detailed analyses in the future. For example, do respondents include naturally-occurring radon gas in their conception of "background radiation", or was the result mainly due to inadequate knowledge? A recent Norwegian public poll showed that almost 20% of all respondents agreed strongly with the statement that all radiation is man-made. This response tendency declined with educational level, but 10% of those with university degrees still strongly supported this statement (Norsk samfunnsvitenskapelig datatjeneste, 1993). See Fig. 6.

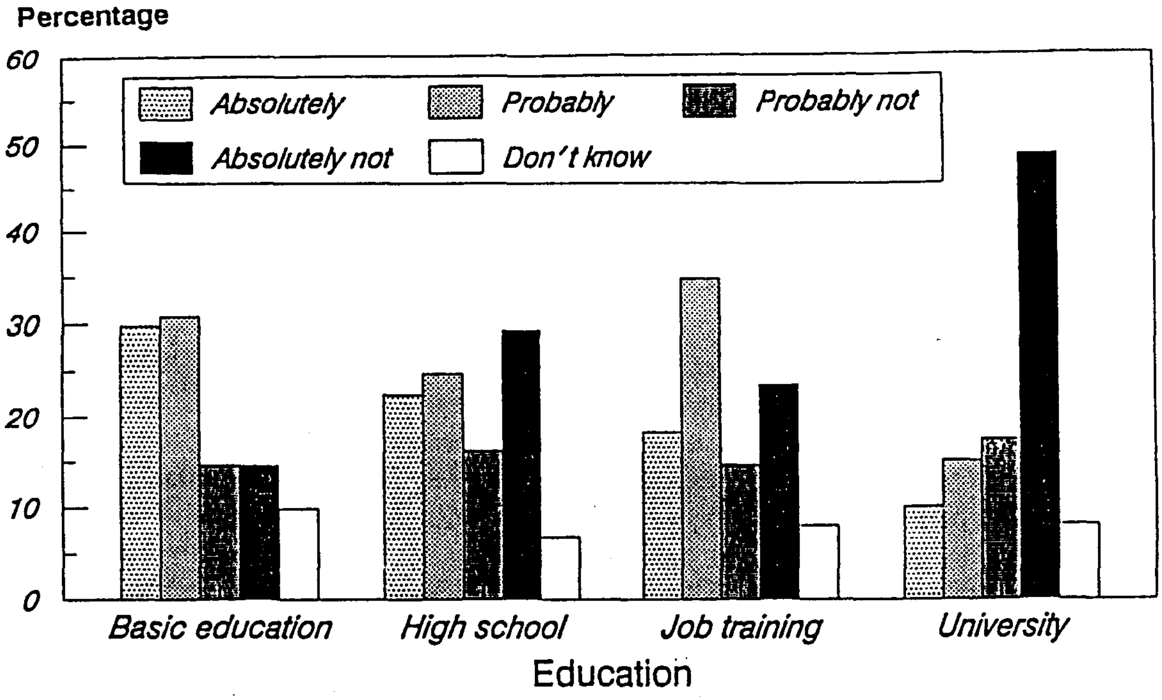

Figure 6 Response percentages of various educational categories related to the statement "All radiation is caused by man", Norwegian data.

In sum, individuals react differently to factual, as well as hypothetical risks, and some of this variation can be predicted on the basis of experience, knowledge, skill and gender. Situation-specific events with certain characteristics, e.g. a nuclear accident involving radioactive fallout, seem to be more important, however, than personality traits when it comes to explaining risk experiences and risk ratings. Lack of personal control and perceived helplessness, as well as negative mood states, are correlated with worry, but these relationships might be influenced by yet other more basic or structural factors, such as actual vulnerability or inability to exert personal control over circumstances or one's safety.

Risk Definitions

"Risk" is an old and common word in many languages (e.g. the French *risque*; damage, bold venture; see also Mathieu-Rosay, 1985). Its everyday meaning denotes uncertainty associated with danger regarding a future, or an imagined event. If something is "risky" or "not without its risk", the implication is that it involves the components of uncertainty and some degree of danger[4]. Certain negative events cannot be described as risks because they lack the component of uncertainty. Growing older is one example. However, there may be risks associated with aging. It is also interesting to note the connotations of the verb "to risk" that include "to dare" and "to venture", words which have a positive connotation.

Lindell and Sjöberg (1989) used Webster's Dictionary to distinguish between meanings of the word "risk" and I quote:

> "(1) the possibility of loss, injury, disadvantage or destruction; (2) someone or something that creates or suggests a hazard or adverse chance: a dangerous element or factor - often used with qualifiers to indicate the degree or kind of hazard; (3)(a)1: the chance of loss or the perils to the subject matter of insurance covered by a contract; (2) the degree of probability of such loss; (b) amount at risk; (c) a person or thing judged as a hazard to an insurer; (d) an insurance hazard from a specified cause or source; (4) the product of the amount that may be lost and the probability of losing it - compare expectation" (p. 4435).

These meanings suggest that risk can be construed as either the *mere possibility* of an adverse event, the *cause* of an event, the *magnitude* of the consequence, as someone or something *judged as a hazard* and as the *conceptualization* of a procedure for the estimation of a quantity. The authors noted that in the generic sense "risk" includes a variety of concepts which together constitute the risk concept. The future orientation is obvious in these meanings of risk, although "risk" can also be discussed from a historic perspective when understood from the point of view of those involved.

Orr and Fogle (1988) traced the word "hazard" to the Arabic "az-zahr", which means "the die", and they referred to two meanings of the word used in Webster's Dictionary: "(1) a game of chance like craps played with dice and (2) an adverse chance, as of being lost, injured or defeated" (p. 1). The relationships between "risk" and "hazard", as derived from some of the examples cited above, therefore become: (1) "risk" as "the possibility of loss" overlaps with the definition of "hazard" as "an adverse chance", and (2) risk as "someone or something that creates or suggests a hazard" relates to "hazard" as a cause to its effect, but since one denotation of "hazard" was "a condition that tends to create or increase the chance of loss" the relationship between risk and hazard may also be understood in terms of both being conditions which include possible adverse events.

The phenomenon of risk requires subjective apprehension and evaluation. Slovic (1987) used "intuitive risk judgments" to denote risk perceptions. Hansson (1987) discussed risk as intimately connected with the societal decision process. The choice of a risk evaluation model is thus also a choice of what aspects will be accounted for or discounted. With respect to *risk comparisons*, he stated the existence of several rational comparison methods. Although all are rational, they differ with regard to evaluative perspective.

Based on the hypothesis that people use different definitions of risk in risk ratings, a special study was conducted which used data from several surveys in which the respondents had reported their "normal" use or understanding of the word "risk" (Drottz-Sjöberg, 1991a,

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[4] There are also differences between languages regarding the use and the "common meaning" of the term "risk" which will not be discussed here, but which complicate matters further. Examples are the different connotations of "risk" and "hazard" in English, both often translated into "risk" in Swedish, and the common translation of "risk" to "danger" in, e.g., Polish and Russian.

1992). The result, shown in figure 7 below, shows that there is a clear tendency that people who use the term "risk" as almost synonymous with probability, overall rate risks lower than those who define "risk" as a concept dominated by the consequences.

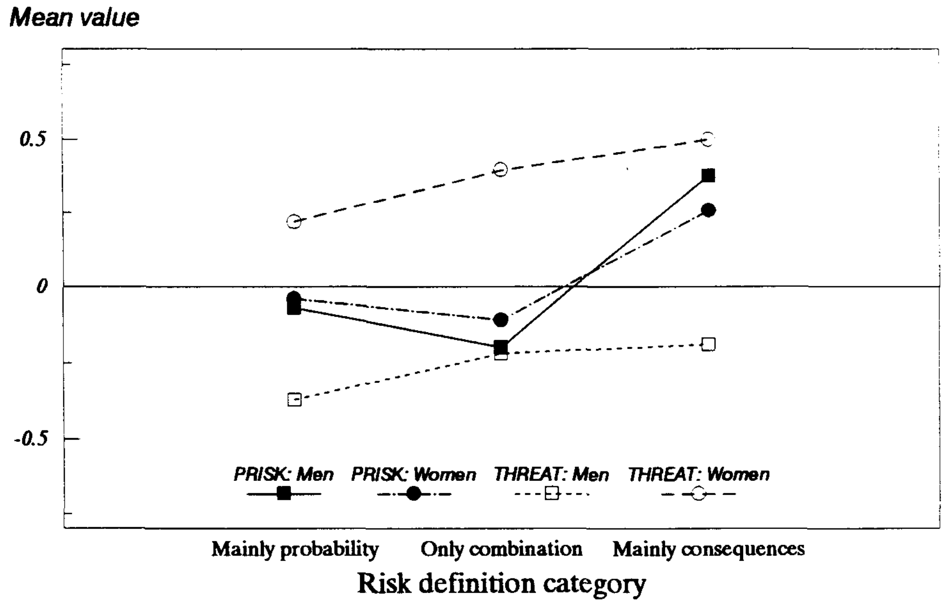

Figure 7 Standardized ratings of perceived personal risk and threat to society, supplied by men and women in three risk definition categories.

It should be added here that definitions of risk, or the use of the risk concept, may differ widely due to what type of "risk" is rated, e.g., high probability-low consequence risks or low probability-high consequence risks, non-fatal or fatal risks. Sjöberg (1993) showed that probabilities were the most influential in accounting for perceived *risk level*, whereas the *consequences* were the most influential in risk tolerance ratings.

The use of terminology, and especially the intended meaning of the term risk, is an important aspect in evaluating risk perception ratings. The implication of risk definition research for risk communication is that the results highlight the importance of the proper choice of terms and concepts in the communication of risk information to different audiences, and between parties with different experience and background knowledge. A short note on risk communication research follows below.

Risk Communication Research

The risk communication literature has increased dramatically during the last decade (for a review, see e.g. Renn, 1992). The general development of the area follows a course from sheer perplexity, over public protest and resistance to centrally planned industrial installations, especially nuclear plants and waste sites, to recommendations for developing an ear sensitive to public opinion, and the encouragement of public participation in decision processes. In effect, the risk communication field can be classified as just a specialized area within the field of communication, and many of the characteristics and methods of successful communication can be, and have been, applied to improve risk communication. What makes risk communication a specific area of research is its study of *risk* messages and, hence, how people perceive and react to risks and how these aspects influence the understanding and the reception of the messages.

Basically there are two kinds of risk messages: first, the type saying "this is dangerous, please take precautions", and, second, the one saying "this is not dangerous, please don´t worry". The first is sent by "protectors" (Sjöberg, 1991b), e.g. the surgeon-general, fire departments, insurance companies and hurricane experts. The second is conveyed by "promoters", e.g. entrepreneurs, social developers, and changers of the status quo. Their message is essentially that an activity should be initiated, continued or expanded and that the associated risk is negligible or under control. Both kinds of risk messages are difficult to transmit to the public or specific recipients, but the difficulties encountered are fundamentally different. The "protector" warnings are often simply ignored or they have considerably less impact than socially desirable, whereas the "promoter" messages are challenged, protested and counteracted. The former often concern life styles and are aimed to induce changes in the behavior of the individual. It is suggested that we drink less, stop smoking, reduce the radon level in the home, and avoid unprotected sex. There are no surgeon-general warnings about living close to a noxious facility, however, and if there is a health risk associated with such a facility or some other place, it would instead be closed down, fenced off or cleaned without need of convincing arguments for the public.

On the other hand, the "promoter" risk messages relate to the public, or common, area of life, where individual interests may be in opposition to the common good, and where interest groups are formed to protect self-interests against perceived threats of all kinds, e.g., economic losses or health risks. A risk message within this context has a greater potential to create controversy than appeals to private citizens to lead healthier or safer lives, because the decision to tolerate the risk is not a private one.

Literature on risk communication deals mainly with issues related to the latter type of risk communication, and it relies heavily on findings in the risk perception area related to the characterization of hazards and factors influencing risk perception. As mentioned earlier, it is well recognized that hazards or hazardous activities that are characterized as potentially catastrophic, novel or unknown to science, and which may have delayed or long-term health effects, are considered especially dangerous or risky. If people perceive that a risk is being imposed on them (involuntary or uncontrollable risk), is of little or no benefit to themselves or the community, is greater for themselves than for others (unfair, or unequally distributed), or morally unjustified, they will react negatively and rate the risk as high. Thus, activities or proposals suggesting the introduction of new or additional risks into one´s life, or into one´s world, often face public opposition or active resistance. Local community protest groups have collectively been named NIMBY (Not In My Back Yard) groups. There are current tendencies, however, that the "local" stamp of such groups is being transformed into a far more generalized perspective, e.g., NOPE (Not On Planet Earth) groups, possibly reflecting both an increasing awareness of the transboundary effects of certain hazardous substances and the unfairness of guarding only local interests.

The controversies over risk issues in the social arena highlight the intricate web of interacting factors when it comes to introducing change (risk or benefit) in the community - fairness in distribution of effects, equality in influencing living conditions, private values and social norms - and it is not surprising that trust has emerged as a central concept in risk communication. Neither should it be surprising that such controversies develop into political power contests instead of intensified efforts to estimate the "true" risk value. It follows from this argumentation that recommendations on how to handle tricky risk communication situations fall back on democratic political principles; create *trust* by encouraging and economically promoting public participation in decisions, use egalitarian principles without power manifestations in a continuous and fair debate, invest much time in the decision process, make efforts to hear everyone out, do not moralize, and stop at nothing less than consensus.

Risk management and risk communication have come a long way from the forceful hammering home of already fully tailored decisions, and are developing towards a much more time-consuming, diffused, participatory decision process, where the final solution, given a happy ending, very well may be quite different from the first proposal, but which instead is enforced by the public or an affected local population. Kunreuther, Fitzgerald and Aarts (1993) recently discussed the current American difficulties in siting noxious facilities (see also Kunreuther, Easterling, Desvousges & Slovic, 1990). They emphasized the importance of creating trust between the developer and the host community; stressed the value of public participation; the importance of showing that the suggested facility meets needs, has an appropriate design, and is the best solution to the problem. They recommended that economic compensation "should be introduced as a part of the process only after the affected public is convinced that appropriate mitigation and control measures will be in place so that the risk associated with the facility is considered to be acceptable" (p. 302). Although their paper explicitly concerns siting of hazardous waste facilities, the guidelines discussed may be of more general interest. The following points are extracted from the paper:

- institute a broad-based participatory process, including representation from all affected groups
- seek consensus by addressing the existing concerns, needs and values
- work to develop trust, e.g. by recognizing that distrust arises from lack of local support
- seek acceptable sites through a volunteer process
- allow reversibility of the process
- consider a competitive siting process
- set realistic timetables
- keep multiple options open at all times
- achieve agreement that the status quo is unacceptable
- choose the solution that best addresses the problem
- guarantee that stringent safety standards will be met
- fully address all negative aspects of the facility
- make the host community better off
- use contingent agreements
- work for geographic fairness

Discussion

Risk perception studies and risk communication research have their roots in social changes and controversies. It is therefore not surprising that research results often involve references to public opinion, trends, social movements, value systems and political or group decision processes. Although human beings are essentially social creatures, the world of today threatens our capabilities of living private, secluded and self-defined lives. The individual reacts to change and the introduction of new risks in a setting of an increased tempo of demands and information. Individuals cluster together to promote their interests and some are willing to actively defend their chosen life-style from intrusion by perceived outsiders. The resulting confrontations deepen mistrust between the parties, and this mistrust may be irreversible. It does not take much of a creative mind to understand that the private good, or specific interest groups´ good, very quickly may come into conflict with the common good, be it the local community, the country or the entire world. Conflict resolution is a skill that must be improved and enhanced on all levels of social organization. The risks associated with failure in this respect are too large to measure. There remain the tepid recommendations of diplomacy, communication, purposeful exchange of information, and mutual giving and gaining. Dialogues are good means of creating and establishing trust if they involve openness and fairness. Efficient societies cannot be built on mistrust because they will disintegrate. Efficient societies require much more, however. For example, innovations, entrepreneurship and a belief in the future. Social leadership, including risk management, must look ahead and plan for a positive society. Positive and powerful ideas and images of the future world are important to current ordinary life because they inspire cooperation, expand the planning horizon and stimulate hope.

Regarding the research areas discussed, that of risk perception is still in its infancy and a step-child of risk analysis when it comes to resource investments. It would develop and benefit, however, if future research is conducted in directions which allow greater contrasts in the analyses. A comprehensive scheme of risk perception should therefore cover findings of both normal, or traditional, risks and novel risks, under the different conditions of ordinary and extraordinary life circumstances (see Table 1). Furthermore, historic perspectives and future prospects should be welcomed into the field because they have important implications for the analysis and interpretation of current risk perceptions, and for the communication and reception of risk messages.

Table 1. Schematic table of possible areas to be covered in risk perception research.

	Ordinary life circumstances	Extraordinary life circumstances
Traditional risks	A	B
Novel risks	C	D

The extensive American and European research on risk perception can be found almost exclusively in the domain of "ordinary life", i.e. areas A and C in the table. Perceived risks regarding, e.g., occupation, traffic, life style, and crime belong to area A. Food additives, food irradiation, and AIDS, e.g., are relatively novel phenomena in area C. All, however, belong within the "ordinary life" framework.

In extending risk perception research to include also risk perceptions in extraordinary life circumstances (areas B and D in Table 1), new dimensions may be found. Some research of this kind can be found in the established risk perception research area if natural or industrial disasters have occurred, e.g. flooding, hurricanes, chemical and nuclear accidents. Such disasters or accidents create extranormal life circumstances for those affected for a certain period of time. Research on catastrophes and risks affecting people living under extraordinary life circumstances is, however, more often found in the disaster research literature (Warheit & Dynes, 1968; Dynes & Quarantelli, 1976; 1977; Quarantelli, 1984; 1988). These authors investigate organized and individual responses to disasters within sociological, organizational and psychological frameworks. Studies usually focus on pre- and post-accident organization, preparedness and communication, but they also cover the reactions of groups of citizens and individuals to traumatic experiences and events. The number of studies to be found that involve developing countries reflects the often disproportionate impact disasters have in these countries. Psychiatric and clinical psychological research are other important areas to consult. Studies of this kind usually focus on the treatment of traumatic experiences, measurement of stress levels and other emotional reactions. However, researchers in those fields seldom ask victims of catastrophes to, e.g., evaluate various hazards with respect to health effects, or the probability or severity of consequences (see however Drottz-Sjöberg, Rumyantseva & Martyushov, 1993). It is also rare that risk perception studies are based on samples of individuals living under extraordinary circumstances within "ordinary-life" affluent societies. In sum, there may be much to learn by extending the scope of research to include a greater variation of actual life conditions in the analyses, as provided by different countries and different cultures and sub-cultures, as well as to consider research findings emanating from other disciplines.

Risk communication research is of necessity more closely linked to the investigation of specific exchanges of messages within certain local cultures. Risk messages should be tailored to meet existing demands for information in a language and style adapted to the selected recipient groups. This implies that the aims of risk communication would be better met if researchers and information transmitters considered investigating the specific qualities of "local cultures" of, e.g., certain neighborhoods, specific professions, men, women, and different age groups. Risk perception studies indicate clearly that individuals and groups may differ considerably with respect to their main concerns, and how they express them. To enhance the dialogue between experts or authorities and population groups also requires the provision of opportunities for the public to gain insight into the realities and responsibilities of the former. Risk communication research would certainly also benefit from national and cultural comparisons, but the focus here would perhaps, at present, be more beneficial if greater effort was invested in finding the best ways of social and organizational restructuring to enhance public participation in decision processes. If trust is a core concept in risk communication, and much points to that conclusion, then the building of efficient communication networks becomes one of the real challenges of our time.

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Appendix V
Costs of Protective Measures in the Nordic Countries

by

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A number of different methods of predicting the economic costs in connection with accidents have been devised in both Europe and the USA. Some of these methods were reviewed in the report NRPB-R243: "COCO-1: Model Assessing the Cost of Offsite Consequences of Accidental Releases of Radioactivity", 1991.

COCO-1 itself considers two different categories of cost, namely of countermeasures and of health effects. The first category, costs in connection with countermeasures, is that of relevance for our purpose, and to a large extent we have used the philosophical concepts of COCO-1 as a foundation for the calculations in this appendix. In particular we have adopted the idea that *the cost of a countermeasure is the benefit foregone.* For example with respect to accommodation, in the case of relocation, the cost is not that of the emergency accommodation but the benefit foregone, i.e. the cost of the housing abandoned.

The countermeasures considered are *sheltering, relocation (repopulation) and food restrictions.* Decontamination of land and buildings has not been dealt with.

A. Costs Arising from the Movement of People

The following categories of cost are considered:

1) Transport,
2) Food and accomodation,
3) Loss of income,
4) Lost capital services.

A.1 Transport

The length of journey is put at 50 km (corresponding to 30 miles as in "COCO-1: Model for Assessing the Cost of Offsite Consequences of Accidental Releases of Radioactivity", NRPB-R243, 1991).
The cost is multiplied by 2 to represent both the outward and the return journey (see footnote in COCO-1 page 8).

Denmark

Based on information given in "Motor", no. 1, 1992 (issued by "Forenede Danske Motorejere") a representative price of 2.50 DKR per km for **transport by private car** is a reasonable choice.

With four people in a car the cost is: 2.50x50x2/4 = **63 DKR per person** (out and back).

According to the Danish State Railways, the price of a ticket covering ca. 50 km) is 35 DKR.

The cost for **transport by rail** is thus 2x35 = **70 DKR per person** (out and back).

Finland

Vehicle running costs are 1.68 FIM per km (Mileage costs of private cars in 1993, Automobile and Touring Club of Finland)
The cost for **transport by car** is thus 1.68x100/4 = **50 FIM per person** (out and back).

The cost for rail transport is 26 FIM per person for a 5o km single ticket. (Finnish Communications, 1993, Finnish Travel Association).

The **cost for rail transport** is thus 2x26 = **52 FIM per person** (out and back).

Norway

Based on information from "Opplysningsrådet for vegtrafikk", a reasonable charge for **transport by private car** is (2.51x100+18.80)/4 = **67 NOK per person** (out and back).

According to NSB the cost for **transport by rail** is 2x53 = **106 NOK per person** (out and back)

Sweden

The "M" Automobile Club gives a reasonable charge for **transport by private car** of (18.6x10+14.5)/4 = **50 SEK per person** (out and back)

A.2 Costs of Food and Accommodation

No specific costs are included for food consumed during evacuation because there would have been expenditure on food by the evacuated or relocated population if the countermeasures had not been implemented (see COCO-1, page 8). Possible differences in prices are taken as positive or negative differences in quality, which are compensated by the convenience or inconvenience respectively.

Estimates are only given for the cost of the accomodation lost (benefit foregone, see COCO-1, page 9). This cost is included in "lost capital services".

A.3 Lost Income

Lost income cost should only be considered within the period of economic recovery. The weighted mean recovery time is about 2.5 years.

Denmark

Gross national product at factor cost 1990: 686,797x10^6 DKR.
(Source:table 2.14, page 40 in "National acounts, 1990", Danmarks Statistik, 1992).

Or income per capita: 686,797/5,135,409 = 133,738 DKR.

Gross national product at factor cost excluding dwellings:
(686,797-66,287)x10^6 = 620,510x10^6 DKR.

Or **lost income**: 620,510/5,135,409 = **120,830 DKR per capita per year.**

Finland

Gross national product at factor cost 1990: 380,843x10^6
(Source: Table 1.2, page 12 in "National accounts 1986-1991", Statistics Finland, 1992)

Or income per capita: 380,843/4,986,000 = 76,382 FIM per capita.

Gross national product at factor cost excluding dwellings, 1990:
(380,843-21,319)x10^6) = 359,524x10^6 FIM.
(Source: Table 2.2, page 30-31 in "National accounts 1986-1991", Statistics Finland, 1992).

Or **lost income**: 359,524/4,986,000 = 72,107 FIM **per capita**.

The average income per household varies from 87,400 FIM in central Finland to 112 800 FIM in Helsinki (1987, Source: Table 287, page 313 in "Statistical Yearbook of Finland 1990", Central Statistical Office of Finland).

Norway

Gross national product at factor cost, 1990: 490,630x10^6 NOK
(Source: Table 5.11, page 142 in "National Accounts Statistics, 1991", Central Bureau of Statistics of Norway, 1993).

Or income per capita: 490,630/4,249,830 = 115,447 NOK.

Gross national product, at factor cost, excluding dwellings, 1990:
(490,630-23,555)x10^6 = 467,075x10^6 NOK.
(Source: Table 5.11, page 142 in "National Accounts Statistics, 1991", Central Bureau of Statistics of Norway, 1993).

Or **lost income**: 467,075/4,249,830 = **109,904 NOK per capita.**

Sweden

Gross national product at factor cost, 1990: 1,178,803 SEK.(Source: Table H1, page 19 in "National Accounts, 1980-1991, Annual Report", Statistics Sweden, 1992)

Or income per capita 1,178,803/8,590 = 137,230 SEK.

Gross national product, at factor cost, excluding dwellings, 1990:
(1,178,803-134,680)x10^6 SEK = 1,044,123X10^6 SEK.
(Source: Table H6, page 3737 "National Accounts, 1980-1991, Annual Report", Statistics Sweden, 1992).

Or **lost income:** 1,044,123/8,590 = **121,551 SEK per capita**.

A.4 Lost Capital Services

The value of lost capital services will decrease with time. The table below shows the mathematical relationships between value, value of rent, and value of rent referred to time 0 (lost capital value):

Year no. n	Value	Value of rent at end of year	Total value of rent at time 0
0	a	$a\times L$	0
1	$a\times(1-\Delta)$	$a\times(1-\Delta)\times L$	$a\times L\times(1-R)$
2	$a\times(1-\Delta)^2$	$a\times(1-\Delta)^2\times L$	$a\times(1-\Delta)\times L\times(1-R)^2$
3	$a\times(1-\Delta)^3$	$a\times(1-\Delta)^3\times L$	$a\times(1-\Delta)^2\times L\times(1-R)^3$
etc.	etc.	etc.	etc.,

where a = capital value at beginning of year 0,
L = rent (fraction per year),
Δ = depreciation (fraction per year),
R = bank rate (fraction per year).

At the end of year T after the accident the lost capital services, referred to time 0, will be:

$a \times L \times (1-R) + a \times (1-\Delta) \times L \times (1-R)^2 + \dots + a \times (1-\Delta)^{T-1} \times L \times (1-R)^T.$

or

$$a \times L \times (1-R) \times \frac{1-[(1-\Delta)\times(1-R)]^T}{1-[(1-\Delta)\times(1-R)]} \qquad (1)$$

For $T \rightarrow \infty$ the sum will be:

$$\frac{a \times L \times (1-R)}{1-[(1-\Delta)\times(1-R)]} \qquad (2)$$

L should at least be equal to $[1-(1-\Delta)\times(1-R)]$ to balance the capital value at time 0.

The bank rate is put at	$R = $	0.10 p.a.	(10% p.a.).
Depreciation is put at	$\Delta = $	0.06 p.a.	(6% p.a.) for buildings excl. dwellings)
	$\Delta = $	0.02 p.a.	(2% p.a.) for dwellings
	$\Delta = $	0.10 p.a.	(10% p.a.) for consumer durables
	$\Delta = $	0 for land areas (according to COCO)	
	$\Delta = $	0.10 p.a.	(10% p.a.) for machinery, equipment, etc.
	$\Delta = $	0.03 p.a.	(3% p.a.) for civil engineering works

The corresponding L-values are 15,4%; 11,8%; 19%; 10%; 19%; and 12.7% p.a. respectively.

The capital considered comprises:

1) Buildings (excl. dwellings)
2) Dwellings
3) Consumer durables
4) Land
5) Machinery and equipment, etc.
6) Civil engineering works

Denmark

Data:

The following data on property, land, and building values are extracted from the "18th general assessment, 1/1 1986":

Total value of real estate	1,461,766x10^6 DKR
Total value of land	385,819x10^6 DKR
Total value of buildings	1,075,947x10^6 DKR
Value of dwellings (excl. land) ..	560,518x10^6 DKR

The annual investment per caput in consumer durables, 1990, (excl. cars) is (39,143 + 62,319 - 16,236)x10^6 = 85,226 DKR.
(Source: Table 2.20, page 46 in "National Accounts 1990", Danmarks Statistik, 1992).

If the rate of depreciation is put at 10% p.a.(COCO, page 57), then the corresponding capital value of consumer durables is 852,260x10^6 DKR.

The annual investment (1990) in machinery, equipment, etc. was 49,095x106 DKR.
(Source: Table 2.22, page 48 in "National accounts 1990", Danmarks Statistik, 1991).

If the rate of depreciation is put at 10% p.a., then the corresponding capital value of machinery, etc. is 490,095x10^6 DKR.

The annual investment (1990) in civil engineering works was 23,306x10^6 DKR.
(Source: Table 2.22, page 48 in "National accounts 1990", Danmarks Statistik, 1991).

If the rate of depreciation is put at 3% p.a., then the corresponding capital value is 776,867x10^6 DKR.

Recapitulation:

Capital values.

1) Buildings (excl. dwellings) ...	515,429x10^6 DKR
2) Dwellings	560,518x10^6 DKR
3) Consumer durables	852,260x10^6 DKR
4) Land	385,819x10^6 DKR
5) Machinery, equipment, etc. ...	490,095x10^6 DKR
6) Civil engineering works	776,867x10^6 DKR

The corresponding **average capital values per capita** are (population = 5,135,409):

1) Buildings (excl. dwellings) ...	100,368 DKR
2) Dwellings	109,148 DKR
3) Consumer durables	165,958 DKR
4) Land	75,130 DKR
5) Machinery, equipment etc. ...	95,434 DKR
6) Civil engineering works	151,277 DKR

Calculations:

The lost capital service per average inhabitant in Denmark per year at time 0 is:

1) Buildings (excl. dwelling)	100,368x0.154 = 15,457 DKR
2) Dwelling	109,148x0.118 = 12,879 DKR
3) Consumer durables	165,958x0.190 = 31,532 DKR
4) Land	75,130x0.100 = 7,513 DKR
5) Machinery etc.	95,434x0.190 = 18,132 DKR
6) Civil engineering works	151,277x0.127 = 19,212 DKR
Total	104,725 DKR

In case of a temporary relocation for e.g. 5 years (this time interval is chosen only for demonstration purposes) the total lost capital service per average inhabitant in Denmark, refered to time 0, would be (according to formula (1)):

1) Buildings (excl. dwelling)	51,185 DKR
2) Dwelling	45,800 DKR
3) Consumer durables	97,282 DKR
4) Land	27,690 DKR
5) Machinery, equipment etc. ...	55,942 DKR
6) Civil engineering works	67,112 DKR
Total	345,011 DKR

This sum is relevant for calculation of the cost of the accident but not for optimization.

Costs in connection with various intervention scenarios are given i subsection A.5.

Finland

Data:

Total value of real estate	$1,659,000 \times 10^6$ FIM
Total value of land	$467,800 \times 10^6$ FIM
Total value of buildings	$1,191,200 \times 10^6$ FIM
Value of dwellings (excl. land) ..	$683,700 \times 10^6$ FIM

(Source: National Accounts, Statistics H3B, Central Statistical Office of Finland, 1990)

The yearly investment in consumer durables, 1990 (excl. cars) is $41,383 \times 10^6$ FIM.
(Source: National Accounts, Statistics H3B, Central Statistical Office of Finland, 1990)

If the depreciation rate is put at 10 per cent p.a., then the corresponding capital value of consumer durables is $413,830 \times 10^6$ FIM.

The yearly investment in machinery, equipment etc., 1990, was 37,500x10^6 FIM.
(Source: Table 3.1.1, page 56 in "National Accounts 1986-1990", Statistics of Finland, 1992)

If the depreciation rate is put at 10 per cent p.a., then the corresponding capital value of machinery, equipment etc. is 375,000x10^6 FIM.

The yearly investment in civil engineering works, 1990 was 13,781x10^6 FIM
(Source: National Accounts, Statistics H3B, Central Statistical Office of Finland, 1990)

If the depreciation rate is put at 3 per cent p.a., then the corresponding capital value is 459,367x10^6 FIM.

Recapitulation:

1) Buildings (excl. dwellings) . . .	507,500x10^6 FIM
2) Dwellings	683,700x10^6 FIM
3) Consumer durables	413,830x10^6 FIM
4) Land	467,800x10^6 FIM
5) Machinery, equipment etc. . . .	375,000x10^6 FIM
6) Civil engineering works	459,367x10^6 FIM

The corresponding average capital values per capita are (population = 4,986,000):

1) Buildings (excl. dwellings) . . .	101,785 FIM
2) Dwelling	137,124 FIM
3) Consumer durables	82,998 FIM
4) Land	93,823 FIM
5) Machinery, equipment etc. . . .	75,211 FIM
6) Civil engineering works	92,131 FIM

Calculations:

The lost capital service per average inhabitant in Finland per year at time 0 is:

1) Buildings (excl. dwelling) . . .	101,785x0.154 =	15,675 FIM
2) Dwelling	137,124x0.118 =	16,180 FIM
3) Consumer durables	82,998x0.190 =	15,770 FIM
4) Land	93,823x0.100 =	9,382 FIM
5) Machinery, equipment etc. . . .	75,711x0.190 =	14,385 FIM
6) Civil engineering works	92,131x0.127 =	11,700 FIM
Total	83,092 FIM	

In case of a temporary relocation for e.g. 5 years (this time interval is chosen only for demonstration purposes) the total lost capital service per average inhabitant in Finland, refered to time 0, would be (according to formula (1)):

1) Buildings (excl. dwelling)	51,908 FIM
2) Dwelling	57,540 FIM
3) Consumer durables	48,653 FIM
4) Land	34,579 FIM
5) Machinery, equipment etc	44,381 FIM
6) Civil engineering works	40,872 FIM
Total	277,933 FIM

This sum is relevant for calculation of the cost of the accident but not for optimization.

Costs in connection with various intervention scenarios are given i subsection A.5.

Norway

Data:

Total value of real estate	$1,233,080 \times 10^6$ NOK
Total value of land	$93,252 \times 10^6$ NOK
Total value of buildings	$1,139,828 \times 10^6$ NOK
Value of dwellings (excl. land) ..	$590,873 \times 10^6$ NOK

(Source: Table 427, page 352 in "Statistical Yearbook of Norway, 1992", Central Bureau of Statistics of Norway, 1992, values for 1990).

The yearly investment in consumer durables, 1990 (excl. cars) is $(29,996+42,564-11,205) \times 10^6$ = $61,355 \times 10^6$ NOK.
(Source: Table 6.1, page 223 and page 224 in "National accounts statistics 1991", Central Bureau of Statistics of Norway, 1993)

If the depreciation rate is put at 10 per cent p.a., then the corresponding capital value of consumer durables is $613,550 \times 10^6$ NOK.

The yearly investment in machinery, equipment etc., 1990, was $26,785 \times 10^6$ NOK.
(Source: Table 6.9, page 247 in "National Accounts Statistics, 1991", Central Bureau of Statistics of Norway, 1993)

If the depreciation rate is put at 10 per cent p.a., then the corresponding capital value of machinery, equipment etc. is $267,850 \times 10^6$ NOK.

The yearly investment in civil engineering works (excluding oil industry), 1990 was $17,497 \times 10^6$ NOK
(Source: Table 6.9, page 247 in "National Accounts Statistics, 1991", Central Bureau of Statistics of Norway, 1993)

If the depreciation rate is put at 3 per cent p.a., then the corresponding capital value is 583,233x10^6 NOK.

Recapitulation:

1) Buildings (excl. dwellings) . . .	548,955x10^6 NOK
2) Dwellings	590,873x10^6 NOK
3) Consumer durables	613,550x10^6 NOK
4) Land	93,252x10^6 NOK
5) Machinery, equipment etc. . . .	267,850x10^6 NOK
6) Civil engineering works	583,233x10^6 NOK

The corresponding average capital values per capita are (population = 4,249,830):

1) Buildings (excl. dwellings) . . .	129,171 NOK
2) Dwelling	139,035 NOK
3) Consumer durables	144,371 NOK
4) Land	21,943 NOK
5) Machinery, equipment etc. . . .	63,026 NOK
6) Civil engineering works	137,237 NOK

Calculations:

The lost capital service per average inhabitant in Norway per year at time 0 is:

1) Buildings (excl. dwelling) . . .	129,171x0.154 = 19,892 NOK
2) Dwelling	139,035x0.118 = 16,406 NOK
3) Consumer durables	144,371x0.190 = 27,430 NOK
4) Land	21,943x0.100 = 2,194 NOK
5) Machinery, equipment etc. . . .	63,026x0.190 = 11,975 NOK
6) Civil engineering works	137,237x0.127 = 17,429 NOK
Total	95,326 NOK

In case of a temporary relocation for e.g. 5 years (this time interval is chosen only for demonstration purposes) the total lost capital service per average inhabitant in Norway, refered to time 0, would be (according to formula (1)):

1) Buildings (excl. dwelling)	65,874 NOK
2) Dwelling	58,342 NOK
3) Consumer durables	84,629 NOK
4) Land	8,087 NOK
5) Machinery, equipment etc. . . .	36,945 NOK
6) Civil engineering works	60,883 NOK
Total	314,760 NOK

This sum is relevant for calculation of the cost of the accident but not for optimization.

Costs in connection with various intervention scenarios are given i subsection A.5.

Sweden

Data:

Total value of real estate	$1{,}161{,}576 \times 10^6$ SEK
Total value of land	$377{,}988 \times 10^6$ SEK
Total value of buildings	$783{,}588 \times 10^6$ SEK
Value of dwellings (excl. land) ..	$510{,}351 \times 10^6$ SEK

(Source: Table 1, page 21, table 3, page 25, table 5, page 31 and table 6, page 34 in "Assessment of Real Estate in 1988, Part 1", Bo 37 SM 8901, Statistics of Sweden, 1989).

The yearly investment in consumer durables, 1990 (excl. cars) is $(63{,}271+111{,}325-19{,}960) \times 10^6 = 154{,}636 \times 10^6$ SEK.
(Source: table 1:2, page 67, in "National Accounts, Annual Report 1980-1991", Statistics of Sweden 1992).

If the depreciation rate is put at 10 per cent p.a., then the corresponding capital value of consumer durables is $1{,}546{,}360 \times 10^6$ SEK.
The yearly investment in machinary, equipment etc., 1990, is estimated at 80.000×10^6 SEK Source: Table 2.2, page 74 in "National Accounts, Annual Report 1980-1991", Statistics of Sweden 1992).

The capital value of machinery, equipment etc. is then $800{,}000 \times 10^6$ SEK if the depreciation rate is put at 20 per cent p.a.

The yearly investment in civil engineering works, 1990, is 60,255 SEK.

If the depreciation rate is put at 3 per cent p.a. then the capital value of civil engineering works is 2,008,500

Recapitulation:

1) Buildings (excl. dwellings) ...	$273{,}237 \times 10^6$ SEK
2) Dwellings	$510{,}351 \times 10^6$ SEK
3) Consumer durables	$1{,}546{,}360 \times 10^6$ SEK
4) Land	$377{,}988 \times 10^6$ SEK
5) Machinery, equipment etc. ...	$800{,}000 \times 10^6$ SEK
6) Civil engineering works	$2{,}008{,}500 \times 10^6$ SEK

The corresponding average capital values per capita are (population = 8,590,000):

1) Buildings (excl. dwelling)	31,809 SEK
2) Dwelling	59,412 SEK
3) Consumer durables	180,019 SEK
4) Land	44,003 SEK
5) Machinery, equipment etc. ...	93,132 SEK
6) Civil engineering works	233,818 SEK

Calculations:

The lost capital service per average inhabitant in Sweden per year at time 0 is:

1) Buildings (excl. dwelling) ...	31,809x0.154 = 4,899 SEK
2) Dwellings	59,412x0.118 = 7,011 SEK
3) Consumer durables	180,019x0.190 = 34,204 SEK
4) Land	44,003x0.100 = 4,400 SEK
5) Machinery, equipment etc. ..	93,132x0,190 = 17,695 SEK
6) Civil engineering works	233,818x0.127 = 29,695 SEK
Total	97,904 SEK

In case of a temporary relocation for e.g. 5 years (this time interval is chosen only for demonstration purposes) the total lost capital service per average inhabitant in Sweden, refered to time 0, would be (according to formula (1)):

1) Buildings (excl. dwelling)	16,222 SEK
2) Dwellings	24,930 SEK
3) Consumer durables	105,525 SEK
4) Land	16,218 SEK
5) Machinery, equipment etc. ...	54,595 SEK
6) Civil engineering works	103,730 SEK
Total	321,220 SEK

This sum is relevant for calculation of the cost of the accident but not for optimization.

Costs in connection with various intervention scenarios are given in subsection A.5 below.

A.5 Calculation of Intervention Costs for Various Scenarios

Sheltering:

Assuming a sheltering time of 6 hours the following costs should be calculated:

Lost income + partly lost capital service (Buildings, exl. dwellings; land; machinary, equipment and civil engineering works) for a time period of 6 hours.

Denmark:	(6/(365x24))x(120,830+15,457+7,513+18,132+19,212)	≅ **125 DKR.**
Finland:	(6/(365x24))x(72,107+15,675+9,382+14,385+11,700)	≅ **85 FIM.**
Norway:	(6/(365x24))x(109,904+19,892+2,194+11,975+17,429)	≅ **110 NOK**
Sweden:	(6/(365x24))x(121,551+4,899+4,400+17,690+26,695)	≅ **120 SEK.**

Relocation

a) Assuming relocation **for one month from residential areas only at time 0** the following costs per person should be calculated:

Transport + partly lost capital services (Dwellings, consumer durables) for a period of 1 month.

Denmark:	63+(1/12)x(12,879+31,530)	≅ **3,750 DKR.**
Finland:	37,5+(1/12)x(16,180+15,770)	≅ **2,700 FIM.**
Norway:	67+(1/12)x(16,406+27,430)	≅ **3,700 NOK.**
Sweden:	50+(1/12)x(7,011+34,204)	≅ **3,500 SEK.**

b) Assuming that **only industrial areas are abandonned for 1 month at time 0** the following costs per person should be calculated:

Lost income + partly lost capital service (Buildings (excl. dwellings); land; machinery, equipment etc.; civil engineering works) for a period of 1 month.

Denmark:	(1/12)x(120,830+15,457+7,513+18,132+19,212)	≅ **15,100 DKR.**
Finland:	(1/12)x(72,107+15,675+9,382+14,385+11,700)	≅ **10,300 FIM.**
Norway:	(1/12)x(109,904+19,892+2,194+11,975+17,429)	≅ **13,400 NOK.**
Sweden:	(1/12)x(121,551+4,899+4,400+17,695+29,695)	≅ **14,900 SEK.**

c) Assuming **relocation of residential areas and abandonning of industrial areas for 1 month at time 0** the folowing costs per person should be calculated:

Lost income + lost capital services for a period of 1 month.

Denmark:	(1/12)x(120,830+104,725)	≅ **18,800 DKR.**
Finland:	(1/12)x(72,107+83,092)	≅ **12,900 FIM.**
Norway:	(1/12)x(109,904+95,326)	≅ **17,100 NOK.**
Sweden:	(1/12)x(121,551+94,904)	≅ **18,000 SEK.**

Repopulation

After economic recovery the relocated population will probably not return but a benefit can nevertheless be gained by repopulating an abandonned area. The benefit is now only the capital services that can be saved. Repopulation can take place when the saved capital service per year exceeds the value of the dose received per year. In practice it may be appropriate to base the calculation on time intervals of one month.

After e.g. 5 years the capital services that can be saved per person of the original population (in the 6th year assessed at the end of year 6) can be calculated as follows:

Denmark:

1) Property	$100{,}368x(1\text{-}0.06)^5x0.154$ = 11,344 DKR
2) Dwelling	$109{,}148x(1\text{-}0.02)^5x0.118$ = 11,642 DKR
3) Consumer durables	$165{,}958x(1\text{-}0.10)^5x0.19$ = 18,619 DKR
4) Land	75,130x0.1 = 7,513 DKR
5) Machinery etc.	$95{,}434x(1\text{-}0.10)^5x0.190$ = 10,707.DKR
6) Civil engineering	$151{,}277x(1\text{-}0.03)^5x0.127$ = 16,498 DKR
Total	**76,323 DKR**

Finland:

1) Buildings	$101{,}785x(1\text{-}0.06)^5x0.154$ = 11,504 FIM
2) Dwelling	$137{,}124x(1\text{-}0.02)^5x0.118$ = 14,626 FIM
3) Consumer durables	$82{,}998x(1\text{-}0.10)^5x0.190$ = 9,312 FIM
4) Land	93,823x0.1 = 9,382 FIM
5) Machinery, etc.	$75{,}711x(1\text{-}0.10)^5x0.190$ = 8,494 FIM
6) Civil engineering	$92{,}131x(1\text{-}0.03)^5x0.127$ = 10,048 FIM
Total	**63,366 FIM**

Norway:

1) Buildings	$129{,}171x(1\text{-}0.06)^5x0.154$ = 14,599 NOK
2) Dwelling	$139{,}035x(1\text{-}0.02)^5x0.118$ = 14,830 NOK
3) Consumer durables	$144{,}371x(1\text{-}0.10)^5x0.190$ = 16,197 NOK
4) Land	21,943x0.1 = 2,194 NOK
5) Machinery, etc.	$63{,}026x(1\text{-}0.10)^5x0.190$ = 10,777 NOK
6) Civil engineering	$137{,}237x(1\text{-}0.03)^5x0.127$ = 16,906 NOK
Total	**75,503 NOK**

Sweden:

1) Buildings	$31{,}809x(1\text{-}0.06)^5x0.154$ = 15,283 SEK
2) Dwelling	$59{,}412x(1\text{-}0.02)^5x0.118$ = 6,337 SEK
3) Consumer durables	$180{,}019x(1\text{-}0.10)^5x0.190$ = 20,197 SEK
4) Land	44,003x0.1 = 4,400 SEK
5) Machinery etc.	$93{,}136x(1\text{-}0{,}10)^5x0.190$ = 10,449 SEK
6) Civil engineering	$233{,}818x(1\text{-}0.03)^5x0.127$ = 25,500 SEK
Total	**82,166 SEK**

Repopulation can take place if this amount exceeds the value of the dose received in the 6th year. In practice it may be appropriate to base the calculation on time intervals of one month to achive the optimum level of protection.

B. Cost in Connection with Banning of Foodstuffs

These costs are already taken into account in regions where people are relocated, because the gross income at factor cost (including that of agriculture) was used to calculate the relocation costs. Accordingly no cost should be considered in connection with relocation.

In the first period after banning of foodstuffs (in regions where the population is remaining) it seems reasonable to calculate retail prices for the lost foodstuffs, until supplies of raw materials with lower concentrations can be acquired by the food industry.

Retail prices of foodstuffs can be found in the statistical yearbooks of Finland, Norway (comprehensive) and Sweden. A very detailed list for Denmark can be found in "Detailpriser", 1989/90, Statistikservice 1989:4, Danmarks Statistik, 1990.

It turns out that the prices of foodstuffs are rather similar in the scandinavian countries It may be practical to classify them in 4 price categories:

Category 1: 0-3 US$ comprising typically milk, vegetables, flour, margarin,
Category 2: 3-6 US$ comprising typically butter, eggs, white bread, cheap fish
Category 3: 6-12 US$ comprising typically medium priced meat, cheap fish
Category 4: 12 - US$ expensive meat

When calculating intervention levels, kg-prices should be put in relation to the collective dose that will be received by the consumption of 1 kg. The relevant unit for intervention is therefore dose/kg. For each isotope this can be transformed to concentration. If more isotopes are present the doses for the individual isotopes should be added. Intervention concentrations for raw materials should be corrected for possible decontamination (but not for dilution) or increased concentration in the final product. It is thus possible to have different intervention levels according to the use of raw materials (e.g use of potatoes for consuption or for productions of alcohol

Appendix V. Cost of Protective Measures in the Nordic Countries

Sources:

COCO-1: Model for Assessing the Cost of Offsite Consequences of accidental releases of Radioactivity", NRPB-R243, 1991.

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Intervention Principles and Levels in the Event of a Nuclear Accident

In case of a large nuclear accident that may affect several countries, it is important that corresponding remedial actions are taken by the national authorities concerned. This will help to avoid confusion and mistrust in the populations. In this project a scheme for uniform intervention principles and levels is proposed, based on considerations of monetary costs for different types of intervention in the Nordic countries. The populations` perception of risk is an important factor , and therefore the psychological aspects of catastrophic events have been examined. The report offers the basis for a joint attitude among authorities, scientists, and others involved in remedial actions in case of a nuclear accident.

The Nordic Committee for Nuclear Safety Research - NKS
organizes pluriannual joint research programmes. The aim is to achieve a better understanding in the Nordic countries of the factors influencing the safety of nuclear installations. The programme also permits involvement in new developments in nuclear safety, radiation protection, and emergency provisions. The three first programmes, from 1977 to 1989, were partly financed by the Nordic Council of Ministers.

The 1990 - 93 Programme
Comprises four areas:

*	Emergency preparedness	(The BER-Programme)
*	Waste and decommissioning	(The KAN-Programme)
*	Radioecology	(The RAD-Programme)
*	Reactor safety	(The SIK-Programme)

The programme is managed - and financed - by a consortium comprising the Danish Emergency Management Agency, the Finnish Ministry of Trade and Industry, Icelands's National Institute of Radiation Protection, the Norwegian Radiation Protection Authority, and the Swedish Nuclear Power Inspectorate. Additional financing is offered by the IVO and TVO power companies, Finland, as well as by the following Swedish organizations: KSU, OKG, SKN, SRV, Vattenfall, Sydkraft, SKB.

ADDITIONAL INFORMATION is available from
the NKS secretary general, POB 49, DK-4000 Roskilde, fax (+45) 46322206

Intervention Principles and Levels in the Event of a Nuclear Accident

The Nordic Council of Ministers

ISBN 92 9120 613 X
ISSN 0908-6692