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Operational Intervention Levels in a Nuclear Emergency, General Concepts and a Probabilistic Approach

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Nordic Nuclear Safety Research

Report by the EKO-3.3 subgroup

Bent Lauritzen (editor) [1)]
Ulf Bäverstam [2)]
Anders Damkjær (head of subgroup) [1)]
Eldri Naadland Holo [3)]
Kari Sinkko [4)]

December 1997

1) *Risø National Laboratory, Denmark.*
2) *Swedish Radiation Protection Institute, Stockholm.*
3) *Norwegian Radiation Protection Authority, Oslo.*
4) *Radiation and Nuclear Safety Authority, STUK, Helsinki.*

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Rapporten er udgivet af:
NKS-sekretariatet
Bygning 100
Postboks 49
DK-4000 Roskilde

Tlf. +45 4677 4045
Fax +45 4677 4046
E-mail annette.lemmens@risoe.dk
http://www.risoe.dk/nks

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Abstract This report deals with Operational Intervention Levels (OILs) in a nuclear or radiation emergency. OILs are defined as the values of environmental measurements, in particular dose rate measurements, above which specific protective actions should be carried out in emergency exposure situations. The derivation and the application of OILs are discussed, and an overview of the presently adopted values is provided, with emphasis on the situation in the Nordic countries. A new, probabilistic approach to derive OILs is presented and the method is illustrated by calculating dose rate OILs in a simplified setting. Contrary to the standard approach, the probabilistic approach allows for optimization of OILs. It is argued, that optimized OILs may be much larger than the presently adopted or suggested values. It is recommended, that the probabilistic approach is further developed and employed in determining site specific OILs and in optimizing environmental measuring strategies.

CONTENTS

I. EXECUTIVE SUMMARY

This report deals with Operational Intervention Levels, pertinent to the early phases of a nuclear or radiation emergency. Operational Intervention Levels (OILs) are defined as the values of environmental measurements above which protective actions should be carried out in emergency exposure situations. Of particular interest are dose rate measurements carried out as part of a nuclear emergency preparedness programme, as they are commonly accessible and may provide for a preliminary estimate of the radiological consequences of an ongoing nuclear accident.

In accident management, the main focus of radiation protection is to reduce the adverse health affects of the accident, by reducing radiation exposures to nuclear radiation workers and the public to a level where deterministic effects can be avoided and where stochastic effects are limited “as much as reasonable achievable”. For an effective protection of the public, the timing of a countermeasure is important, since the countermeasure normally will be more effective when implemented at an early time. In this context, the OILs are introduced as decision aiding tools. That is, environmental (dose rate) measurements will facilitate a rapid emergency response by invoking pre-determined OILs as observable thresholds for specific intervention measures.

Intervention is usually considered to be justified when the avertable dose exceeds an Intervention Level (IL), defined in the same units of avertable dose. At the time for the implementation of urgent countermeasures however, the information about the scale and severity of the accident may be very limited, and an assessment of the avertable dose will be very uncertain. If this uncertainty is not addressed explicitly, decisions on invention will to a large extent be arbitrary.

For the purpose of accident management, OILs will, for urgent countermeasures, replace the less practical ILs. An OIL can be defined based on the same general principles as the IL, namely that the expected benefit of dose reduction just offsets the negative effects inevitably associated with the intervention measure. It is emphasized, that with this definition of the OIL there is, a priori, no need for the introduction of an IL in the process of deriving the OIL. On the other hand, since ILs have already been optimized, they may play a role as a calculational tool in the derivation of OILs.

Within the Nordic countries both national and joint approaches have been taken to establish ILs and OILs. So far, no consensus has been reached and national approaches are mainly in draft versions. The aim of the EKO 3.3 project has been to provide the technical background for the determination of OILs in Nordic nuclear emergency preparedness programmes.

Accident management has traditionally been considered a real-time problem where the situation is to be assessed and the response optimized in real time. The consequences of an accident are calculated deterministically, based on a specified source term, meteorological conditions, and the effect of the countermeasures in question. In a realistic situation the information available will be less than complete, especially in the early phases of an accident, thereby rendering deterministic calculations unfeasible. The approach taken here is to evaluate OILs for early countermeasures in a probabilistic setting, in which only a few basic facts concerning the accident are known and any detail about the accident is treated as unknown information at the time of decision making. This is consistent with the requirements that OILs should be predetermined and that decision need to be based solely on the measurements (e.g. dose rate measurements) in case that no other information on the accident is available.

At a later stage when detailed information is available, doses avertable by means of a protective action may be calculated deterministically and compared directly to the ILs expressed in avertable dose. In this case OILs will be less important as decision aiding tools for the accident management.

The calculations performed for the present report do not intend to cover all possible accident scenarios and meteorological conditions. Rather, the focus has been to investigate the consequences of the probabilistic approach in determining OILs and to derive OILs in typical scenarios associated with severe reactor accidents. OILs are derived separately for different intervention measures. However, for this report only dose rate measurements and the sheltering intervention option was investigated in detail.

Fig. 1.1 is an excerpt of Fig. 5.3 in the main text and shows, as an example, the result of a Monte Carlo calculation of dose rates and doses averted by sheltering. Each dot in the figure results from a specific choice of parameters describing all processes from the release to the radiation exposure, and the density of dots gives the joint probability distribution of dose rates and avertable doses. The large variability in avertable dose is

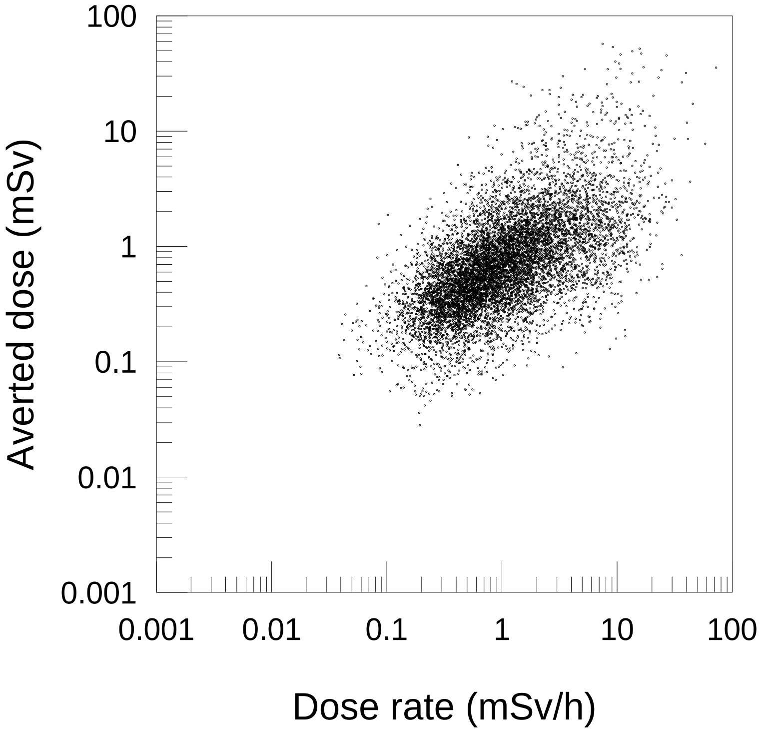

Fig. 1.1. Joint probability distribution for sheltering at 20 km distance, "large releases". The variability is due to the distribution of parameter values describing all processes from the release to the radiation exposure.

evident from the figure and, in particular, it is clear that there is no one-to-one correspondence between dose rates and avertable doses.

The probability distributions comprise the information available for decision making. OILs may be derived from the distributions and it is found that OILs in general are *not* proportional to the ILs of avertable dose. Typical dose rate OILs for sheltering are found to be in the range of $d_{\mathrm{OIL}} > 1$ mSv/h for distances larger than 5 km, i.e. values that are an order of magnitude larger than values adopted in Nordic and international emergency preparedness planning, cf. Table 3.3 below. The OILs depend both on the accident scenario and the distance from the site of the accident to the site where the countermeasures are taken. The implication is that a single OIL cannot be optimal, except for at one distance and for a specified source term. Site-specific calculations will be needed to take into account local differences in assumed source terms, effectiveness of countermeasures as well as differences in measurement strategies.

The probabilistic approach developed in this report offers a method to characterize the uncertainties in the effect of early intervention measures. Such a probabilistic safety assessment is a prerequisite for optimization, both with respect to the planning and the implementation of emergency countermeasures.

We recommend that operational intervention levels (OILs) are defined within the probabilistic framework. In this framework, an optimized OIL is given as the measurement value, for which the average avertable dose is equal to the (generic) intervention level.

Furthermore, we recommend that the probabilistic approach is developed as a tool for optimizing existing and future measuring strategies. This may involve optimizing the type and number of measurements and the time scheme for deployment of mobile measurement units.

Acknowledgements

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II. INTRODUCTION

1. Background. The concept of Operational Intervention Levels in nuclear emergency preparedness planning.

A diversity of sources contributes to the risk of radiation from nuclear accidents. Radioactive materials are widely used in medicine, research, industry, agriculture and teaching. In particular, radioactive materials are abundant in the generation of nuclear power and the entire cycle of related activities from the mining and processing of radioactive ores to the operation of nuclear reactors and the fuel cycle facilities, the management of radioactive waste and the transportation of radioactive sources.

During the nuclear history there has been several accidents causing dispersion of and contamination with radioactive materials. Depending on the accident sequence and the magnitude of the release, history has shown that accidents may have significant radiological consequences, both close to the accident site but also further away. Especially the Chernobyl accident in 1986 taught us that nuclear accidents may have widespread consequences. The radiological impact of an accident however, clearly depends on the distance. Hence, one of the main differences between the Nordic countries regarding the risk pictures is the national nuclear power plants in Sweden and Finland.

The safe design, construction and operation of nuclear facilities (called practices) will greatly reduce the risk of accidents occurring. The risk for severe accidents is, however, not to be ignored and it is essential that appropriate emergency plans are developed. From a radiation protection point of view, the general objectives of emergency planning and management are to reduce the risk or mitigate the consequences of the accident at the source, and, to reduce the adverse health effects by preventing deterministic health effects and by limiting stochastic health effects “as much as reasonably achievable”.

These objectives are accomplished by intervention. That is, the radiological consequences of a nuclear or radiation accident can be reduced by implementing various countermeasures. The important countermeasures are, in the early phases of an accident, *sheltering*, *evacuation*, *iodine prophylaxis*, and *control of access*. Later, e.g. *foodstuff restrictions* and *relocation* will be relevant countermeasures to consider. In this report, only the former, i.e. the urgent countermeasures will be discussed.

Planning for interventions in case of a nuclear accident will be different for the different geographical zones surrounding a nuclear facility. There are several reasons for this. Most importantly, with airborne radionuclides, less time will be available for decision making in the areas closer to the release site, thus requiring more advance planning or precautionary intervention measures, than in areas further away from the release site. Furthermore, close to a nuclear facility, in planning for the management of nuclear accidents one must consider the risk of people suffering deterministic health effects, while further away from the source the main objective will be to limit the risk of stochastic health effects. In the near zone around a nuclear power plant protective actions are both in Sweden and in Finland under all circumstances planned to be of a precautionary nature based on plant conditions.

A nuclear accident is often divided into three phases: a *pre-release phase*, a *release phase* with a time scale of hours/days and a *post-release phase* with a time scale of weeks/months/years, depending on the nature of the release, cf. Fig. 2.1. Protective measures to be taken with the purpose of averting radiation exposure from atmospheric releases of radioactive materials are often divided into emergency measures corresponding to the pre-release and release phases, and longer term protective measures corresponding to the post-release phase of the accident.

In the early stages of an accident, the plume exposure pathways including inhalation are most likely to dominate, although deposition of short-lived γ-emitting radionuclides by rainfall could result in significant external exposures from the ground. In later stages, the relative significance of exposure pathways will depend on the radionuclides involved. When the release contains particulates, the dominating pathways will include ingestion of contaminated food, and external radiation from deposited radionuclides.

Decision on proper intervention measures to be taken will, at any time, be based on the information available. For accidents at a major nuclear installation, e.g. a power plant, the information will at the onset of the accident (the initiating event) be limited to information on the plant status. Later, as the accident evolve, the information is supplemented by environmental monitoring data and meteorological data, eventually allowing for an accurate assessment of the radiological damage.

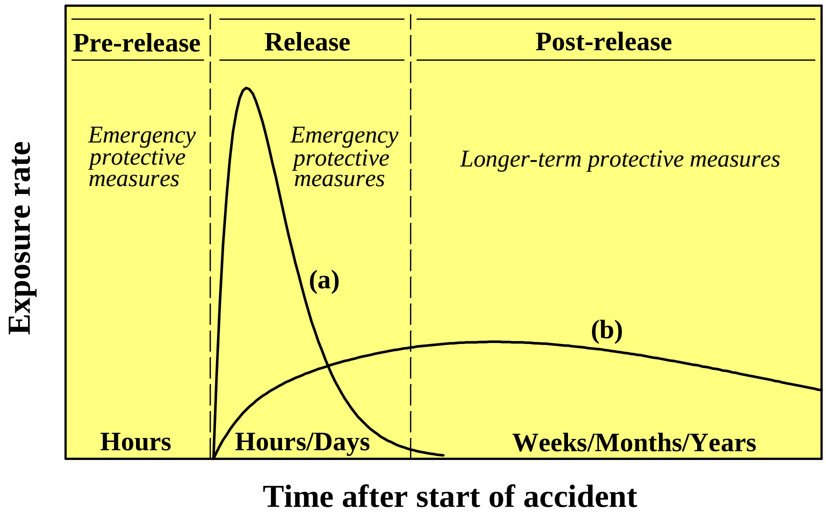

Fig. 2.1. Time phases of a nuclear accident involving atmospheric releases of radioactive materials. During the release phase the exposure predominantly stems from the plume exposure pathways (*a*). *In the post-release phase the exposure is dominated by the ground deposition pathway* (*b*), *the exposure rate is relatively low while the exposure time may be very long.*

As a decision aiding tool, various intervention levels may be defined, that will trigger intervention. The levels relate to the information that is available and therefore may have varying degree of complexity, corresponding to the complexity of information comprising both measurements and calculated quantities. The levels are referred to as Operational Intervention Levels (OILs) when defined directly in terms of measurable quantities, such as plant condition or environmental monitoring data (e.g. dose rate measurements), and they are termed (generic) Intervention Levels (ILs) when they are defined in terms of the radiation dose that may be averted by a specific countermeasure.

Decisions on intervention may have a more solid foundation when based on an extensive set of data, leading to a high degree of confidence in the assessment of the radiological consequences, that is, during the later stages of the evolving accident. On the other hand, the effectiveness of any countermeasure will be reduced when implemented too late, thus favouring early interventions based on a less than complete information about the scale of the accident. While the avertable dose is the key quantity for justifying intervention and is used internationally to establish guidelines for intervention, the concept is not very practical in the early phases of an accident, at which time avertable doses can only be assessed with a large uncertainty. In an accident situation with limited time for assessments, quantities amenable to measurements are needed for making decisions on intervention.

As the accident evolves, management decisions will be based on an ever more complete picture of the accident and its off-site radiological consequences. While the accident assessment is at any time a probabilistic endeavor the uncertainty in the assessment constantly should decrease. At the onset of the accident, decisions are necessarily based on very limited information and the OILs of e.g. plant condition or environmental dose rate measurements act as important decision aiding tools. Later, when a more complete picture of the accident has emerged, decision on a protective measure may be based directly on an estimate of the avertable doses (when compared to the IL of avertable dose), rather than being dependent on OILs of the measurements themselves.[1]

Work has been carried out to establish generic ILs in terms of avertable doses. International guidelines are provided by IAEA [1] and ICRP [2]. Within the Nordic countries several initiatives regarding development of intervention levels have been made. In Sweden[3] and in Finland [4], generic sets of intervention levels have been suggested but not yet approved. In Denmark a similar work is going on [5]. In addition an initiative from the Nordic authorities has been taken on a joint Nordic approach [6]. This work has not yet been finalized. During the last NKS period a Nordic work on defining generic intervention levels was undertaken [7]. The present status regarding ILs and OILs in the Nordic countries are summarized in Section III.6.

The OILs can be determined based on a principle of optimizing the response to hypothetical accidents, that is, by maximizing the expected net benefit associated with

[1] In case of foodstuff restrictions, decisions will not be based on an estimate of the avertable dose, but first on the deposited ground activity concentration and later on the activity concentration in the foodstuffs.

either invoking or not invoking a specific countermeasure. The optimized OILs will be both accident- and site-specific, thus in principle precluding OILs from being harmonized, in the sense of the OILs having a single, common value. On the other hand, harmonizing the OILs will act to reduce non-quantifiable effects such as confusion, psycho-social effects, ambiguity in the decision making process and loss of confidence in the adequacy of intervention measures. Also, since nuclear accidents may have cross-boundary implications, it may be desirable to harmonize OILs between the Nordic countries. Harmonization however, may not be consistent with optimization, so that OILs may only be harmonized on the expense of higher anticipated costs.

2. Scope and limitations of the present project.

The present work addresses the technical background for defining OILs to be used in a nuclear emergency. When decisions are to be based on environmental monitoring data, assumptions have to be made on the relation between the radiological risks to the public and the monitoring data acquired. This necessitates the modelling of accident scenarios including the environmental consequences in order to investigate which avertable doses that are consistent with a given set of monitoring data.

In the standard approach to derive intervention guidelines, i.e. OILs, the model variables attain single point values, thereby implying a definite relationship between all observables and the exposures. In this work we investigate the consequences of allowing the important parameters to vary, by ascribing a probability distribution to the parameter space. This probabilistic approach reflects the general uncertainty or the lack of knowledge at the time of decision making, when decisions are to be based on only a few measurements.

Dose rate OILs for sheltering are calculated within the probabilistic approach. The present work, however, must be seen more as expanding on the idea of employing a probabilistic approach, rather than giving an exclusive account for what OILs to use in an emergency. Proper OILs need to be optimized locally, depending on the radiation source and local conditions. Such investigations remain to be carried out, and the calculations performed for this report do *not* present the final work on the topic. Rather, the present results suggest that calculations of optimized OILs be carried out independently for each major potential source of radionuclide contaminants.

Only short term intervention measures, and in particular the sheltering option, have been treated here. Indeed, the use of OILs are more valuable for urgent countermeasures than for late interventions, at the time of which a more complete picture of the radiological consequences must be expected to have formed, allowing for an estimate of doses and dose reductions and thereby rendering OILs obsolete, with the exception of foodstuff control where they remain important tools.

The urgent countermeasures of evacuation and iodine prophylaxis have not been investigated in detail. Evacuation is a much more costly intervention measure than sheltering, and the prospect of evacuating a population is extremely sensitive to local conditions, making a general treatment less meaningful. When decisions on iodine prophylaxis are to be based on environmental monitoring, the data should include spectroscopic information, making an assessment of the iodine concentrations possible. Such information is not widely accessible in the Nordic countries, and calculations must be based on the actual equipment available and on the measuring strategies envisioned.

As optimized OILs may differ from one locality to another, harmonization of the OILs, e.g., within the Nordic countries, may not be reasonable. Rather, if harmonization is desired, it might be more appropriate to harmonize the prescriptions for deriving OILs and the rationale behind the implementation of OILs in nuclear emergency preparedness planning than simply to settle on identical OILs. The advantages and disadvantages of harmonization however, will not be discussed further in this report.

III. NUCLEAR EMERGENCY PLANNING

1. Principles of intervention.

Radiological protection in a nuclear or radiation emergency aims at limiting the adverse health effects that may result from unwarranted radiation exposure. The International Commission on Radiological Protection (ICRP) has in 1991 published its latest recommendations on the system of radiological protection for practices and for interventions [8]. A distinction is made between *practices*, which cause or increase the exposure of individuals, and *interventions*, which reduce such exposure. In situations demanding intervention, the sources, the pathways and the exposed individuals are already in place when the decisions about control measures are being considered.

In intervention situations, the radiation exposure should be reduced, in order to limit stochastic health effects, and at least to a level where deterministic health effects (e.g. radiation sickness) can be avoided. Considering only stochastic health effects, the key dose quantity relevant for decisions taken during a nuclear accident or a radiological emergency is the *avertable dose*, i.e. the dose that may be averted by means of a protective action.

Dose limits with respect to stochastic health effects do not apply in the case of intervention. Intervention cannot reduce doses already received[2] and decisions on the introduction of protective measures should focus on the reduction of future doses. However, it is recognized that past doses may affect social perceptions and so may influence decisions through consideration of the social factors.

2. Intervention Levels and avertable doses.

An Intervention Level (IL) is the terminology for a level of avertable dose at which action is taken in the case of emergency or chronic exposure situations. In the International Basic Safety Standards, ILs are defined as "*the level of avertable dose at which a specific protective action or remedial action is taken in an emergency exposure situation or a chronic exposure situation*" [9].

An IL relates to a specific protective action taken to mitigate the consequences of an accidental release of radionuclides or of other de facto radiation sources and refers to the avertable dose from this specific protective measure. In general, the IL 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 sub-group being considered for inclusion in such a group. Thus, the IAEA define ILs referring to "suitable chosen samples of the

[2] The committed dose however, may be reduced in some cases, for instance the committed equivalent dose to the thyroid gland resulting from the intake of radioactive iodine can in a few hours after the intake be reduced by administering stable iodine.

population, not to the most exposed individuals" [1]. The estimation of the dose averted should be realistic, to be consistent with the way that the IL is determined.

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 otherwise intended and that this is in the best interests of those affected. This view however, ignores the negative features of the protective action itself, which may be considerable. If the intervention criterion has been properly evaluated as being the best for 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 only remain reasonable provided that 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 ILs to heterogeneous groups in the population, it will therefore be necessary to ensure that the variation in the overall risk within the affected group is not too great. Where it is, doses to the most sensitive sub-groups, e.g. children, might be used for decisions on intervention. This may, however, lead to potential social problems if protective actions are implemented selectively in a general population [10].

Generic ILs are determined taking into account the detrimental effects due to radiation and the adverse effects of the intervention measures, as well as the resources needed to implement the protective actions. Socio-political factors or psychological factors are explicitly *not* taken into account in determining generic ILs. An IL in terms of avertable dose, ΔE_{IL}, is evaluated as the ratio between the costs C of the protective action and the α-value, $\Delta E_{\mathrm{IL}} = C/\alpha$, in which the α-value is the benefit of a unit of dose reduction, expressed in monetary values. Avertable doses for urgent protective measures must be evaluated accordingly, i.e. for the same choice of population group and their habits as is used in determining the IL.

Sheltering. Assuming that people *not* affected by the intervention measure only contributes a minor part of the total costs of sheltering (e.g. the collective loss of income), only those people that actually follow the advice of sheltering (and would not otherwise have done so) should be included in the estimate of avertable dose. Hence, the avertable dose ΔE is estimated as

$$\Delta E = (1-L)\, E_{\mathrm{L}} + (1-F)\, E_{\mathrm{F}},$$

where L and F are the location and filtration dose-reducing factors, and E_{L} and E_{F} are the unsheltered dose values for external radiation and inhalation pathways, respectively.

Evacuation. Since all people at a given location are affected by the evacuation, the avertable dose can be estimated as

$$\Delta E = \overline{L} E_{\mathrm{L}} + \overline{F} E_{\mathrm{F}},$$

where $\overline{L}$ and $\overline{F}$ denote the time-averaged location and filtration factors, thus taking into account the likelihood that the population would have remained sheltered if they were not evacuated. If x denote the fraction of time spent indoors, $\overline{L}$ and $\overline{F}$ are given by

$$\overline{L} = xL + (1-x), \quad \overline{F} = xF + (1-x),$$

respectively.

Iodine prophylaxis. The costs associated with the administration of stable iodine necessarily include the medical adverse effects of the intervention, and an estimate of these costs seems very uncertain. Since the intervention measure only affects those people that have immediate access to iodine tablets, the avertable dose is calculated as

$$\Delta D = f_{\mathrm{Thyroid}}\, D_{\mathrm{Thyroid}}\ ,$$

where f_{Thyroid} denotes the effectiveness in the dose reduction from the intake of tablets, D_{Thyroid} being the unprotected thyroid absorbed dose due to inhalation or ingestion of radioiodine.

The three intervention measures above are treated as stand-alone protective actions, the intervention levels determined independently of each other. In practice however, the protective actions are more likely to be combined, for instance sheltering may be advised until appropriate means of evacuation can be established, and iodine prophylaxis will usually only accompany sheltering or evacuation. When different courses of actions are possible the choice of one or more protective actions should be based on a total optimization of the countermeasures.

The costs associated with the implementation of different protective actions are likely to add, such as the loss of income associated with sheltering and the medical costs associated with an intake of stable iodine. With ILs being determined as the ratio of cost to α-value, the ILs given above also apply when protective countermeasures are combined. That is, each protective measure has its own IL irrespective of whether other protective measures are carried out.

The benefits on the other hand, do not add. Rather, the benefit in form of a dose reduction resulting from a specific protective action will normally be reduced when other protective measures have already been taken. As an example, the dose reduction to the thyroid due to the intake of iodine tablets may for a sheltered person be estimated as

$$\Delta D = f_{\mathrm{Thyroid}}\, F\, D_{\mathrm{Thyroid}}\ ,$$

when the thyroid dose stems entirely from inhalation. The avertable dose are therefore reduced by the filtration factor F as compared to the avertable dose for an unsheltered person. The reduced avertable dose is the appropriate quantity to compare with the IL, in this case for iodine prophylaxis, in order to justify intervention.

3. Operational Intervention Levels as decision aiding tools.

Although the avertable dose in a given time, suitably qualified, is the relevant quantity for judging the need for a protective action, this does not preclude the use of other quantities. Indeed, the concept of avertable dose is impractical when it comes to urgent intervention measures, as a reliable estimate of the avertable dose requires both detailed information on the release and transport of radionuclides, and, even in the unlikely situation that such information would be available, the calculation of the avertable dose still requires a considerable amount of computing.

Because of the need to act quickly in case of a nuclear or radiological emergency, there is merit in establishing, *in advance*, values of operationally measurable quantities to be used as basis for decisions on different countermeasures. Actual measured quantities such as dose rate or level of contamination are in this sense used as surrogates for the avertable dose, and Operational Intervention Levels (OILs) are defined in terms of these measurable quantities.

Depending on the protective action being considered, the avertable dose will be a function of some or all of the following: the release characteristics and composition, the adequacy of the warning, the time of day, the season of the year, weather conditions, shielding provided by buildings, size of population affected etc.. Measurable quantities on the other hand, such as dose rates, will depend in a different way on some of these parameters and they may also be subject to uncertainties associated with the measurements themselves. It is evident that the measurable quantities do *not* translate unambiguishly into avertable doses, and, consequently, OILs *cannot* be derived in a simple way from the ILs of avertable dose.

Rather, the measurements merely act to reduce the uncertainty in forecasting. The accident assessment process is an iterative one in which knowledge and appreciation of the radiological situation is constantly being refined, updated and reconstructed. As more results come from the field measurements and from laboratory analysis and more information is received from the facility, the raw data are collated, compiled and compared with results from models to produce a composite picture of the radiological situation off-site. The aim of the assessment is at any time to facilitate decision making on the implementation of protective measures.

While the radiation exposures of the public cannot be predicted accurately, especially during the early phases of an accident, it may be possible to estimate the likelihood of a specified range of radiation exposures, that is, to associate with any level of radiation exposure a probability of the occurrence. From such probabilities, or rather the probability distribution of avertable doses ΔE, cf. Section IV, one may compare the average avertable dose, $\mathrm{EXP}(\Delta E)$, to the IL of avertable dose, ΔE_{IL}. Instead of an accurate assessment, intervention would be called for if the expected avertable dose is larger than the IL, i.e. $\mathrm{EXP}(\Delta E) > \Delta E_{\mathrm{IL}}$.

When environmental monitoring is in place and e.g. dose rate measurements are available for decision making, the measurement data will constrain the probability distribution of avertable doses. In this case, the average avertable dose is replaced by the conditional expectation value, e.g. EXP(ΔE | d) where d denote the measured dose rate, and intervention is merited if EXP(ΔE | d) > ΔE_{IL}. Assuming that the average avertable dose increases with the measurement values, the OIL of dose rate, d_{OIL}, may be defined by the equality,

$$\mathrm{EXP}(\Delta E \mid d_{OIL}) = \Delta E_{IL}.$$

This equation defines the OIL implicitly. The IL is given a parametric dependence on the OIL and a closed expression for the OIL does not exist. Because of the many factors involved in determining OILs, these levels may in general be expected to be both *site* and *accident* specific.

When additional information besides the environmental monitoring data is available for decision making, e.g. information on the composition of radionuclides released, this information may lead to an adjustment of the OILs. For instance, if the dose rate OIL is determined taking into account the likelihood that the release contains particulates, information that only noble gases are released will result in an increased OIL, since the inhalation doses have ceased to play a role.

4. Environmental monitoring.

A radiological monitoring programme, properly equipped and organized, is required to determine the level and extent of the off-site contamination and radiation levels. Priorities and courses of action will be dictated by the nature of the accident and the resources available. Many different methods and techniques can be used in the environmental monitoring. The monitoring results can be divided into broad categories such as:

External radiation data. These data include total β- and/or γ-dose rates of the radiation field, and, if γ-spectrometers are at hand, information on the contributing γ-emitting radionuclides.

Surface contamination data. α, β, and γ contamination data are determined by field measurements with surface monitors, properly shielded from the ambient radiation fields, or by surface samples analyzed in the laboratory.

Activity concentration in the air. α, β, and γ activity concentrations are determined by measurement on air filter samples from fixed or mobile stations. The data will be sensitive both to the meteorological conditions, the site of the sampling, and the time of sampling due to the possibly fast changing conditions.

Environmental samples data, such as activity concentration in foodstuff, water, crops, animal products, soils, sediments etc..

Individual dosimetric data, as determined by externally placed dosimeters, and internal contamination determined by whole body counting or bioassays.

The operational quantities available for the accident assessment process are summarized in Table 3.1. For the urgent countermeasures sheltering and evacuation, plant condition, the dose rate from the plume, and possibly the air concentration are the important quantities. The ground contamination density and the dose rate from that, both while the plume is present and after the plume has passed, is of less or no importance for these countermeasures. In case however, that the release phase is very short leaving insufficient time for environmental monitoring during the release phase, decision on e.g. evacuation may be based on dose rate or on high levels of ground contamination.

Decision on iodine prophylaxis should preferably be based on measurement of the air concentration of radioiodines. Other monitoring data is not expected to display a strong correlation with the doses from iodine to the thyroid gland.

Decisions on relocation may be based either on measurements of dose rate from deposited activity, of surface contamination density, or on the concentration in air of resuspended activity, especially that of α-emitting radionuclides. Since decisions on relocation are taken at a relatively late stage of an accident, it may be possible to estimate directly the avertable dose by relocation.

Precautionary restrictions on the use of agricultural land could be based on the surface contamination density with the purpose of making early decisions on the use of the food products produced on the land. Longer term restrictions on the use of foodstuffs produced in contaminated areas should be based on measurements of the activity concentration in the foodstuffs.

Table 3.1. Operational quantities to be used in an emergency exposure situation.

Protective Action	**Operational Quantity**
Sheltering	Plant conditions - *Before release* Air activity concentration (Bq/m^3) - *Plume present* Dose rate (mSv/h) - *Plume present*
Control of access	Plant conditions - *Before release* Air activity concentration (Bq/m^3) - *Plume present* Dose rate (mSv/h) - *Plume present*
Iodine prophylaxis	Plant conditions - *Before release* Iodine activity concentration in air (Bq/m^3) - *Plume present*
Evacuation	Plant conditions - *Before release* Air activity concentration (Bq/m^3) - *Plume present* Dose rate (mSv/h) - *Plume present* Ground activity concentration (kBq/m^2) - *Plume past*
Temporary or permanent relocation	Dose rate (mSv/h) - *Plume past* Ground activity concentration (kBq/m^2) - *Plume past* Air activity concentration (Bq/m^3) - *Plume past*
Foodstuff restrictions	Foodstuff activity concentration (Bq/kg) - *Plume past* Ground activity concentration (kBq/m^2) - *Plume past*

For completeness, the radiometric services available for accident management in the Nordic countries are shown in Table 3.4. The available measurement resources are described in detail in [11]. In addition to the services listed in the table, there are measuring points and stations around the nuclear power plants and research reactors within the Nordic countries. These latter measurement stations are mainly owned by the plant operator and thus the results may not always be publicly available.

Table 3.4. Available radiometric services in the Nordic countries.

Type of measurement	**Denmark**	**Finland**	**Iceland**	**Norway**	**Sweden**
Stationary automatic gamma monitoring stations	11	290	1	28	37
Mobile automatic gamma monitoring stations		1	4-6	-	Planned
Semi-automatic or manual stations		200	Planned	-	-
Local survey teams	Yes	Yes	Organized as needed	Yes	Yes
Air filter stations	1 + 2 standby	30	1	9 + 7 standby	8
On-line filter monitoring of γ or β/γ		Yes, 17 stations	Yes	Yes, 3 stations	No
Airborne measurements					
Fallout mapping	Yes	Yes	No	Yes	Yes
Air sampling	No	Yes	No	Yes	Yes
Food contamination measurements	γ, Sr, Pu	52 labs. γ, Sr, Pu, Am	γ, β	70 labs. γ, Sr, Pu, Am	γ, Sr, Pu
Environmental sampling	Yes	Yes	Yes	Yes	Yes
Contamination checks of vehicles, goods etc. (α, β, γ)	Yes	Yes	Yes	Yes	Yes
Field measurements:					
γ-spectrometry	Yes	Yes	No	Yes	Yes
total γ	Yes	Yes	Yes	Yes	Yes
air filter γ analysis	Yes	Yes	Yes	Yes	Yes
β	Yes	Yes	No	Yes	Yes
α	Yes	Yes	No	Yes	No
Whole body counter(s)	Yes	Yes	No	Yes	Yes
Organ measurements	Yes	Yes	Yes	Yes	Yes
Excreta and body fluid measurements	Yes	Yes	Yes	Yes	Yes

5. Intervention Levels and Operational Intervention Levels - the present situation.

Several international organizations and national authorities have developed generic ILs, expressed in terms of avertable doses. The ILs suggested by the Nordic countries, by IAEA, and by ICRP are provided in Table 3.2. Recommendations from the CEC [10,12] on generic European ILs encompass the range of levels suggested by IAEA and ICRP.

Table 3.2. Generic Intervention Levels of avertable dose. Recommendations from the CEC [10,12] encompass the range of levels suggested by IAEA and ICRP.

	Denmark [5]	**Finland** [13]	**Sweden** [3]	**Nordic (draft)** [6]	**ICRP** [2]	**IAEA** [1]	**BER-3** [7]
Sheltering	0.4 mSv/h in max. 2 days	few mSv/h	1-10 mSv/6h	10 mSv/ 2 days	5-50 mSv < 1 day	10 mSv < 2 days	2 mSv/6h
Normalized to 1 day	10 mSv	≤ 50mSv	4-40 mSv	5 mSv	5-50 mSv	5 mSv	8 mSv
Evacuation	10 mSv/day in max. 1 week	≈ 10 mSv/day	3-30 mSv/day	50 mSv < 1 week	50-500 mSv a) < 1 week	50 mSv < 1 week	10 mSv < 1 week
Normalized to 1 week	70 mSv	≈ 70 mSv	20-200 mSv	50 mSv	50-500 mSv	50 mSv	10 mSv
Relocation (temporary)	10 mSv/month or 1 Sv life time dose		5-50 mSv 1st month	30 mSv/month < 2 years	5-15 mSv/month or 1 Sv in lifetime	30 mSv 1st month, 10 mSv/month subsequently or 1 Sv in lifetime	50 mSv 1st month
Relocation terminated			< 3-30 mSv/month	< 10 mSv/month		< 10 mSv/month	
Permanent resettlement				1 Sv in lifetime		relocation lasting > 2 years or 1 Sv in lifetime	
Iodine prophylaxis	-	few tens mGy b)	10-100 mSv children, 100-1000 mSv adults c)	50 mGy b)	50-500 mSv c)	100 mGy b) (all age groups)	100 mSv c)
Closing industrial activity	50 mSv/month						200 mSv 1st month
Control of access		depends on duration					
Protection of cattle and feed		depends on circum-stances					

a) Whole body. For equivalent skin dose: 5000 mSv.
b) Absorbed dose to thyroid
c) Equivalent dose to thyroid

For comparison, all numbers have been normalized to the same time period. Neither the Danish, Swedish nor the Finnish suggested ILs have been given an official status. Norwegian and Icelandic authorities have not developed specific national ILs but are awaiting the common Nordic approach. The Nordic joint approach has not been finalized and the numbers provided are only preliminary values.

The optimized IL for iodine prophylaxis depends on the target group. Hence, IAEA estimates optimum ILs to range from a few mGy absorbed thyroid dose for infants to a few hundred mGy for elderly people, and has settled on a single value of 100 mGy avertable dose to the thyroid. This value may be changed in the recommendations of the authorities of Denmark, Finland and Norway to 50 mGy, argued by the latest knowledge about thyroid cancer among children in Belarus [6].

IAEA[1] and ICRP [2] also have provided intervention guidelines in form of Action Levels for the use of foodstuffs. The Action Levels are given as the activity concentrations in foodstuffs, at which some sort of protective action should be carried out. The Action Levels defined by IAEA are identical to the values recommended by the WHO/FAO Codex Alimentarius Commission for international trade [14].

None of the Nordic countries have developed a formal basis for interventions so far, neither for ILs nor for OILs. However, STUK has written a proposal for OILs to be used in Finland in case of a nuclear accident. These levels are in use in practice but they have not yet been formally approved by the Ministry of Interior in Finland. Danish authorities are working on OILs to be used in Denmark, but this work has not yet been completed. Norwegian, Swedish and Icelandic authorities have not developed national OILs. The OILs are summarized in Table 3.3. In case of a national accident in Finland or Sweden, both Swedish and Finnish authorities will take precautionary actions within the near zone of the plant suffering an accident.

Table 3.3. Suggested dose rate OILs in Denmark and Finland.

	Denmark noble gases	**Denmark** particles	**Finland** [a]
Sheltering	300 μSv/h	10 μSv/h	100 μSv/h
Evacuation			500 μSv/h [b]
3 hours	10 mSv/h	300 μSv/h	
10 hours	3 mSv/h	100 μSv/h	
> 1 day	1 mSv/h	30 μSv/h	
Iodine prophylaxis			100 μSv/h
Relocation		0.1 mSv/h [c]	
Closing industrial activity		1 mSv/h [c]	
Control of access			100 μSv/h [d]
Protection of cattle and feed			10 μSv/h

a) Predicted external dose rate in outdoor air if no further information is given.
b) Preventive evacuation
c) Long-lived, particulate fallout
d) Predicted or measured external dose rate in outdoor air

IV. INTERVENTION, A PROBABILISTIC APPROACH

1. Probabilistic assessment of avertable doses.

Successful management of a nuclear or radiation emergency depends among other things on the ability to forecast radiation doses. At the outset of an accident, the radiation exposure of the public will be largely unpredictable, and preventive actions to protect the public must be based on plant conditions or on an early accident classification. As more information becomes available, both regarding the possible or ongoing release and transport of radionuclides, the precision of forecasting improves, thereby facilitating an adequate response to the emergency.

Nuclear emergency management is usually considered a “real-time” problem, in which the radiation exposures of the public is modelled as a deterministic event, based first on information on plant condition and later on a specified source term and meteorology. The results of the modelling, even if uncertain, then form the decision basis for the emergency management. In contrast, modelling the consequences of future accidents, at the time of which neither the atmospheric conditions nor the source term can be specified, calls for a probabilistic assessment such as a Level-3 PSA (Probabilistic Safety Assessment). In the PSA, the model input parameters are not assigned single values but instead they are drawn from assumed probability distributions of values.

It will, however, be useful also to consider emergency management as a probabilistic problem. The reason is twofold. First, even in the unlikely case that detailed information on the accident is available, thus in principle allowing for an accurate estimate of the off-site consequences, the demand for a rapid emergency response may effectively preclude the data administration and processing needed in order to perform the estimate and to optimize the response. Second, by assessing in advance the uncertainty of the forecasting process in terms of a probability distribution of the off-site consequences, decision making is aided, since the uncertainty will be a measure of the level of confidence one may have in the modelling.

The variability of forecasted exposures has its origin partly in the incomplete knowledge about the source term and the local meteorology (accident-specific variability) and partly in the variability in the efficiency of dose reducing measures (site-specific variability). Even if the accident history were fully specified, and the uncertainty associated with the stochastic nature of the atmospheric dispersion and deposition processes could be neglected, the radiation doses to the public would still display a distribution stemming from variations in the behavior of individuals and their access to adequate protective arrangements.

In modelling accident scenarios, one may correspondingly separate the model parameters into those that are site-specific and those that are accident-specific. While the accident-specific parameters, such as nuclide release fractions and parameters governing the meteorology, are unknown parameters at the outset of the accident, the site-specific parameters, such as shielding factors or transport facilities for evacuation, are quantities that at least in principle could be assessed prior to the accident.

The results of forecasting may be expressed in terms of probability densities $p_a(\Delta E\ )$ of averting a dose ΔE by means of a protective action a. This is illustrated in Fig. 4.1, where the probability of averting the dose ΔE is shown schematically. The figure illustrates that if a certain protective action a, e.g. sheltering, is implemented then one cannot exactly foretell the averted dose resulting from the action. Instead, there is a most likely range of avertable doses centered around a certain value $\Delta E_{0.}$ There is thus approximately a 50% chance of averting doses less than ΔE_0, and a 50% chance of averting more than ΔE_0.

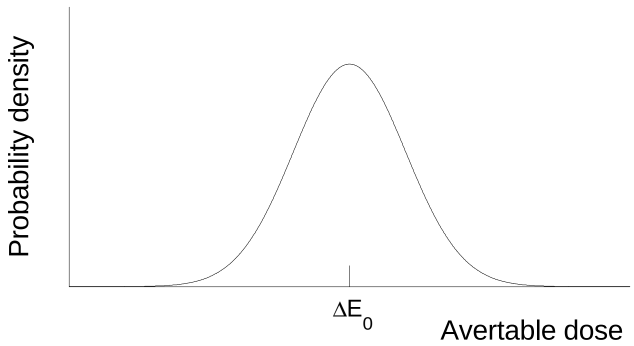

Fig. 4.1 Schematic presentation of the probability density $p_a(DE\ )$.

The general appearance of the probability density as a single humped function is the same, whether there is none or some prior knowledge about the situation, provided however, that a severe accident has occurred. The details of the distribution (e.g. the width and the mean value) depend on the information available, with any added piece of information in principle constraining the range of possible avertable doses. Data acquisition either from the plant or from environmental monitoring may be utilized to improve the precision in forecasting. If the monitoring yields a set of parameters $\{x_i\}$, where each x_i for example could specify an accident classification (plant condition) or be a dose rate, measured at a location r_i and time t_i, $x_i = d(r_i, t_i)$, the doses avertable by means of the protective action a obey a conditional probability distribution

$$p_a(\Delta E\ |\{x_i\}).$$

That is, given the set of parameters $\{x_i\}$ describing the available information, the probability density distribution for the avertable dose by means of a protective action a is $p_a(\Delta E\ |\{x_i\})$. From such a distribution all information about the magnitude of avertable doses may be derived and, in particular, the mean value and the variation in avertable dose can be obtained. The variations associated with the distributions p_a will be indicative of the information content of the parameters x_i.

Modelling $p_a(\Delta E\ |\{x_i\})$ is a non-trivial problem, since dose rate measurements and avertable doses need not be directly related. For instance, if the release contains particulates, the avertable doses may be dominated by exposures via the inhalation pathway, while dose rate measurements only register external γ- and in some cases β-radiation. Using environmental monitoring data to estimate avertable doses therefore represents an inverse problem, as it ultimately involves reconstruction of the source term. Also, it is a priori not obvious to what extent the acquisition of e.g. dose rate data will act to reduce the uncertainty in the avertable doses estimate.

2. Operational Intervention Levels.

An Operational Intervention Level (OIL) is defined as the value of any one of the parameters x_i that would trigger intervention. If x_i for instance denotes the result of a dose rate measurement carried out as part of a nuclear emergency preparedness programme, a specific protective action should be taken if the dose rate measurements exceed the OIL of dose rates for the action considered. Clearly, the definition is only meaningful to the extent that dose rates and avertable doses are correlated, such that larger values of measured dose rates correspond, on the average, to larger avertable doses.

Since the x_i in the present context is to be viewed as a parameter that controls the probability distributions p_a, an Intervention Level (IL) of avertable dose does not unambiguishly translate into an OIL. Rather, to each IL of avertable dose there is a range of possible OILs as shown schematically in Fig 4.2, and any chosen value of OIL is subject to interpretation.

The IL itself is evaluated on the basis of, for example, cost-benefit optimization, its value being determined by requiring the intervention measure to have zero total benefit, i.e. the benefits minus the costs of introducing the intervention measure, both

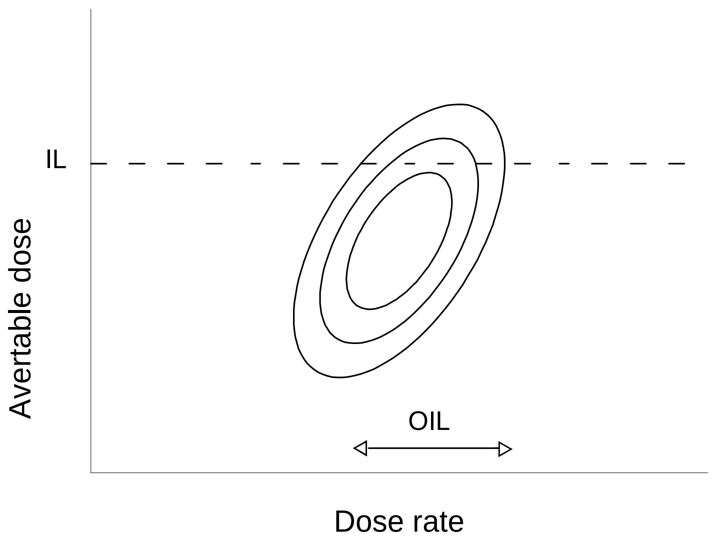

Fig. 4.2. The joint probability distribution of dose rates and avertable doses is shown schematically as contour lines, with the largest probability density to be found in the center of the figure.

expressed in the same, e.g. monetary, units. Therefore, taking action for avertable doses larger than the IL will result in a positive net benefit.

When the benefits are ascribed a probabilistic distribution, it is natural to substitute for the benefits their expectation value (the mean value) in defining the OIL. Then, assuming a linear avertable dose - total benefit relationship, the IL translates into an OIL through the expectation value of the avertable dose. For instance, writing d_{OIL} for the dose rate OIL and ΔE_{IL} for the avertable dose IL, the defining equation for d_{OIL} becomes

$$\Delta E_{\mathrm{IL}} = \int \mathrm{d}(\Delta E)\; p(\Delta E \mid d_{\mathrm{OIL}})\; \Delta E, \qquad (4.1)$$

i.e. the dose rate measurement value for which the mean avertable dose equals the IL.

A more conservative approach in choosing an OIL, is to require that the likelihood of having avertable doses exceeding the IL is small, whenever the measured dose rates are equal to or less than d_{OIL}. If the likelihood is to be smaller than a value q%, d_{OIL} is determined as the dose rate value for which the high q^{th} percentile of the corresponding distribution $p_a(\Delta E \mid d_{\mathrm{OIL}})$ equals ΔE_{IL}. In other words, one prescribes that the probability to fail to implement a protective action, when it should have been implemented, to be less than q%. For q sufficiently small, such a definition will reduce d_{OIL} to a value below the OIL given by Eq. (4.1).

3. Distance projection.

Measured dose rates and the forecasted avertable doses both depend on time and location. In a nuclear emergency, only a limited number of measurements may be carried out prior to any decision on intervention. It is therefore of practical use in a nuclear emergency to project the avertable doses to areas different from those surrounding the measuring locations. That is, dose rates measured at one location might be used in forecasting avertable doses to people at a different location.

The national nuclear emergency preparedness programmes in the Nordic countries operate with predetermined, fixed sets of measurement locations, cf. Section III.3. This is obviously so for the stationary measuring stations, but also the mobile units will in most cases measure the outdoor dose rates at predetermined positions. Each measurement point will be representative of an area or a geographical sector surrounding the measurement point, provided that the spatial variation of nuclide concentrations remains small over the distance between neighboring measurement points.

While the doses in general, and therefore also the dose variation, decrease with increasing distance from the site of release, the relative uncertainty in the dose estimate will be smallest for locations where the dose rate measurements take place. Thus, projection to areas further away from the measurement point becomes less reliable and should be supplemented by additional local measurements. The projection itself, however, remains a valuable tool for a fast evaluation of the areas subject to a protective course of action. In case of a single dose rate measurement at the point r_1 and time t_1, $x_1 = d(r_1, t_1)$, the task is to estimate the distribution

$$p_a(\Delta E(r) \mid x_1),$$

where $r \neq r_1$.

In nuclear emergency preparedness programmes, one may have accident contingency plans that include a specification of geographical sectors, surrounding an NPP, inside which sectors countermeasures are to be carried out on an all-or-nothing basis. In this case, the avertable dose $\Delta E(r)$ should be replaced by a suitable chosen average for the area in question.

Much the same way that OILs are introduced for use at a single location, one may define OILs for projected distances. That is,

$$\Delta E_{\mathrm{IL}} = \int \mathrm{d}(\Delta E(2)\,)\; p(\Delta E(2) \mid d_{\mathrm{OIL}}(1,2)\,)\; \Delta E(2) \qquad (4.2)$$

will define the dose rate OIL for intervention at a location (2) based on measurements at location (1). The usefulness of this approach does, of course, decrease with increasing distance between the measuring point and the point where the action should be implemented.

4. Methodology.

The conditional probability distribution p_a of avertable doses due to a protective action a may be estimated by running a series of atmospheric dispersion model calculations using an accident consequences assessment code. For a probabilistic assessment, the important parameters describing both the accident scenario and the atmospheric transport and deposition of radionuclides must be treated as stochastic variables and as such be ascribed a multivariate probability distribution function.

A Monte-Carlo calculation of the atmospheric dispersion and deposition yields a joint probability distribution $p_a(\Delta E, d\,)$ from which the conditional probability density is derived as

$$p_a(\Delta E \mid d\,) = p_a(\Delta E, d\,) \,/ \int \mathrm{d}(\Delta E\,)\; p_a(\Delta E, d\,).$$

The dose rate d is the effective dose rates measured outdoors due to external radiation from the plume and from the ground. The avertable dose ΔE is the effective dose averted by means of the protective action a. In practice, only doses from external radiation and effective, committed dose from inhalation are important for short term intervention measures and doses from the ingestion pathway and from inhalation of resuspended material need not be included.

The dose rates are evaluated for a limited number of positions mimicking the locations of measurement points, cf. Fig. 4.3. The number of measuring points and

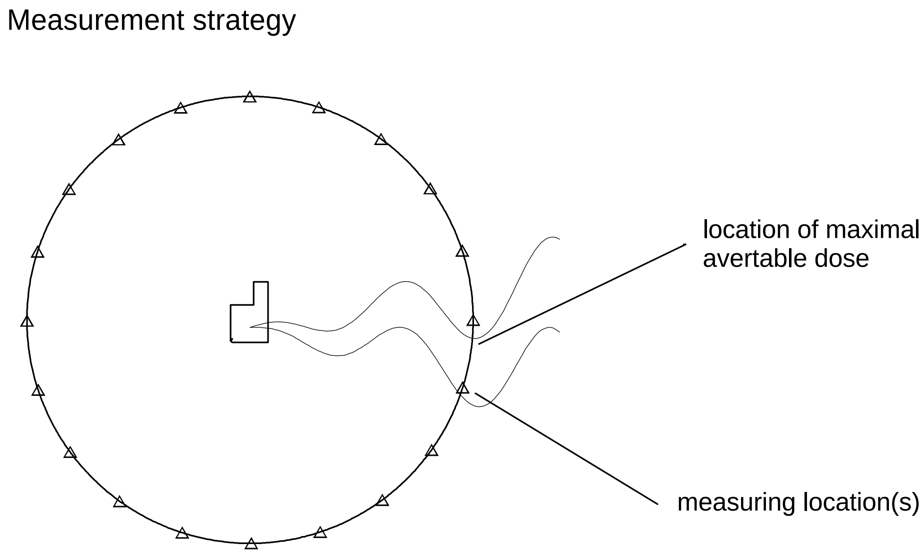

Fig. 4.3. The locations where dose rates are measured in general differ from the location where the avertable dose is maximal.

their positioning is dictated by the contingency plans of the emergency preparedness authorities. Since the emergency response, if any, will trigger on the largest measurement value, this largest value d of the dose rates is utilized in the distribution $p_a(\Delta E \mid d)$. The avertable doses on the other hand, are evaluated for all positions of the same distance to the release site, i.e. on the entire circle centered on the emission point, and the value ΔE that is used in the distribution is taken to be the largest avertable dose so found.

It is important that the choice of avertable dose is consistent with the philosophy underlying intervention and, in particular, with the calculation of ILs. If intervention aimed at small groups is considered and the IL is evaluated for such a small group of highly exposed individuals, then also the avertable dose must be representative for this group, i.e. it should be the maximum value to be found at the same distance from the site of emission. If on the other hand, intervention only is carried out on an all-or-nothing basis in a specified geographical sector, the avertable dose must be an average over the same sector.

V. MODEL CALCULATIONS

1. Atmospheric dispersion.

The joint probability distribution $p_a(\Delta E, d)$ has been evaluated by using a modified version of the atmospheric dispersion model LENA 3.0, developed by SSI [15]. The atmospheric dispersion model of LENA 3.0 is a straight line Gaussian plume model, in which a continuous release of activity is dispersed downwind forming a Gaussian shaped plume. The modifications allow the meteorology (e.g. wind direction and speed) to change every hour, such that the total release is segmented into hourly releases, each forming a straight line Gaussian plume.

The model assumes total reflection of the plume at the ground surface and at the top of the atmospheric mixing layer. Dry deposition is modelled by "source depletion", using a constant dry deposition velocity, while wet deposition is modelled by a precipitation rate-dependent scavenging coefficient. LENA 3.0 has a library of 69 different radioactive nuclides, arranged into 9 different release groups according to the physical-chemical properties of the nuclides. Nuclides within a release group are ascribed the same release fraction, and the release is in the present application assumed to occur at a constant rate throughout the specified release period.

In section V.2 describing an accident at the Barsebäck nuclear power plan (NPP), the dispersion model parameters are taken from an ensemble of meteorological data, consisting of two years meteorological time series collected by the Swedish Meteorological and Hydrological Institute at the Sturup airport not far from Barsebäck. The data set provides hourly meteorological information, including wind direction and speed, atmospheric stability and precipitation rates.

2. Case study: Severe reactor accident.

The reactor undergoing the accident is taken to be the Barsebäck nuclear power plant. Two accident scenarios have been selected that could result from a severe core melt-down with a loss of coolant, and the joint probability density $p_a(\Delta E, d)$ is evaluated independently for each of the two scenarios. The accident scenarios are chosen mainly for illustrational purposes and they do *not* result from a PSA Level-2 calculation.

The accident parameters used are given in Table 5.1, and in Figs. 5.1-2. In accident scenario 1 (small releases), the containment is assumed to be functioning and the activity is only released through the filter system, causing a delay before release. In accident scenario 2 (large releases), the containment is malfunctioning and a substantial amount of activity bypasses the filter and is released to the atmosphere.

Table 5.1. Release fractions and release times of the Barsebäck scenarios 1 and 2.

	1: Small releases	**2: Large releases**
Description	Containment functioning	Containment breach
Release delay (h)	4 - 8	1 - 3
Release duration (h)	4 - 8	2 - 8 [a)]
Release fractions		
Noble gases	1	1
Organic Iodine	10^{-3}	10^{-3}
I	$3.3\cdot10^{-6}$ - $3.3\cdot10^{-3}$	10^{-4} - 10^{-1}
Cs, Rb	$3.3\cdot10^{-6}$ - $3.3\cdot10^{-3}$	10^{-4} - 10^{-1}
Co, Ru etc.	$3.3\cdot10^{-7}$ - $3.3\cdot10^{-4}$	10^{-5} - 10^{-2}
Sb, Te	$3.3\cdot10^{-6}$ - $3.3\cdot10^{-3}$	10^{-4} - 10^{-1}
Zr, Nb etc.	$3.3\cdot10^{-8}$ - $3.3\cdot10^{-5}$	10^{-6} - 10^{-3}
Sr, Ba	$3.3\cdot10^{-7}$ - $3.3\cdot10^{-4}$	10^{-5} - 10^{-2}
Trans-uranium	$3.3\cdot10^{-8}$ - $3.3\cdot10^{-5}$	10^{-6} - 10^{-3}

a) Release duration is correlated with the release fractions, cf. Fig. 5.2.

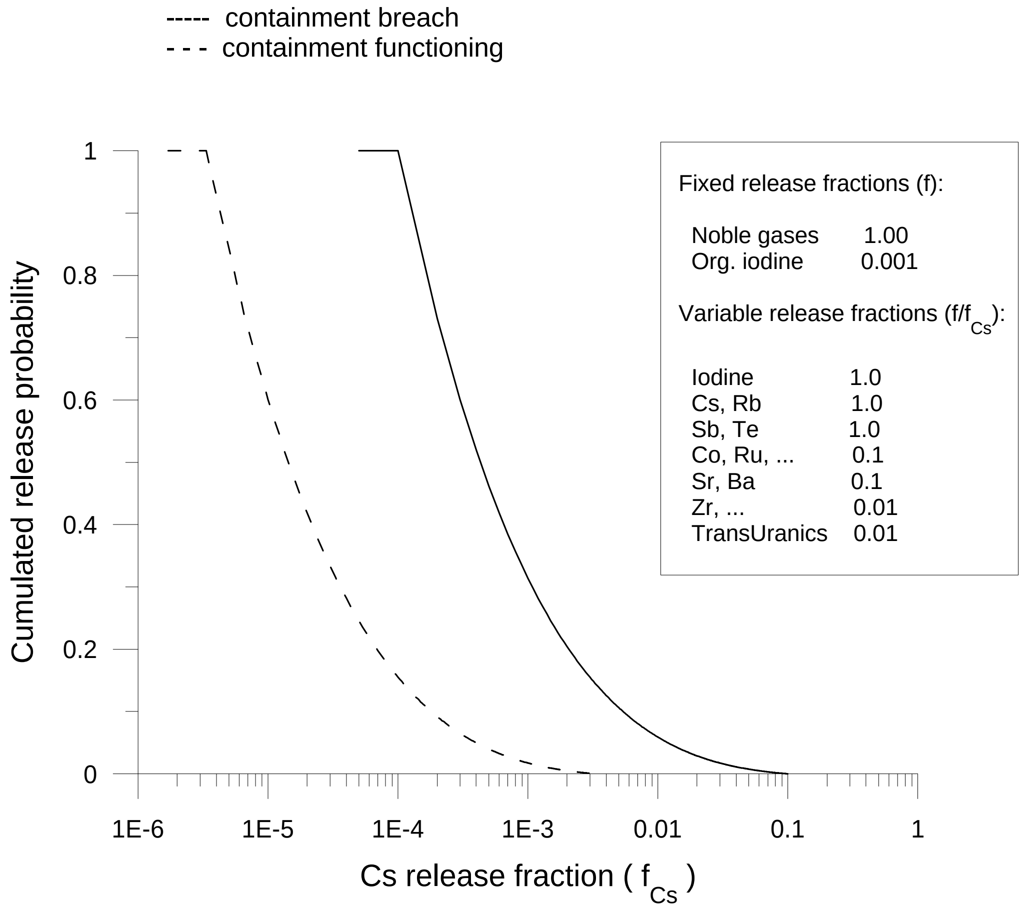

Fig. 5.1. Release fractions. The cumulated probability distribution of the cesium release fraction decreases as the fourth power of the exponent. Other radionuclides have either fixed release fractions (noble gases and organic iodine) or scale with the cesium release fraction as indicated.

In both accident scenarios, all of the noble gases as well as the organically bound iodine, constituting approximately 0.1 % of the total amount of iodine, is thought to be released to the atmosphere. The release of other nuclides in form of aerosols is specified by their release fractions. For both scenarios it is considered more likely to have a small release of particulates than a large release, the release probability density decreasing with the amount released as the 3rd power of the logarithm of the release fraction, cf. Fig. 5.1. The time scales specifying the release are assumed to be correlated with the amount of particulates released as shown in Fig. 5.2.

The remaining model parameters describing the source term, the atmospheric dispersion and deposition, and the shielding factors applicable for sheltering and evacuation are shown in Table 5.2. The variable parameters, t_r, t_d, L_{PL}, F, and ϕ, are all ascribed uniform probability distributions, i.e. probability distributions with equal weights to all parameter values within the specified interval. The sheltering period starts one hour after plume arrival and ends after passage of the plume.

The angular separation between measuring locations, as given in the table, are values that are adopted for this study, and they do not necessarily represent the actual distance between measuring stations around the Barsebäck reactor, being either the plant-owned stations or the fixed and mobile units used by the Swedish and Danish authorities.

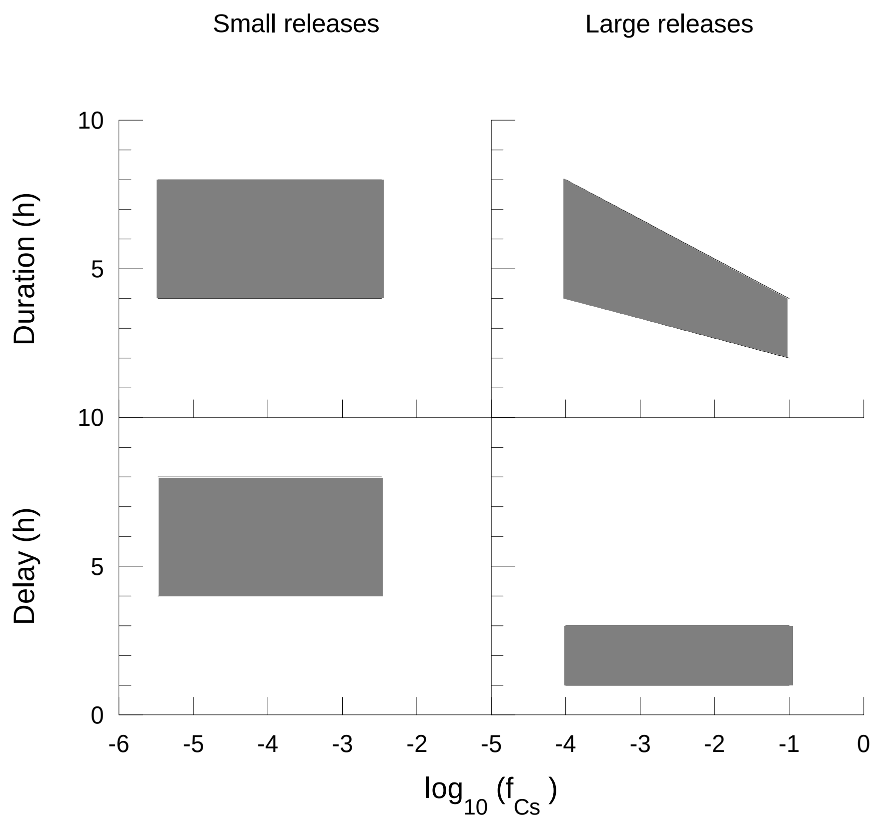

Fig. 5.2. Release times. In scenario 2, the duration of the release is correlated with the amount of released material.

Table 5.2. Model parameters used in the calculations.

	Parameter	**Symbol**	**Value**
Source term	Time from shutdown to release begins.	t_r	Table 5.1, Figs. 5.2 - 5.3
	Release duration.	t_d	
	Release fractions		
	Release height	h	50 m
Atmospheric dispersion and deposition	Pasquill-Gifford stability classification		2 years cumulated meteorological data
	Wind speed and direction	**u**	
	Mixing layer height	z_{mix}	
	Precipitation	J	
	Wet deposition scavenging coefficient	Λ organ. I :	10^{-4} (J/(mm/h))$^{0.8}$ s^{-1} 10^{-6} (J/(mm/h))$^{0.8}$ s^{-1}
	Dry deposition velocity	v_d organ. I :	10^{-3} m/s $5 \cdot 10^{-4}$ m/s
Sheltering	Location factor, plume	L_{PL}	0.1 – 0.6
	Location factor, ground	L_{GR}	$= L_{PL} / 2$
	Filtration factor	F	0.2 – 0.7
	Sheltering time: Initiate one hour after plume arrival		= (t_d - 1 hour)
Measurement	Distance from site of release	x	5, 20 and 50 km (fixed values)
	Angular separation between measuring locations	ϕ	0.1 – 0.28 radian
	dose rate measurement uncertainty		± 20 %

3. Results.

In Fig. 5.3, the joint probability density $p_a(\Delta E, d)$ for sheltering is shown for the two accident scenarios and for three selected distances. The probability densities are evaluated by a Monte Carlo technique, each point in the figure results from a definite choice of parameter values and the density of points indicates the joint probability density $p_a(\Delta E, d)$. The dose rates and the avertable doses are seen both for the small and the large releases to be correlated: On the average, when dose rates increase so do the averted doses.

This is also evident from Figs. 5.4-5, where the conditional probabilities $p_a(\Delta E \mid d)$ are shown for a number of dose rate values. As dose rates are increased, the probability distributions are shifted towards higher values. The spread in avertable doses, given by the width of the distributions, is seen to be more or less independent of the dose rate in case of small releases (Fig. 5.4) while the spread in avertable dose increases with the dose rate value in case of large releases (Fig. 5.5).

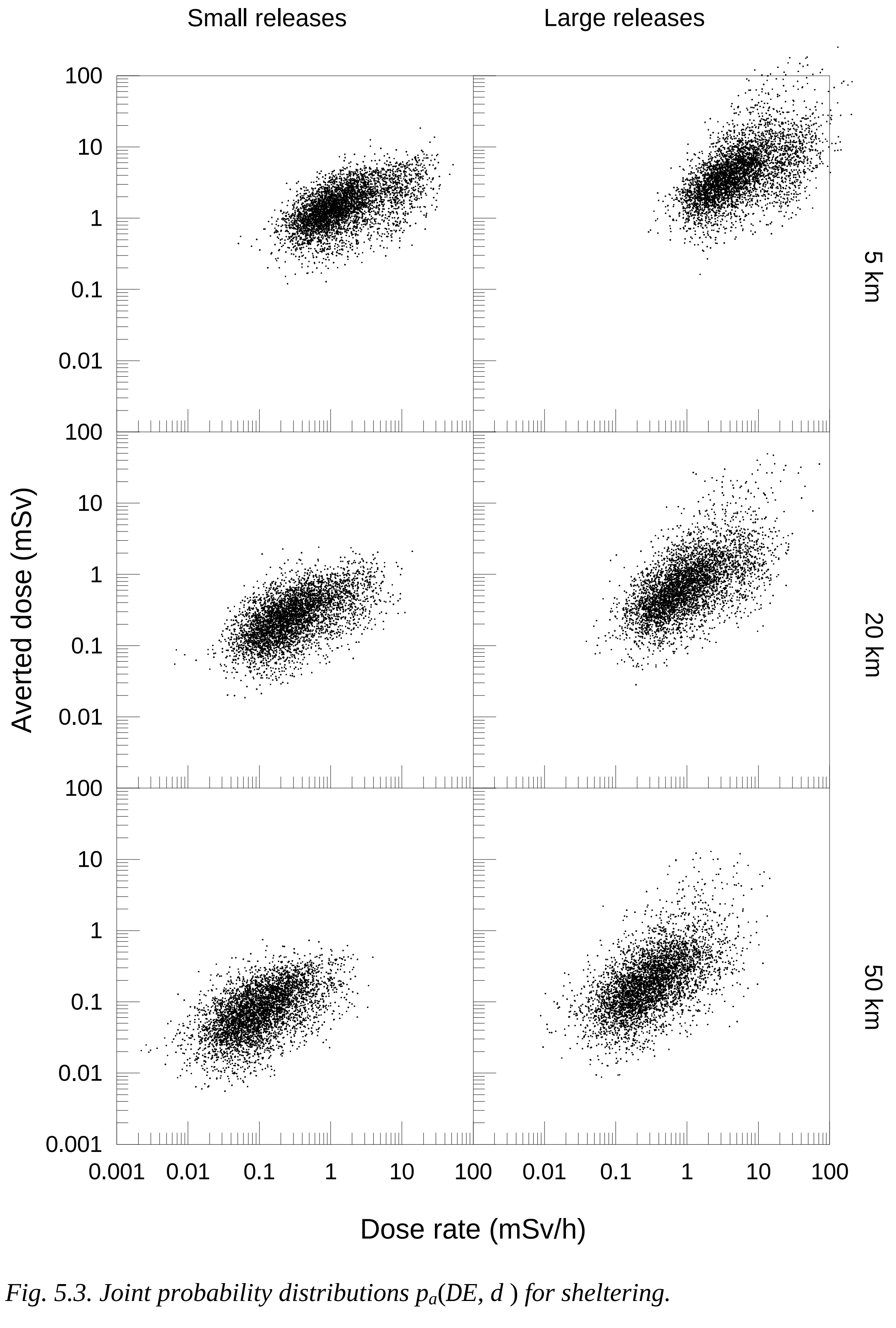

Fig. 5.3. Joint probability distributions $p_a(DE, d)$ for sheltering.

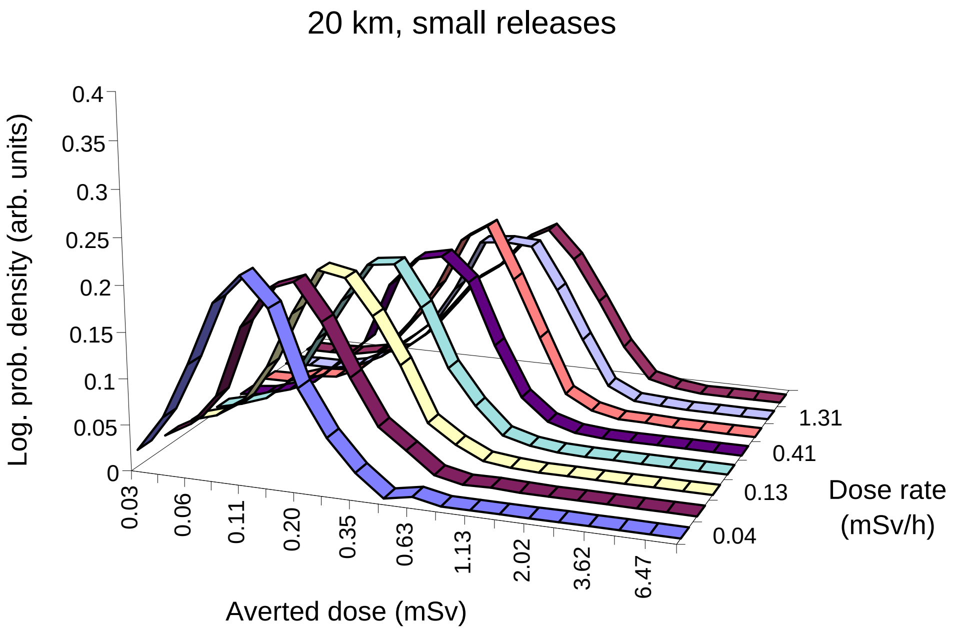

Fig. 5.4. Conditional probability distributions $p_a(\Delta E|d\ )$ for sheltering, small releases.

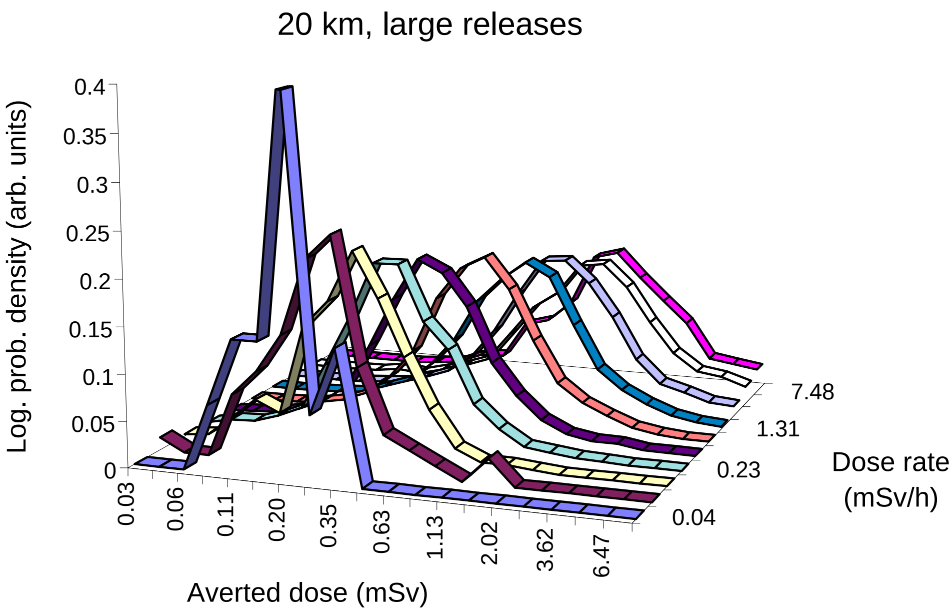

Fig. 5.5. Conditional probability distributions $p_a(\Delta E|d\ )$ for sheltering, large releases.

From the conditional probability distributions $p_a(\Delta E \mid d\,)$, the OILs are deduced as the dose rates that ensure that the IL equals either the average avertable dose or a certain quantile of the distribution, cf. Eq. (4.1) and the discussion following it. The average avertable dose is shown in Fig. 5.6, and in Fig. 5.7 the high 5th percentile of the avertable dose is shown. The symbols and the statistical error bars indicate the numerical results, while the straight lines in the figures are power law fits to the data.

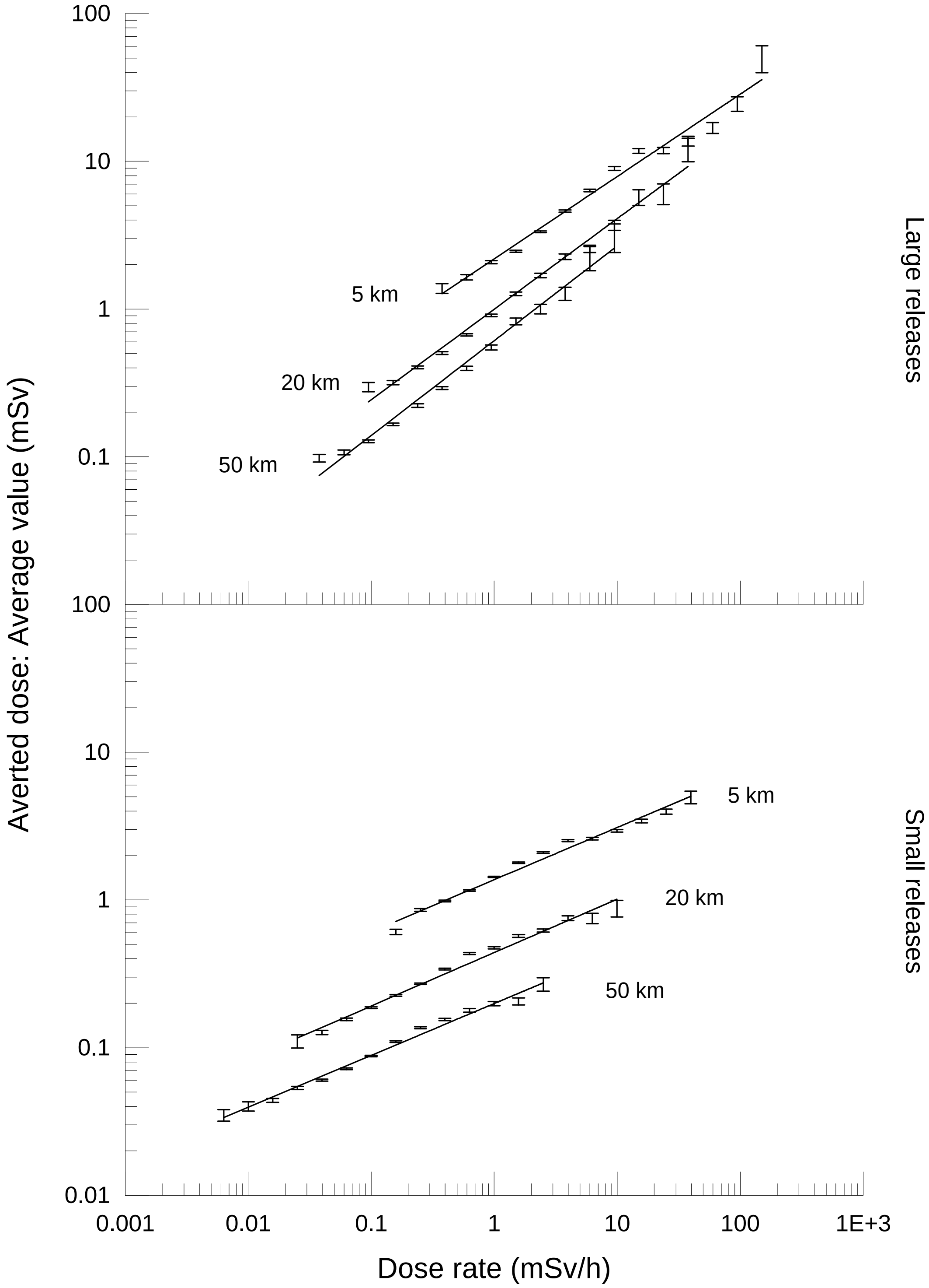

Fig. 5.6. Average avertable dose vs. dose rate. Error bars indicate the statistical error.

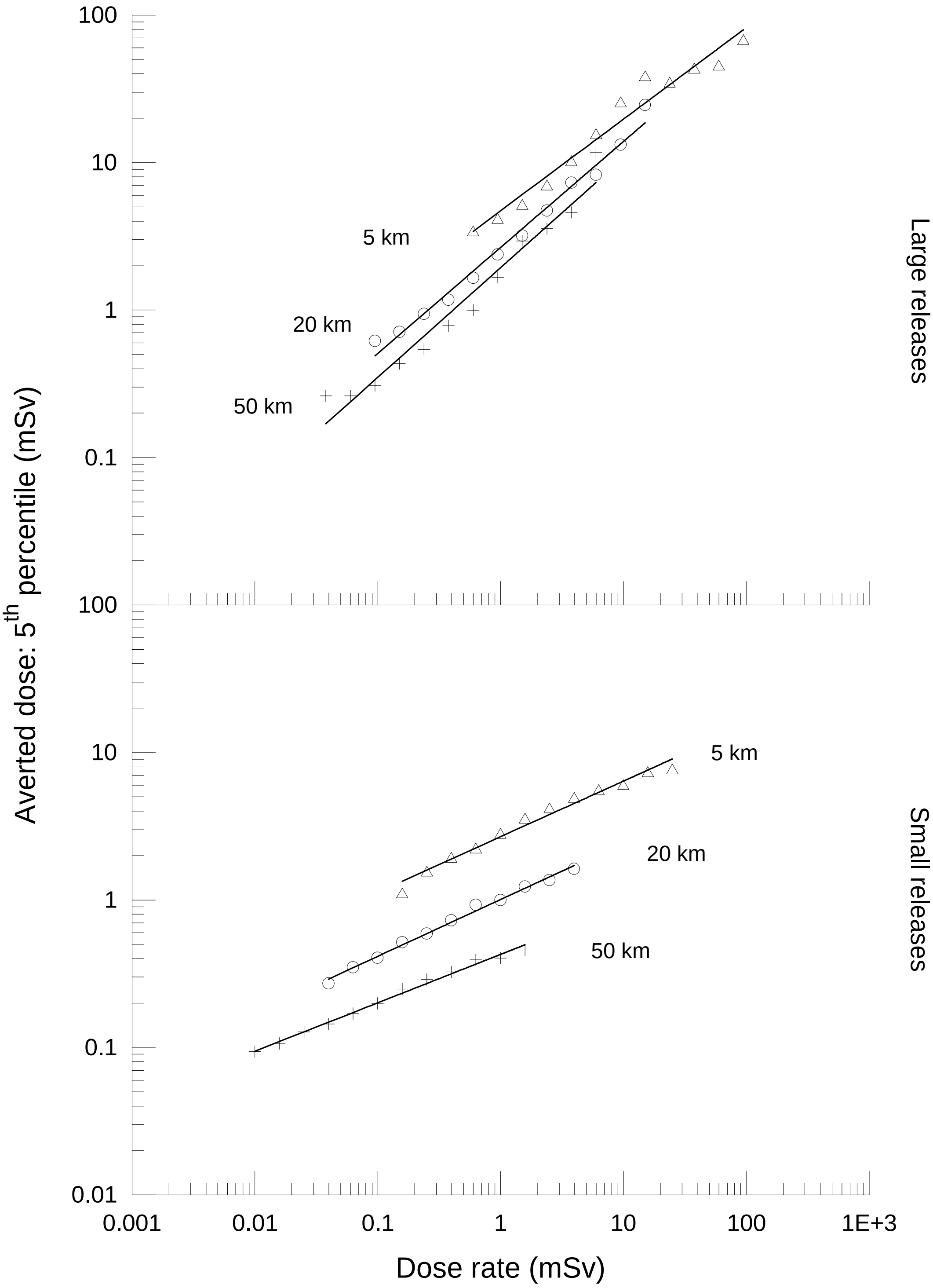

Fig. 5.7. High 5th percentile of avertable dose vs. dose rate

The dose rate OIL may be read off from the figures, as the dose rate that corresponds to an IL of avertable dose. Dose rate OILs so obtained both depend on the release scenario and on the distance to the source term. With an IL for sheltering of either 2 mSv or 5 mSv, the corresponding dose rate OILs are shown in Tables 5.3 and 5.4 for the small and large releases respectively. For instance, at a distance of 5 km from the reactor at which the containment has failed (large releases, Table 5.4), measuring a dose rate of 4 mSv/h implies that the average avertable dose from sheltering is 5 mSv. A measured dose rate of 1 mSv/h would imply that the avertable dose in 95% of all cases stays below 5 mSv. When the IL is beyond the range of avertable doses resulting from the calculations no value is given.

Table 5.3. OILs for sheltering during passage of the plume. Release scenario 1(small releases).

IL	**r (km)**	**average (mSv/h)**	**5th percentile (mSv/h)**
5 mSv	5	40	5
	20	-	-
	50	-	-
2 mSv	5	3	0.5
	20	-	(6)
	50	-	-

Table 5.4. OILs for sheltering during passage of the plume. Release scenario 2 (large releases).

IL	**r (km)**	**average (mSv/h)**	**5th percentile (mSv/h)**
5 mSv	5	4	1
	20	15	2
	50	> 10	4
2 mSv	5	0.9	< 0.6
	20	3	0.7
	50	6	1.0

The scenario dependence of the dose rate OIL reflects the contribution of inhalation dose to the total avertable dose. In accident scenario 1, the exposure is mostly external radiation and the OIL is evaluated accordingly. When the release contains particulates (accident scenario 2), inhalation doses become important and doses from the external radiation pathway must be reduced to accommodate inhalation doses within the chosen intervention level. Reduced external doses imply reduced dose rates as well, resulting in the lower OIL in the scenario 2.

The reasoning behind the distance dependence of the OIL is more subtle, cf. the analytic treatment in Section V.5 below. The rather strong distance dependence has its origin in the fact that dose rates and avertable doses are only weakly correlated; if they were strongly correlated the OILs would not display any significant distance dependence. The actual form of the distance dependence will be influenced by all factors contributing to the specific variation in dose rates, such as measurement uncertainty and the distance between measuring locations.

The dose rates and the avertable doses in general decrease with the distance from the source. In Fig. 5.8, the avertable doses is plotted against the distance from the source

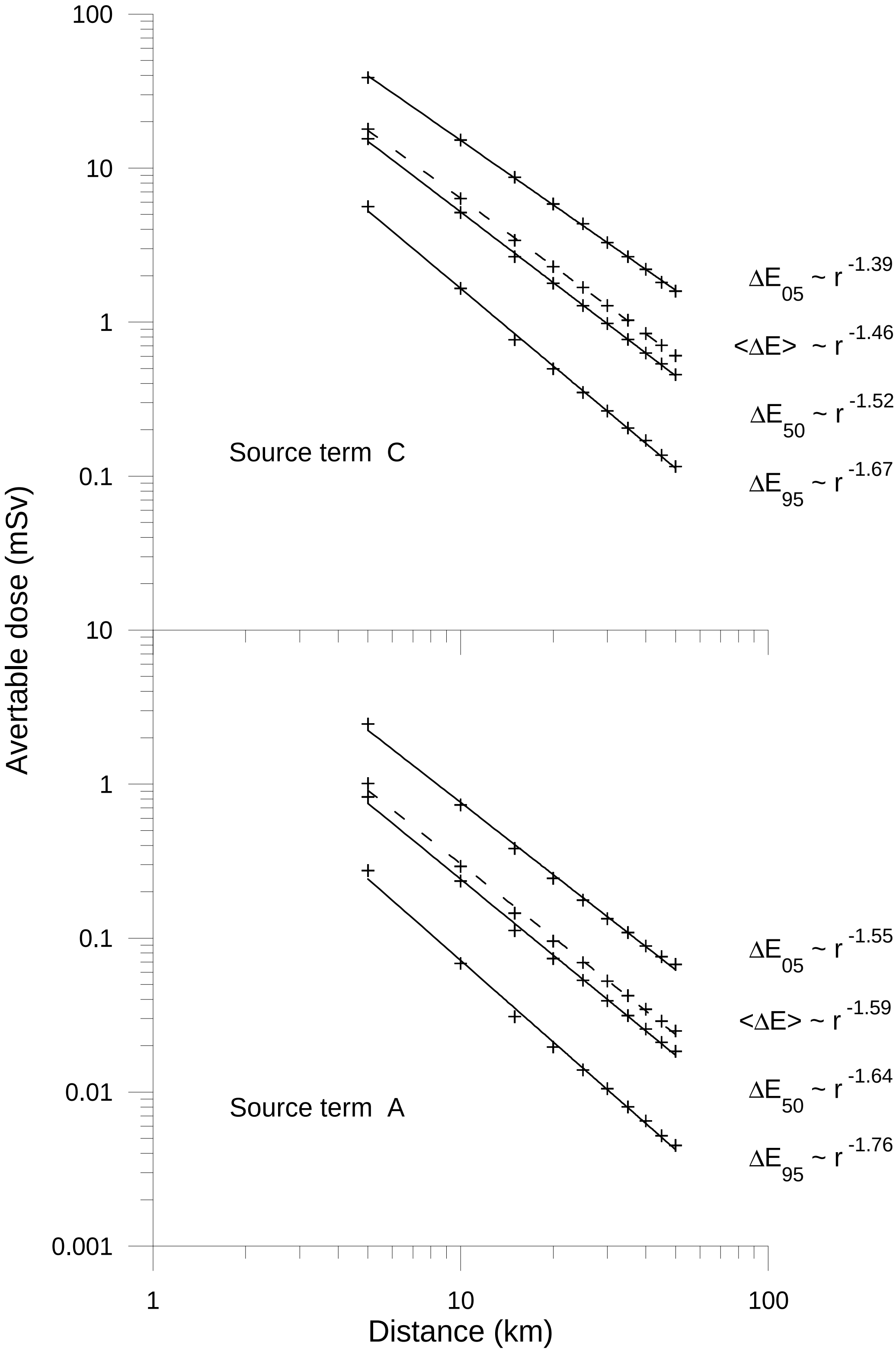

Fig. 5.8. Avertable dose vs. distance. Power law fits to the three quantiles (5%, 50% and 95%) are shown as solid lines, while the power law fits to the averages are shown as dashed lines. The exponents are given to three decimals to illustrate the increase in the geometrical width of the distribution with increased distances.

for two release scenarios “A” and “C” described in Ref. [16]. The source term “A” almost entirely consists of noble gases and organically bound iodine, thus resembling the “small releases” scenario 1, while the source term “C” has a cesium release fraction of 1%.

For both source terms, the distance dependence of the avertable doses seems well described by a power law $\Delta E \propto r^{n}$, with the exponent corresponding to the average avertable dose being $n \approx -1.5$. This value of the exponent applies to the distances considered between 5 and 50 km from the source. At smaller distances, the small upbend seen in the figure indicates a stronger distance dependence, i.e. with an exponent $n < -1.5$. The relative uncertainty in the avertable dose estimate increases with the distance from the source as indicated by the slow divergence of the 5% and 95% quantiles of the distribution at large distances.

The results of Fig. 5.8 apply to the entire distribution $p_a(\Delta E)$ for each of the two scenarios. It has been verified, however, that the same distance dependence results if the underlying probability distributions are constrained by a dose rate measurement, e.g. a distribution $p_a(\Delta E(r)|\, d(5\text{ km}))$ in which the dose rate measurement is performed at 5 km’s distance from the source. Also, the exponents are insensitive to precipitation.

4. Model comparison.

A number of runs were performed for the Loviisa power plant in southern Finland in which site specific meteorological date were used. However, no specific probabilistic data regarding the source term were at hand, why the same parameters and relations used for the Barsebäck case were also used in the calculations for Loviisa. The only exception is that, according to Finnish specifications [17], no more than 50% of the noble gases were released while all of the noble gases were released in the Barsebäck accident scenarios. Moreover, the measuring points around the Loviisa plant are distributed at fairly different distances in different sectors. This fact could not be easily implemented in the computer code used, and therefore also here the Barsebäck parameters were used.

The remaining differences between the Barsebäck and Loviisa cases were limited to the meteorology and the source terms. While noticeable, the differences in input data were not large and the results for Loviisa were very similar to those for Barsebäck.

In order to examine the effect of using a different atmospheric dispersion model than LENA 3.0 a small number of calculations were performed using the dispersion model Rimpuff [18], used by the Danish Emergency Management Agency. While Rimpuff is unsuitable for probabilistic assessments requiring a large number of calculations, doses obtained with Rimpuff were found to be in general agreement with those obtained with LENA 3.0. The distance dependence, while uncertain, seems better described by using an exponent $n \approx -1.7$ in the power law fit, $\Delta E \propto r^{n}$.

5. Analytic treatment.

When the release predominantly consists of noble gases, the joint probability distribution $p_a(\Delta E, d)$ may be treated analytically. In this case, the joint probability distribution closely resembles a bivariate log-normal distribution in the two variables ΔE and d, cf. Figs. 5.3-4. This is to be expected when the dose is dominated by external radiation from the passing plume, i.e. for accident scenarios with a small releases of particulates. For accident scenarios having a large release of particulates inhalation dose will be important and the joint probability distribution will deviate from the log-normal form.

From the log-normal form follows the power law dependence of the expectation value of avertable dose on the dose rate, cf. Fig. 5.6. Using the expectation value of avertable dose to define the OIL, the dose rate OIL can be written

$$d_{\mathrm{OIL}} = d_{\mathrm{m}} \left(\Delta E_{\mathrm{IL}} \exp(-\sigma^2/2) \;/\Delta E_{\mathrm{m}}\right)^{\kappa}, \tag{5.1}$$

where the subscript "m" denotes the median value and σ^2 is the variance of the logarithm of avertable dose, taken at a fixed dose rate. The exponent κ depends on the relative fluctuations in d and ΔE and is approximately equal to 3 for the chosen accident parameter values (accident scenario 1).

Both d_{m} and ΔE_{m} decrease with the distance r from the source, the functional forms being well described by power laws, $(d_{\mathrm{m}}, \Delta E_{\mathrm{m}}) \propto r^{-1.6}$, cf. Fig. 5.8, while $\exp(-\sigma^2/2)$ decreases roughly as $r^{-0.1}$. Inserting these distance dependencies into Eq. (5.1), the dose rate OIL takes the approximate form,

$$d_{\mathrm{OIL}} \propto r^{\lambda} (\Delta E_{\mathrm{IL}})^{\kappa}, \qquad \lambda \approx 2.5,\ \kappa \approx 3. \tag{5.2}$$

Using instead of the average value, the high 5$^{\mathrm{th}}$ percentile value of avertable dose to define the OIL, the dose rate OIL takes the form

$$d_{\mathrm{OIL}} = d_{\mathrm{m}} \left(\Delta E_{\mathrm{IL}}\, e^{-1.65\,\sigma} \;/\Delta E_{\mathrm{m}}\right)^{\kappa}, \tag{5.3}$$

with approximately the same distance dependence as in Eq. (5.2),

$$d_{\mathrm{OIL}} \propto r^{\lambda} (\Delta E_{\mathrm{IL}})^{\kappa}, \qquad \lambda \approx 2.5,\ \kappa \approx 3. \tag{5.4}$$

For the large releases described in scenario 1, $\kappa \approx 1.5$ while λ is being closer to 1. For large releases however, the relation between ILs and OILs may not adequately be described by a power law.

From the distance dependence of avertable dose, also the OIL for distance projection may be derived as

$$d_{\mathrm{OIL}}(1,2) \approx d_{\mathrm{m}}(1) \left(\Delta E_{\mathrm{IL}} \exp(-\sigma^2/2) \;/\Delta E_{\mathrm{m}}(1)\right)^{\kappa} (\mathrm{r}_2/\mathrm{r}_1)^{1.5\,\kappa} \tag{5.5}$$

$$= d_{\mathrm{OIL}}(1)\, (\mathrm{r}_2/\mathrm{r}_1)^{1.5\,\kappa},$$

provided that the expectation values of avertable dose have a simple scaling behavior as function of the distance. With $\kappa \approx 3$, this implies a rather strong distance dependence for the projected OIL.

6. Discussion.

Our model calculations show that measured dose rates and doses averted by sheltering are correlated, the joint probability distribution to a first approximation being of a bivariate log-normal form. The correlation coefficient in the log-log representation is of the order of 0.5 - 0.7 for the case we have treated, i.e. with no knowledge of the weather, and with other factors varying within the limits given in Tables 5.1 and 5.2. This correlation is fairly independent of distance and source term strength.

OILs (as given by a dose rate) and ILs (of averted doses by sheltering) are not proportional. Rather, the relation is $d_{\mathrm{OIL}} = c\cdot(\Delta E_{\mathrm{IL}})^{n}$, with n between 1.5 and 3, and c a constant which depends on the source term. Also, OILs depend on the distance from the source: the OIL increasing with the distance r as r^{n}, n between 1 and 2.5. The implication of this is that a single OIL cannot be optimal, except for at one distance and for a given source term. Either, the values chosen must be some averages (weighted over source terms and distances), or there must be more than one OIL for sheltering.

If no prior knowledge is at hand but a crude estimation of the source term, i.e. no measurements and no meteorological information, then the overall uncertainty in avertable dose by sheltering is at least a factor of 10 for the accident scenarios treated here (“small”, “large” and the modified Loviisa case). Clearly, additional uncertainties related to the release parameters increase the overall uncertainty. The difference in average averted dose between “large” and “small” is about a factor 5 - 10.

The analysis also indicates that the uncertainty in avertable dose from sheltering should decrease (by a factor between one and two) when the information from a dose rate measurement is added. The overall uncertainty will decrease more than this if extra information is added (e.g. meteorological data). More importantly however, the correlation between dose rates and avertable doses implies that the average avertable dose increases as the measured dose rate is increased.

The numbers may all change in a more detailed study, e.g. in a study that is tailored to a specific nuclear reactor. For instance, the two years of meteorological data employed in the present study may not be representative for the meteorological sequences encountered in a longer time period.

VI. CONCLUSIONS AND RECOMMENDATIONS

Our model analysis of the conditional probability distribution of avertable doses has been carried out in a simplified setting, both regarding the source term and the choice of atmospheric dispersion model. Moreover, not all parameters relevant for the dose estimation have been varied in the present study but only those that are deemed more important. Consequently, the results presented should be considered foremost an illustration of the consequences of a probabilistic approach to intervention.

We have not addressed the uncertainties caused by the above limitations. When applied in nuclear emergency management planning, more detailed descriptions of the source term is certainly desirable, as well as data specific to the nuclear installations in question. Nonetheless, the qualitative results obtained here could serve as a starting point in a discussion of emergency planning using a probabilistic approach.

The OILs obtained in this study (given for example the IL recommended by the IAEA) are larger than those adopted in Nordic and international emergency preparedness planning, especially so if the average values in the distribution of avertable doses are chosen. This indicates that one has been very conservative in defining the OILs, neglecting that optimization already was done in defining the ILs.

Part of the explanation is likely to be found in the principal difference between the deterministic and the probabilistic approaches. In the former there is an underlying hypothesis of a linear one-to-one relation between dose rate and averted dose. This hypothesis is unsubstantiated. The inevitable fluctuations preclude a simple relation between avertable dose and the measured dose rate.

The probabilistic analysis shows that environmental dose rates and doses averted by sheltering are to some extent correlated. Hence, OILs for sheltering may be defined in terms of the measurable dose rates. Optimized values of the dose rate OIL are defined by requiring that the expectation value of avertable dose is equal to the IL, cf. Eq. (4.1). These optimized OILs are, perhaps surprisingly, not proportional to the ILs. Rather, our analysis shows that because of the inevitable fluctuations, the OIL and the IL have a non-linear relationship that approximately is a power law dependency. In addition, the analysis shows that the optimized OILs depend both on the source term and on the distance from the source.

As a consequence, harmonization of OILs, e.g. within the Nordic countries, aiming at having a single or a few representative OILs will be inconsistent with the principle of optimization of intervention. On the other hand, harmonization may be deemed so important for effective accident management that the authorities nonetheless may choose to use a single value for the OIL.

The probabilistic approach developed in this report offers a method to characterize the uncertainties in the effect of early intervention measures. Such a probabilistic safety assessment is a prerequisite for optimization, both with respect to the planning and the implementation of emergency countermeasures.

We recommend that operational intervention levels (OILs) are defined within the probabilistic framework. In this framework, an optimized OIL is given as the measurement value, for which the average avertable dose is equal to the (generic) intervention level.

Furthermore, we recommend that the probabilistic approach is developed as a tool for optimizing existing and future measuring strategies. This may involve optimizing the type and number of measurements and the time scheme for deployment of mobile measurement units.

References

1. International Atomic Energy Agency (IAEA), *Intervention Criteria in a Nuclear or Radiation Emergency*, Safety Series No. 109, IAEA, Vienna (1994).
2. International Commission On Radiological Protection (ICRP), *Principles for Intervention for Protection of the Public in a Radiological Emergency*, Publication 63, Pergamon Press, Oxford, New York, Seoul, Tokyo (1993).
3. "Allmänna råd avseende åtgärdsnivåer för skydd vid kärnenergiolyckor", (SSI, Stockholm, Maj 1993).
4. STUK-B-VYK3 Säteilysuojelun periaatteet ja ohjeelliset toimenpidetasot onnettomuustilanteessa, ed. Raimo Mustonen (1995) (in Finnish).
5. Per Hedemann Jensen og Kaare Ulbak, "Forslag til retningslinjer for iværksættelse af beskyttelsesforanstaltninger ved nukleare eller radiologiske ulykker", (06.10.1997).
6. "Nordic Application to Intervention Criteria in a Nuclear or Radiation Emergency". Second Draft of the Working group established by the Radiation Protection Authorities of Denmark, Finland, Norway and Sweden.
7. *Intervention Principles and Levels in the Event of a Nuclear Accident*. (TemaNord, 1995:507).
8. International Commission On Radiological Protection (ICRP), *1990 Recommendations of the International Commission on Radiological Protection*, Publication 60, Pergamon Press, Oxford, New York, Frankfurt, Seoul, Sydney, Tokyo (1991).
9. International Atomic Energy Agency (IAEA), *International Basic Safety Standards for Protection Against Radiation and for the Safety of Radiation Sources*, Safety Series No. 115, Vienna (1996).
10. Commission of the European Communities (CEC), *Radiation Protection Principles for Relocation and Return of People in the Event of Accidental Releases of Radioactive Materials*, Radiation Protection - 64, Doc. XI-027/93 (1993).
11. *Monitoring Artificial Radioactivity in the Nordic Countries*, (TemaNord, 1995:559.
12. Commission of the European Communities (CEC), *Radiological protection principles for urgent countermeasures to protect the public in the event of accidental releases of radioactive material*. Radiation Protection 87 (Luxembourg, 1997).

13. Raimo Mustonen: “The Finnish Model for Short Term Countermeasures after a Nuclear Accident”, in *Proc. NEA Workshop on Short-term Countermeasures*, (Stockholm, 1994).
14. Codex Alimentarius Commission, Joint FAO/WHO Food Standards Programme, *Proposed FAO/WHO Levels for Radionuclide Contamination in Food in International Trade*, CX/FAC 89/17 (1989).
15. U. Bäverstam, “Lena 3.0 Users Manual” (Statens Strålskyddsinstitut (SSI), Stockholm, 1996)
16. B. Lauritzen and U. Bäverstam, “Dose rate Measurements and Action Levels in the Event of a Nuclear Accident, Variational Analysis”, in *Proc. of IAEA TCM on Special Topics Related to Level-3 PSA/Dose Calculations*, Vienna, (1997). (Risø-I-1121(EN), Risø National Laboratory, Denmark, March 1997).
17. Finish data are based on expert assessment of nuclear safety personnel of STUK.
18. T. Mikkelsen, S.E. Larsen and S. Thykier-Nielsen, “Description of the Risø Puff Diffusion Model”, *Nuclear Technology*, Vol. 67 (1984) 56-65.

Glossary

Absorbed dose. The energy imparted per unit mass of the irradiated material. The SI unit of absorbed dose is the joule per kilogram, termed the gray (1 Gy = 1 J/kg).

Action Level. The level of dose rate or activity concentration above which remedial actions or protective actions should be carried out in chronic exposure or emergency exposure situations.

Avertable dose. The dose to be saved by a protective action, that is, the difference between the dose to be expected with and without the protective action.

Collective dose. An expression for the total radiation dose incurred by a population, defined as the sum of the doses received by the individuals of the population. It is expressed in man-sieverts (man·Sv).

Contamination. The presence of radioactive substances in or on a material or the human body or other place where they are undesirable or could be harmful.

Countermeasure. An action aimed at alleviating the consequences of an accident.

Decontamination. The removal or reduction of contamination in or on materials, persons or the environment.

Deterministic health effect. A radiation effect resulting from cell killing, for which generally a threshold level of dose exists above which the severity of the effect is increasing with an increase in absorbed dose.

Dose. A measure of the radiation received or absorbed by a target. Depending on the context, quantities such as organ dose, effective dose, equivalent dose etc. are used but these modifying terms are often omitted when they are not necessary for defining the quantity of interest.

Equivalent dose and Effective dose are the quantities to be used to assess the risk of stochastic health effects. The unit for both of them is the sievert (Sv).

Evacuation. Evacuation is used to refer to the urgent moving of people from their homes, or from places of work or recreation, for a limited period of time (less than a week) in order to avert short-term exposure from an airborne plume or from deposited radioactive material due to an accident.

Exposure. The act or condition of being subject to irradiation. Exposure can be either external or internal exposure depending on whether the radiation source is outside or inside the body.

Generic Intervention/Action Level. A level determined by the optimization of a protective action, based on generic assumptions on the costs and benefits associated with the action, as opposed to accident- or site-specific optimization. Socio-political, psychological and cultural factors are *not* taken into account in deriving generic levels.

Intervention. Any action intended to reduce or avert exposure or the likelihood of exposure to sources which are not part of a controlled practice or which are out of control as a consequence of an accident.

Intervention Level (IL). The level of avertable dose at which a specific protective action or remedial action is taken in an emergency exposure or a chronic exposure situation.

Operational Intervention Level (OIL). The value of an environmental measurement at which a specific protective action or remedial action is taken in an emergency exposure or a chronic exposure situation.

Permanent resettlement. Permanent resettlement is the term used for the deliberate complete removal of people from the contaminated area with no expectation of return.

Precautionary evacuation. Evacuation taken as a precautionary measure before there has been any significant release of radioactive material.

Projected dose. The total dose to be expected if no protective or remedial action is taken.

Protective action. An intervention intended to avoid or reduce doses to members of the public in chronic or emergency exposure situations.

Remedial action. Action taken when a specified action level is exceeded, to reduce radiation doses that might otherwise be received, in an intervention situation involving chronic exposure.

Residual dose. The remaining dose from all pathways after implementation of the protective action.

Sheltering. Sheltering refers to staying inside or moving into dwellings or to other buildings, closing doors and windows, and turning off any ventilation systems in order to reduce the dose from inhalation of radioactive material, and to reduce the direct exposure to airborne radionuclides and to surface deposits.

Stochastic health effect. Radiation effects resulting from cell multiplication, assumed to occur without a threshold level of dose, whose probability is proportional to the dose and whose severity is independent of the dose.

Temporary relocation. Temporary relocation is used to refer to the organized and deliberate removal of people from the area affected by an accident for an extended but limited period of time (typically several months but less than about a year) to avert exposures principally from radioactive material deposited on the ground and from inhalation of resuspended radioactive material.