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Basis for Nordic Operational Intervention Levels

Methodology for deriving Operational Intervention Levels

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Content

Foreword

One of the four main sections of the four-year Nordic research programme in the field of nuclear safety and radiation protection from 1990-1993 was *Emergency Preparedness (BER)*. The purpose of the BER-programme was to systematically evaluate those parts of emergency preparedness that ought to be harmonized within the Nordic countries in order to lay the grounds for uniform action in case of a nuclear accident or radiological emergency.

The BER-programme included a project on intervention measures to be taken after a nuclear accident (BER-3). The aim of the BER-3 project was to prepare for the Nordic authorities the background material needed to make common decisions on the most likely protective action to be taken. Intervention levels in terms of avertable dose were proposed based on monetary costs of the protective actions and the averted individual doses by those actions.

In the present four-year Nordic research programme on nuclear safety and radiation protection for the period 1994-1997, one of the sub-projects, *Basis for Nordic Operational Intervention Levels (EKO-3.3)*, is a continuation of the work on intervention levels in the BER-3 project. Because of the inherent difficulty of forecasting doses that could be averted, there is a merit in establishing surrogate quantities which can be more readily addressed from conditions pertaining when decisions need to be made. The term "*Operational Intervention Level (OIL)*" is reserved for such operational quantities. OILs are based on Intervention Levels (ILs) of avertable dose that could be achieved by a *specific protective action* and they would be both country-, accident- and site-specific.

The purpose of EKO-3.3 is to lay out the methodology for determination of Operational Intervention Levels in the Nordic Countries. The project will concentrate on the protective actions *sheltering*, *evacuation* and *iodine prophylaxis* and produce results that are directly applicable in emergency response plans within the Nordic countries.

1 Basic principles for intervention

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 (ICRP Publication 60) [1]. The system of radiological protection recommended by ICRP for interventions is based on the following general principles:

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

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

Dose limits do not apply in the case of intervention. The ICRP Publication 60 makes a distinction between *practices*, which cause or increase the exposure of individuals, and *interventions*, which reduce such exposure.

Interventions can be defined in the following way. Some human activities can *decrease* the overall exposure, *eg*, by removing existing sources, modifying pathways, or reducing the number of exposed individuals. In those situations the sources, the pathways and the exposed individuals are already in place when the decisions about control measures are being considered. Protection can therefore only be achieved by interventions, which always have some disadvantages.

2 Dose quantity for intervention

The level of protective measures to be introduced for the purpose of averting doses from existing sources should, according to ICRP [3] and IAEA [2], be found from the principles of justification of the intervention and the optimization of the form, scale and duration of the intervention. The dose quantity relevant for decisions taken in a nuclear accident or radiological emergency is the *avertable dose*.

2.1 Avertable dose

The net benefit of a protective action which would reduce the risk of stochastic effects can be expressed as the dose that *can be averted* in the time period for which the protective action lasts. Fig. 1 illustrates the concept of an *avertable dose*. At a particular time, t_1, it is supposed that a protective action is introduced such that the dose rate for the individuals affected is significantly reduced. At a given time, t_2, the measure is withdrawn and the dose rate to the involved individuals increases again. In this situation, the avertable dose, ΔE, would be equal to the time-integral of the dose per unit time over the time interval, $\tau = t_2 - t_1$.

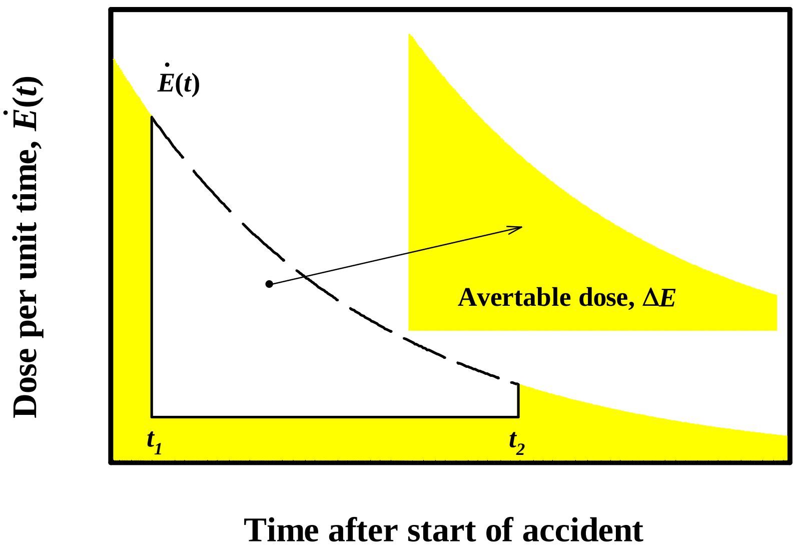

Figure 1. Avertable dose and effective dose accumulated per unit time when the protective measure is introduced at time t_1 and lifted again at time t_2.

Only the avertable doses from those pathways that can be influenced by the protective action should normally be taken into account in judging whether to take the action or not. Intervention cannot reduce doses already received, and it is therefore not appropriate to include doses already received at the time when a decision is to be taken on introduction of protective measures. However, it is recognized that past doses may affect social perceptions and so may influence decisions through consideration of social factors. Since protective actions considered here will normally be invoked at levels of dose at which the concepts of equivalent and effective dose apply, the levels of avertable dose can be expressed in units of sieverts (Sv).

2.2 Intervention Level of avertable dose

Intervention Level (IL) is the terminology for levels at which action is taken in the case of emergency or chronic exposure situations. In the International Basic Safety Standards [5] Intervention Level is defined as:

> *Intervention level* is 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

An *Intervention Level* 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 averted dose from this specific protective measure.

The Intervention Level is specified in terms of the dose that is anticipated to be averted by the associated protective action and ILs are specified separately for different protective actions. If an IL for a specific protective action is anticipated to be exceeded, *ie*, if the expected avertable individual dose is greater than the IL, then it is indicated that this protective action is likely to be appropriate for that situation. The avertable doses would therefore be *at least* equal to the IL. The practical interpretation of an IL will therefore be the dividing line between areas in which intervention is *not* justified and areas in which intervention is justified and by which the resulting avertable doses ranges from the IL and - at least in theory - to infinity (see Fig. 2).

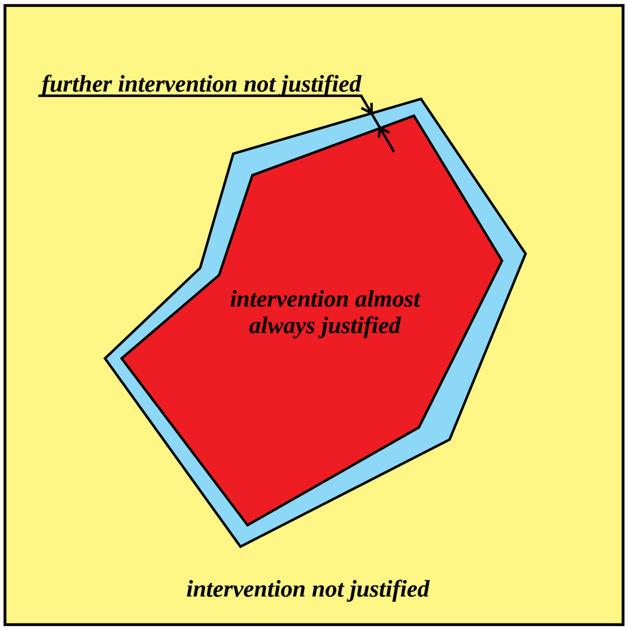

Figure 2. Concept of intervention level. Intervention is always justified for the inner area, which can delineate a population to be evacuated, relocated, sheltered etc. In the optimization process this area will be enlarged until the marginal increase in avertable doses becomes just less valuable than the increased marginal costs. The optimized intervention level therefore corresponds to the differential dose saving at the border between intervention and non-intervention areas.

In general, the Intervention Level should be applied to a typical member of the group to whom the protective action is to be applied or to a typical member of a sub-group being considered for inclusion in such a group. The estimation of the dose averted should be realistic. The adoption of a conservative approach in the estimation of dose is often defended as being beneficial to those affected, on the grounds that action will be taken at lower doses than intended and that this is in the best interests of those affected. This view is, however, misguided and ignores the negative features of the protective action itself, which may be considerable. 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, however, only remain reasonable provided the variation in risk (both that associated with the exposure and the protective action) within the affected group is not too great. In applying the Intervention Levels to heterogeneous groups in the population, it will be necessary, therefore, 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 due to the potential social problems of introducing protective actions selectively into a general population [4].

3 Operational Intervention Levels (OILs)

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. Actual measured quantities such as dose rate or level of contamination are used as surrogates for the intervention level of avertable dose. Depending on the protective action being considered, these will be a function of some or all of the following: the release characteristics, the adequacy of the warning, the time of day, the season of the year, weather conditions, shielding provided by buildings, size of population affected and others. Thus, quantities derived from the avertable dose that take into account these factors will often be *country*, *site* and *accident* specific.

Because of the need to act quickly in case of a nuclear or radiological emergency, there is merit in establishing - *in advance* - values of surrogate quantities for doses that could be averted by different countermeasures. Such quantities can be more readily assessed from conditions pertaining when decisions need to be made.

The term "Operational Intervention Level (OIL)" is reserved for these quantities that can be more easily assessed at the time of decision on intervention. Operational Intervention Levels are related to the dose that could be averted, and the relationship between these quantities and the avertable dose will vary considerably with the circumstances of the accident and nature of the released activity, with obvious implications for criteria expressed in these terms. The operational quantities would, therefore, be both accident and site specific but will still be related to the Intervention Level of avertable dose. OILs could also be specified in terms of plant conditions, *ie* conditions prevailing before any operational quantities can even be measured.

The Operational Intervention Levels are related to the Intervention Level of avertable dose, and they are expressed in measurable quantities above which it is likely that intervention for some specified time will result in an avertable dose just large enough to offset the disadvantages of the intervention itself, i.e. in an optimized intervention. Quantities such as *dose rate in air, surface contamination density* and *activity concentration in air* can be applied as surrogates for averted doses from different protective actions.

The optimized OILs are based on optimized Intervention Levels (ILs) of avertable individual dose and assumptions on site and accident specific parameters. If the OIL for a given countermeasure is given, say, in terms of a dose rate, implementation of that countermeasure at a *measured* dose rate equal to or larger than the OIL would result in an avertable dose equal to or larger than the IL, but *only* if the future course of the accident is the same as assumed in the derivation of the OIL regarding *duration of the release*, *types of radionuclides* in the release and the *expected duration* of the countermeasure.

It is important to express the OILs for specific countermeasures in relevant quantities. As an example, it would not be sufficient to base the implementation of iodine prophylaxis alone on dose rate measurements with no information on radioiodines in the release. Only in case of a release (or a potential release) of radioiodines alone, dose rate measurements can be used as an indicator for the introduction of iodine prophylaxis. Thus, the relevant quantity for expressing the OIL for iodine prophylaxis would be time-integrated air concentration of radioiodine (or average air concentration). Similar arguments can be used in case of releases of α-emitters like plutonium and uranium. However, actions can be triggered based on plant conditions *before* concentrations or dose rates can be measured.

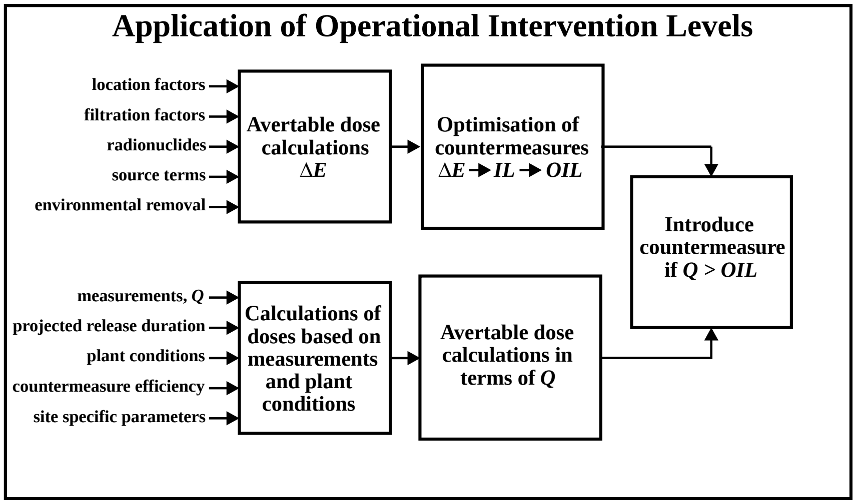

Figure 3. In calculating avertable doses, Δ*E*, for different accident scenarios, dose assessment models are used. A site specific optimization will give the Intervention Level, *IL*, and the *OIL*. The same kind of dose assessment model is used in an accidental situation where environmental measurements will be used as input to the model. The avertable doses from specific protective measures can thus be expressed in terms of a measured quantity, *Q*, and intervention be introduced when *Q* > *OIL*.

The avertable dose, *ie* the dose that can be averted by a given protective action, is *not* a measurable quantity. Measurements in the environment combined with calculations is the only way to predict doses that could be averted by a given countermeasure or remedial action. Many different types of environmental monitoring would be carried out. In the early stages of an accident these will principally be external dose rates and gross air concentrations. As time passes more radionuclide specific data will be gathered and concentrations of radionuclides in foodstuffs and other environmental material determined.

Estimation of avertable doses using the results of environmental measurements requires *modelling* of the various processes involved in the transfer of an environmental contaminant to man. A model like the one shown in Fig. 3 can be used to calculate the avertable individual doses, $\Delta E(Q,\tau)$, from all relevant pathways over the period of time, τ, in which the countermeasure is implemented. These doses can normally be expressed as a function the measured quantity, Q, in the environment.

It must be recognised that in the initial stage of an accident, accurate measurements of the amounts of radionuclides released may not be possible and predictions would need to be made on the basis of, for example, plant conditions and design safety analyses in relation to postulated fault conditions. Such predictions would be validated or modified as a result of the actual measurements that become available in the later phase.

4 Methodology for deriving OILs

Decision making in an emergency may be more rapid and effective if the intervention levels of dose are expressed in terms of the levels of measurable environmental quantities. The latter are the practical expression of the intervention level of dose. The need for, and extent of, protective measures can be judged by comparison of the monitoring results with these operational levels some of which are shown in Table 1.

Table 1. Operational quantities to be used after an accident as surrogate quantities for intervention levels of avertable dose (OILs).

Protective Action	Environmental Measurement Quantity
Sheltering	Average air concentration (Bq/m^3) - *Plume present* Dose rate (mSv/h) - *Plume present* Dose rate (mSv/h) - *Plume past* Ground activity concentration (kBq/m^2) - *Plume past*
Stable iodine	Average air concentration (Bq/m^3) - *Plume present*
Evacuation	Average air concentration, (Bq/m^3) - *Plume present* Dose rate (mSv/h) - *Plume present* Ground activity concentration (kBq/m^2) - *Plume present* Dose rate (mSv/h) - *Plume past* Ground activity concentration (kBq/m^2) - *Plume past*
Temporary relocation	Dose rate (mSv/h) - *Plume past* Ground activity concentration (kBq/m^2) - *Plume past* Average air concentration from resuspension (Bq/m^3) and average air concentration (Bq/m^3) - *Plume past*
Permanent relocation	Dose rate (mSv/h) - *Plume past* Ground activity concentration (kBq/m^2) - *Plume past* Average air concentration from resuspension (Bq/m^3) and average air concentration (Bq/m^3) - *Plume past*
Foodstuff restrictions	Foodstuff concentration (Bq/kg) Ground activity concentration (kBq/m^2)

For the urgent countermeasures sheltering and evacuation, the dose rate from the plume or the air concentration would be the relevant quantities to use. 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. For iodine prophylaxis the relevant quantity would be the air concentration of radioiodines. Relocation would be based on measurements of either dose rate from deposited activity or surface contamination density. For certain nuclides like α-emitters, the time-integrated air concentration from resuspension would be of importance when considering relocation. Precautionary restrictions on the use of agricultural land could be based on surface contamination density with the purpose to make early decisions on the use of the food products produced here.

Longer term restrictions on the use of foodstuffs produced in contaminated areas should be based on measurements of the activity concentration in the foodstuffs.

Regarding the duration of the release, the OIL would be related to the IL and the reciprocal of the release time, *ie* the OIL would be higher the shorter the release time is for a given value of the IL. This makes it difficult to make decisions about the introduction of countermeasures in the earlier phases of the accident based on measurements because of the need to forecast the future cause of the accident.

4.1 Calculation principles

If it were possible to be precise, taking a fully rigorous approach to selecting generic intervention levels would mean that for each separate site and facility and for a full spectrum of accident scenarios describing the nature and magnitude of the radioactive release, and possible meteorological and other local conditions optimisation could be performed. These calculations would result in a set of possible intervention levels from which a value representative of the set could be selected.

This process would necessarily not be able to include the preference of unknown decision makers/national authorities involved and their attitudes towards the importance of the various factors in the decision making process, some of which would be extremely difficult to quantify. It is therefore extremely important that it be clearly stated which factors have been included in the selection of generic levels and which have been deliberately excluded.

In most cases the generic intervention levels will be adequate for the decision maker's use, provided they satisfy other requirements with regard to ensuring critical or radiosensitive groups are adequately protected. The approach adopted here is that political factors, as well as other social factors have been deliberately excluded.

OPERATIONAL INTERVENTION LEVELS FOR SINGLE RADIONUCLIDES

Intervention levels are expressed in terms of avertable dose, i.e. *the dose that is anticipated to be averted by a specific protective action*. An generically optimised intervention level for each protective action can be chosen, above which the action is normally taken and below which the action is not normally taken. The value of the intervention level for each protective action should be chosen in such a way as to produce the maximum net benefit.

In general terms, the avertable dose, $\Delta E_{c,r,p}$, from exposure to a single radionuclide, r, and pathway, p, which could be averted by implementing a countermeasure, c, is given by the following *dose subtraction*:

$$\Delta E_{c,r,p} = E_{r,p} - E_{c,r,p} \qquad \textbf{(1)}$$

where $E_{r,p}$ is the dose without any countermeasure and $E_{c,r,p}$ is the dose after implementing the countermeasure, c. The latter dose would be zero for 'complete' countermeasures like evacuation and relocation and greater than zero for 'incomplete' countermeasures like sheltering and decontamination.

The avertable dose, $\Delta E_{c,p}$, from exposure to radionuclide, r, and *all exposure pathways* by implementing the countermeasure, c, can be calculated as the sum of avertable doses from each pathway, p:

$$\Delta E_{c,r} = \sum_{p} \Delta E_{c,r,p} \qquad \textbf{(2)}$$

If the sum of avertable doses from all the relevant pathways would exceed the intervention level of avertable dose, IL_c, for that specific countermeasure c, i.e. if:

$$\Delta E_{c,r} \geq IL_c \qquad \textbf{(3)}$$

then the countermeasure should be implemented.

The nuclide specific avertable dose from all the relevant pathways can be expressed by an environmental measurement quantity, q, e.g. average air concentration, C, or effective γ-dose rate, $\dot{E}$:

$$\Delta E_{c,r}(q) = \sum_{p} \Delta E_{c,r,p}(q) \qquad \textbf{(4)}$$

If the radionuclide specific avertable dose is equal to the intervention level of dose for the countermeasure, then the value of the environmental measurement quantity is the operational intervention level, $OIL_{c,r,q}$, for countermeasure, c, and radionuclide, r:

$$\Delta E_{c,r}(q{=}Q_{o,r}) = IL_c \Rightarrow OIL_{c,r,q} = Q_{o,r} \qquad \textbf{(5)}$$

This means that when the avertable dose, ΔE, expressed by the operational quantity, q, is equal to the generic intervention level, IL, the value of the operational quantity is equal to the operational intervention level, OIL. Consequently, the implementation of the countermeasure, c, should be introduced if the environmental measurement quantity exceeds the operational intervention level:

$$q_r > OIL_{c,r,q} \Rightarrow \text{countermeasure } c \text{ is indicated} \qquad \textbf{(6)}$$

A simple method for calculating the operational intervention level for a particular combination of environmental measurement quantity and countermeasure is to use avertable doses from each relevant exposure pathway calculated assuming unit values of the environmental quantity. The total avertable dose calculated in this manner can be used with the intervention level of dose to determine the operational intervention level, as follows:

$$OIL_{c,r,q} = \frac{IL_c}{\sum_{p} \Delta E_{c,r,p}(q{=}1)} \qquad \textbf{(7)}$$

It follows from this equation that the unit for the $OIL_{c,r,q}$ is that of the quantity q, because the avertable dose for each pathway p, $\Delta E_{c,r,p}$, is given per unit of the quantity q. This is clearly only applicable because $\Delta E_{c,r,p}(q)$ is a linear function of q. It should also be emphasized that in the calculation of $\Delta E_{c,r,p}(q{=}1)$ site specific parameters like location factors, filtration factors and indoor/outdoor occupancy are used.

OPERATIONAL INTERVENTION LEVELS FOR MIXTURES OF RADIONUCLIDES

The avertable doses per unit measurable quantity are similar for many radionuclides of the same type (β-/γ-emitters and α-emitters). The avertable dose from all nuclides of similar type can be calculated as:

$$\Delta E_c(q_{total}) = \sum_p \sum_r \Delta E_{c,r,p}(q_{total}) \quad \textbf{(8)}$$

where:

$$q_{total} = \sum_r q_r \quad \textbf{(9)}$$

The nuclides might be grouped in a few major groups. Such a grouping would make it easy to predict avertable doses from environmental measurements of, *eg* gross activity concentration in air/on ground or dose rate when the nuclides present are known only qualitatively.

4.2 Models for calculating avertable doses and OILs

The protective actions to be taken after a nuclear or radiological emergency can be divided into *urgent protective actions* and *longer term protective actions*. The data needed for calculation of avertable doses and Operational Intervention Levels are shown in Table 2. The dose parameters in units of gray (Gy) are relevant for deriving OILs for avoiding deterministic effects.

Simple dose models have been used to illustrate the calculation of avertable doses from the most important exposure pathways. Simplicity is aimed at because the difference between results from simple and more complex models normally would be much less than the overall uncertainty in dose estimates from both types of models.

Table 2. Parameters used in the calculation of Operational Intervention Levels.

PARAMETER	SYMBOL	UNIT
Intervention level	IL	Sv
Operational intervention level	OIL	µSv/h, Bq/m^2, Bq/m^3
Effective dose	E	Sv
Avertable effective dose	ΔE	Sv
Absorbed dose	D	Gy
Avertable absorbed dose	ΔD	Gy
Activity concentration in air	C	Bq/m^3
Average activity concentration in air	C	Bq/m^3
Surface contamination density	Q	Bq/m^2
Average surface contamination density	Q	Bq/m^2
Time period for countermeasure	T	h, week, month, year
Breathing rate	I	m^3/h
Filtration factor	F	dimensionless
Time-averaged filtration factor	$F=1-x+x\cdot F$	dimensionless
Location factor	L	dimensionless
Time-averaged location factor	$\bar{L}=1-x+x\cdot L$	dimensionless
Fraction of time spent indoors	x	dimensionless
Resuspension factor	K	1/m
Radionuclide	r	dimensionless
Exposure pathway	p	dimensionless
Countermeasure	c	dimensionless
Committed effective inhalation dose per unit activity inhaled (committed over 50 or 70 years)	$e_{inh}(50)$, $e_{inh}(70)$	Sv/Bq
Effective gamma dose rate per unit air concentration	$\dot{e}_{plume,\gamma}$	$Sv\cdot h^{-1}/Bq\cdot m^{-3}$
Effective beta dose rate per unit air concentration	$\dot{e}_{plume,\beta}$	$Sv\cdot h^{-1}/Bq\cdot m^{-3}$
Effective gamma dose rate per unit surface contamination density	$\dot{e}_{ground,\gamma}$	$Sv\cdot h^{-1}/Bq\cdot m^{-2}$
Effective beta dose rate per unit surface contamination density	$\dot{e}_{ground,\beta}$	$Sv\cdot h^{-1}/Bq\cdot m^{-2}$
Absorbed gamma dose rate per unit air concentration	$\dot{d}_{plume,\gamma}$	$Gy\cdot h^{-1}/Bq\cdot m^{-3}$
Absorbed beta dose rate per unit air concentration	$\dot{d}_{plume,\beta}$	$Gy\cdot h^{-1}/Bq\cdot m^{-3}$
Absorbed gamma dose rate per unit surface contamination density	$\dot{d}_{ground,\gamma}$	$Gy\cdot h^{-1}/Bq\cdot m^{-2}$
Absorbed beta dose rate per unit surface contamination density	$\dot{d}_{ground,\beta}$	$Gy\cdot h^{-1}/Bq\cdot m^{-2}$
Absorbed dose over 2 days per unit surface contamination density	$d_{ground}(2)$	$Gy/Bq\cdot m^{-2}$
Absorbed dose over 2 days per unit air concentration	$d_{plume}(2)$	$Gy/Bq\cdot m^{-2}$
Absorbed beta dose rate to skin per unit skin contamination density	$\dot{d}_{skin,\beta}$	$Gy\cdot h^{-1}/Bq\cdot m^{-2}$
Committed equivalent organ dose per unit activity inhaled (committed over 50 or 70 years)	$h_{inh}(50)$, $h_{inh}(70)$	Sv/Bq
Committed effective ingestion dose per unit activity ingested	$e_{ing}(50)$, $e_{ing}(70)$	Sv/Bq
Deposition velocity	v_d	m/s

<u>SHELTERING</u>

The radionuclide specific avertable dose by sheltering when the plume is present can be calculated using a measured average air concentration, C_r:

$$\Delta E_{shelter,r} = \bar{C}_r \, T \, [\, (1-F) \, I \, e_{inh,r}(50) + (1-L_{plume}) \, \dot{e}_{plume,\gamma,r} + (1-F) \, \dot{e}_{plume,\beta,r} + (1-L_{ground}) \, \dot{e}_{ground,\gamma,r} \, v_d \, \frac{T}{2} \,] \quad \textbf{(10)}$$

where the appropriate exposure pathways are inhalation of radioactive material in the plume and external ß- and γ-irradiation from the plume and external γ-irradiation from radioactive deposits on the ground. The avertable dose is here calculated as 'full' avertable, *ie* individuals outdoors all move indoors and individuals indoor stay there.

The avertable dose by sheltering per unit average air concentration, C_r, of radionuclide r can be calculated from the above equation to be:

$$\frac{\Delta E_{shelter,r}}{\bar{C}_r} = T \, [\, (1-F) \, (I \, e_{inh,r}(50) + \dot{e}_{plume,\beta,r}) + (1-L_{plume}) \, \dot{e}_{plume,\gamma,r} + (1-L_{ground}) \, \dot{e}_{ground,\gamma,r} \, v_d \, \frac{T}{2} \,] \quad \textbf{(11)}$$

The operational intervention level for sheltering, expressed as an average outdoor air concentration, can be calculated as:

$$OIL_{shelter,r} = \frac{IL_{shelter}}{\Delta E_{shelter,r} \, / \bar{C}_r} \quad \textbf{(12)}$$

As the dose rate per unit activity concentration, $\dot{e}_{plume,\gamma,r}$, is given by $\dot{E}_r/C_r$, the avertable dose by sheltering per unit outdoor dose rate, $\dot{E}_r$, can be calculated as:

$$\frac{\Delta E_{shelter,r}}{\dot{E}_r} = T \, [\, (1-F) \, (I \, \frac{e_{inh,r}(50)}{\dot{e}_{plume,\gamma,r}} + \frac{\dot{e}_{plume,\beta,r}}{\dot{e}_{plume,\gamma,r}}) + (1-L_{plume}) + (1-L_{ground}) \, \frac{\dot{e}_{ground,\gamma,r}}{\dot{e}_{plume,\gamma,r}} \, v_d \, \frac{T}{2} \,] \quad \textbf{(13)}$$

The operational intervention level for sheltering, expressed as an outdoor effective dose rate, can be calculated as:

$$OIL_{shelter,r} = \frac{IL_{shelter}}{\Delta E_{shelter,r} \, / \dot{E}_r} \quad \textbf{(14)}$$

<u>IODINE PROPHYLAXIS</u>

The radionuclide specific avertable dose by iodine prophylaxis can be calculated using a measured average air concentration of radioiodine and for an average indoor/outdoor occupancy.

$$\Delta D_{prophylaxis} = \overline{C}_{iodine} \cdot \overline{F} \cdot I \cdot T \cdot h_{inh,iodine} \quad \textbf{(15)}$$

The avertable equivalent thyroid dose from iodine prophylaxis is here calculated as 'full' avertable, *ie* the iodine tablets are assumed to be taken before the exposure to the plume.

The avertable dose by thyroid blocking per unit average air concentration of iodine would then be:

$$\frac{\Delta D_{prophylaxis}}{\overline{C}_{iodine}} = T \cdot \overline{F} \cdot I \cdot h_{inh,iodine} \quad \textbf{(16)}$$

The operational intervention level for iodine prophylaxis, expressed as an average outdoor iodine concentration, can be calculated as:

$$OIL_{prophylaxis} = \frac{IL_{prophylaxis}}{\Delta D_{prophylaxis} / \overline{C}_{iodine}} \quad \textbf{(17)}$$

EVACUATION

The radionuclide specific avertable dose by evacuation when the plume is present can be calculated using a measured average air concentration or γ-dose rate from the plume. If there are particulates in the plume there would be ground deposition and the external dose rate from deposited material would gradually increase and thus disturb the measured dose rate from the plume. Therefore, the most efficient way of determining the presence of the plume is the measurement of activity concentration in air.

The nuclide specific avertable effective dose by evacuation would be from the exposure pathways of inhalation of radioactive material in the plume and external γ-irradiation from the plume. The avertable dose is here calculated for an average indoor/outdoor occupancy.

$$\Delta E_{evac,r} = \overline{C}_r \; T \; [\; \overline{F} \; (I \; e_{inh,r}(50) + \dot{e}_{plume,\beta,r}) + \overline{L}_{plume} \; \dot{e}_{plume,\gamma,r} + \overline{L}_{ground} \; \dot{e}_{ground,\gamma,r} \; v_d \; \frac{T}{2} \;] \quad \textbf{(18)}$$

The avertable dose by evacuation per unit average air concentration of radionuclide *r* can be calculated from the equation above to be:

$$\frac{\Delta E_{evac,r}}{\overline{C}_r} = T \; [\; \overline{F} \; (I \; e_{inh,r}(50) + \dot{e}_{plume,\beta,r}) + \overline{L}_{plume} \; \dot{e}_{plume,\gamma,r} + \overline{L}_{ground} \; \dot{e}_{ground,\gamma,r} \; v_d \; \frac{T}{2} \;] \quad \textbf{(19)}$$

The operational intervention level for evacuation, expressed as an average outdoor air concentration, can be calculated as:

$$OIL_{evacuation} = \frac{IL_{evacuation}}{\Delta E_{evacuation,r} / \overline{C}_r} \quad \textbf{(20)}$$

The avertable dose by evacuation per unit dose rate from the plume, $\dot{E}_r$, of radionuclide *r* can be calculated to be:

$$\frac{\Delta E_{evac,r}}{\dot{E}_r} = T \left[\bar{F} \left(I \frac{e_{inh,r}(50)}{\dot{e}_{plume,\gamma,r}} + \frac{\dot{e}_{plume,\beta,r}}{\dot{e}_{plume,\gamma,r}} \right) + \bar{L}_{plume} + \bar{L}_{ground} \frac{\dot{e}_{ground,\gamma,r}}{\dot{e}_{plume,\gamma,r}} v_d \frac{T}{2} \right] \quad \textbf{(21)}$$

The operational intervention level for evacuation, expressed as an outdoor γ-dose rate from the plume, can be calculated as:

$$OIL_{evacuation} = \frac{IL_{evacuation}}{\Delta E_{evacuation,r} / \dot{E}_r} \quad \textbf{(22)}$$

<u>RELOCATION</u>

The avertable dose from a relocation is the sum of doses from all relevant exposure pathways and from all radionuclides in the release. The avertable dose can be expressed in terms of measurable quantities in the environment such as dose rate or surface contamination density.

The avertable individual effective dose, $\Delta E_{rel,r}$, from relocation in a time period, T, would be the external effective γ-dose and the committed effective inhalation dose from resuspended radioactive material on the ground. The relation between the avertable dose and the surface contamination density, Q_r, can be calculated to be:

$$\Delta E_{rel,r} = Q_r \frac{1 - e^{-\lambda_r T}}{\lambda_r} \left(\dot{e}_{ground,\gamma,r} \bar{L}_{ground} + K\ I\ e_{inh,r}(50)\ \bar{F} \right) \quad \textbf{(23)}$$

The avertable individual effective dose can also be expressed in terms of γ-dose rate, $\dot{E}_{ground,\gamma,r}$, over large open areas as:

$$\Delta E_{rel,r} = \dot{E}_{ground,\gamma,r} \frac{1 - e^{-\lambda_r T}}{\lambda_r} \left(\bar{L}_{ground} + \left(\frac{e_{inh,r}(50)}{\dot{e}_{ground,\gamma,r}} \right) K\ I\ \bar{F} \right) \quad \textbf{(24)}$$

The avertable dose from relocation per unit surface contamination density, Q_r, or per unit γ-dose rate, $\dot{E}_{ground,\gamma,r}$, for radionuclide r can be calculated from the equations above to be:

$$\frac{\Delta E_{rel,r}}{Q_r} = \frac{1 - e^{-\lambda_r T}}{\lambda_r} \left(\dot{e}_{ground,\gamma,r} \bar{L}_{ground} + K\ I\ e_{inh,r}(50)\ \bar{F} \right) \quad \textbf{(25)}$$

or:

$$\frac{\Delta E_{rel,r}}{\dot{E}_{ground,\gamma,r}} = \frac{1 - e^{-\lambda_r T}}{\lambda_r} \left(\bar{L}_{ground} + \left(\frac{e_{inh,r}(50)}{\dot{e}_{ground,\gamma,r}} \right) K\ I\ \bar{F} \right) \quad \textbf{(26)}$$

The operational intervention level for temporary and permanent relocation, expressed as surface contamination density or outdoor γ-dose rate from the deposited activity, can be calculated as:

$$OIL_{relocation} = \frac{IL_{relocation}}{\Delta E_{relocation,r} \; / Q_r} \qquad \textbf{(27)}$$

or:

$$OIL_{relocation} = \frac{IL_{relocation}}{\Delta E_{relocation,r} \; / \dot{E}_{ground,\gamma,r}} \qquad \textbf{(28)}$$

<u>FOODSTUFF RESTRICTIONS</u>
The radionuclide specific avertable collective dose per unit mass of foodstuff is given as:

$$\Delta S_{food,r} = C_r \; e_{ing,r}(50) \qquad \textbf{(29)}$$

where C_r is the concentration of activity of nuclide r in a given foodstuff.

The Operational Intervention Level in terms of activity concentration, C_r, of a given radionuclide in a given foodstuff corresponding to an optimized Intervention Level of avertable collective dose per unit mass of that foodstuff is given as:

$$OIL_{food,r} = \frac{IL_{food,r}}{\Delta S_{food,r} / C_r} = \frac{IL_{food,r}}{e_{ing,r}(50)} \qquad \textbf{(30)}$$

The radionuclide specific avertable collective dose per unit mass of foodstuff can be expressed also by the surface contamination density, Q_r, and the transfer factor, $g_{food,r}$, for the given foodstuff and nuclide as:

$$\Delta S_{food,r} = Q_r \; g_{food,r} \; e_{ing,r}(50) \qquad \textbf{(31)}$$

The corresponding Operational Intervention Level in terms of surface contamination density, Q_r, can then be expressed as:

$$OIL_{food,r} = \frac{IL_{food,r}}{\Delta S_{food,r} / Q_r} = \frac{IL_{food,r}}{g_{food,r} \; e_{ing,r}(50)} \qquad \textbf{(32)}$$

5 Data for deriving Operational Intervention Levels

In the event of a nuclear accident which results in an atmospheric release of radioactive materials, the dominant contributors to short time exposures would be:

- whole body exposure from external γ-radiation
- thyroid exposure from inhalation or ingestion of radioiodines
- exposure of other organs from inhalation of radioactive materials

The longer term exposure from long-lived radionuclides dispersed in the environment will be dominated by:

- whole body exposure from external γ-radiation from deposited activity
- internal exposure from ingestion of contaminated foodstuffs

Examples on basic data are given for selected nuclides and some of the exposure pathways mentioned above. Consideration is limited to those nuclides likely to be of major radiological significance in the context of accidental releases from installations in the nuclear fuel cycle.

5.1 External γ-dose from plume

In the calculation of external γ-dose from the plume it is assumed that the semi-infinite cloud geometry can be used. Values of the effective dose rate per unit activity concentration, $\dot{e}_{plume,\gamma}$, are shown in Table 3.

Table 3. Effective dose rate per unit activity concentration from a semi-infinite volume source above the ground.

Radionuclide	Effective dose rate per unit concentration, $\dot{e}_{plume,\gamma}$ (mSv h^{-1} per kBq m^{-3})
^{85}Kr	$4.2 \cdot 10^{-7}$
^{87}Kr	$1.4 \cdot 10^{-4}$
^{88}Kr	$3.5 \cdot 10^{-4}$
^{133}Xe	$4.6 \cdot 10^{-6}$
^{135}Xe	$3.8 \cdot 10^{-5}$
^{131}I	$6.0 \cdot 10^{-5}$
^{134}Cs	$2.6 \cdot 10^{-4}$
^{137}Cs	$9.3 \cdot 10^{-5}$

Dosimetry data for other relevant radionuclides can be found in *Dose-rate conversion factors for external exposure to photon and electron radiation from radionuclides occurring in routine releases from nuclear fuel cycle facilities* [9] and the *International Basic Safety Standards* [5], Table II-X.

5.2 Committed effective inhalation dose from plume

The committed effective doses per unit intake by inhalation, $e_{inh}(50)$, have recently been published in the International Basic Safety Standards [5] based on values from the ICRP. Values of the dose conversion factors, $e_{inh}(50)$, are shown in Table 4.

Table 4. Committed effective inhalation dose for different age groups. The absorption type is assumed to be medium (M).

Radionuclide	Committed effective inhalation dose, e_{inh} (Sv/Bq)		
	Infants (< 1 y)	Children (2-7 y)	Adults
^{90}Sr	$1.5 \cdot 10^{-7}$	$6.5 \cdot 10^{-8}$	$3.6 \cdot 10^{-8}$
^{106}Ru	$1.4 \cdot 10^{-7}$	$6.4 \cdot 10^{-8}$	$2.8 \cdot 10^{-8}$
^{144}Ce	$1.9 \cdot 10^{-7}$	$8.8 \cdot 10^{-8}$	$3.6 \cdot 10^{-8}$
^{131}I	$2.2 \cdot 10^{-8}$	$8.2 \cdot 10^{-9}$	$2.4 \cdot 10^{-9}$
^{134}Cs	$3.2 \cdot 10^{-8}$	$1.6 \cdot 10^{-8}$	$9.1 \cdot 10^{-9}$
^{137}Cs	$3.6 \cdot 10^{-8}$	$1.8 \cdot 10^{-8}$	$9.7 \cdot 10^{-9}$
^{239}Pu	$8.0 \cdot 10^{-5}$	$6.0 \cdot 10^{-5}$	$5.0 \cdot 10^{-5}$

Dosimetry data for other relevant radionuclides can be found in the *International Basic Safety Standards* [5], Table II-VII.

5.3 Committed equivalent inhalation dose to thyroid from plume

The committed equivalent thyroid dose, $h_{inh}(50)$, from inhalation of radioiodines are shown in Table 5.

Table 5. Committed equivalent thyroid dose from inhalation of radioiodines to different age groups.

Radionuclide	Committed equivalent dose to thyroid (Sv/Bq)		
	Infant	Child	Adult
$^{132}Te + ^{132}I$	$5.8{\cdot}10^{-7}$	$1.6{\cdot}10^{-7}$	$5.6{\cdot}10^{-8}$
^{131}I	$2.2{\cdot}10^{-6}$	$7.3{\cdot}10^{-7}$	$2.7{\cdot}10^{-7}$
^{133}I	$4.6{\cdot}10^{-7}$	$1.3{\cdot}10^{-7}$	$4.4{\cdot}10^{-8}$
^{135}I	$7.8{\cdot}10^{-8}$	$2.1{\cdot}10^{-8}$	$7.6{\cdot}10^{-9}$

5.4 External γ-dose from deposited activity

The effective dose rate from deposited activity at the time of deposit on an infinite surface of grass is shown in Table 6.

Table 6. Effective dose rate per unit (wet) deposit on a large field of grassland.

Radionuclide	Effective dose rate per unit surface contamination density, $\dot{e}_{ground,\gamma}$ (mSv h^{-1} per kBq m^{-2})
^{95}Zr	$3.5{\cdot}10^{-6}$
^{103}Ru	$1.1{\cdot}10^{-6}$
$^{132}Te + ^{132}I$	$5.6{\cdot}10^{-6}$
^{131}I	$8.9{\cdot}10^{-7}$
^{135}I	$3.4{\cdot}10^{-6}$
^{134}Cs	$3.6{\cdot}10^{-6}$
^{137}Cs	$1.5{\cdot}10^{-6}$
^{144}Ce	$1.1{\cdot}10^{-7}$

Dosimetry data for other relevant radionuclides can be found in *Organ Doses from Radionuclides on the Ground. Part I: Simple Time Dependences* [7] and *Gamma Exposures due to Radionuclides Deposited in Urban Environments. Part I: Kerma Rates from Contaminated Urban Surfaces* [8].

5.5 Committed effective dose from ingestion of foodstuffs

The committed effective doses per unit intake by ingestion, $e_{ing}(50)$, have recently been published in the International Basic Safety Standards [5] based on values from the ICRP. Values of the conversion factors, $e_{ing}(50)$, are shown in Table 7.

Table 7. Committed effective ingestion dose for different age groups.

Radionuclide	Committed effective ingestion dose, e_{ing} (Sv/Bq)		
	Infants (< 1 y)	Children (2-7 y)	Adults
^{90}Sr	$2.3 \cdot 10^{-7}$	$4.7 \cdot 10^{-8}$	$2.8 \cdot 10^{-8}$
^{106}Ru	$8.4 \cdot 10^{-8}$	$2.5 \cdot 10^{-8}$	$7.0 \cdot 10^{-9}$
^{144}Ce	$6.6 \cdot 10^{-8}$	$1.9 \cdot 10^{-8}$	$5.2 \cdot 10^{-9}$
^{131}I	$1.8 \cdot 10^{-7}$	$1.0 \cdot 10^{-7}$	$2.2 \cdot 10^{-8}$
^{134}Cs	$2.6 \cdot 10^{-8}$	$1.3 \cdot 10^{-8}$	$1.9 \cdot 10^{-8}$
^{137}Cs	$2.1 \cdot 10^{-8}$	$9.6 \cdot 10^{-9}$	$1.3 \cdot 10^{-8}$
^{239}Pu	$4.2 \cdot 10^{-6}$	$3.3 \cdot 10^{-7}$	$2.5 \cdot 10^{-7}$

Dosimetry data for other relevant radionuclides can be found in the *International Basic Safety Standards* [5], Table II-VI.

5.6 Other exposure pathways

There are other exposure pathways which can contribute to the total effective dose. Some of these exposure pathways are listed below. They are, however, in most situations of less importance.

- β-dose to skin from plume
- β-/γ-doses to skin and organs from deposition on skin
- β-dose to skin from deposited activity on ground
- other relevant exposure pathways

5.7 Location and filtration factors

For the assessment of external exposures to γ-radiation from radionuclides in air and deposited on ground and structure surfaces, the shielding due to structures have to be taken into account, expressed by location factors, L. For assessment of inhalation doses, filtration factors, F, should be applied. Typical values of L and F are shown in Table 8.

Table 8. Location factors and filtration factors for Nordic buildings.

Location	Location factor, *L*		Filtration factor, *F*
	Plume	Ground	
Outdoors:			
sub-urban	1.0	1.0	-
urban	0.6	0.3	
Single-family houses:			
light constructions	-	-	0.3-0.7
masonry house	0.3	0.1	
basement, with windows	0.05	0.01	0.2-0.5
basement, no windows	0.01	0.001	
Large buildings:			
above ground	0.05	0.01	0.3-0.6
basement	0.001	0.0005	0.2-0.4

The location and filtration factors would differ between the Nordic countries due to differences in housing conditions.

6 Example calculations of OILs

For illustrative purposes, OILs have been calculated from the models described in Section 4 for *sheltering*, *evacuation* and *temporary relocation*. The calculations have been made for single radionuclides only. Nuclide grouping would be relevant for developing OILs for 'reference accidents', *eg* in the following groups:

- noble gases
- β-/γ-emitters like ^{137}Cs, ^{131}I, ^{103}Ru etc.
- β-emitters like ^{90}Sr, ^{106}Ru, ^{144}Ce etc.
- α-emitters

Such grouping needs to be explored based on Nordic data on housing conditions and also for selected accident types.

There are several nuclear installations both within the Nordic countries and close to the borders of the countries. Some of these installations will be selected for calculations of doses from accidents where radionuclides are released to the environment, *eg*:

- Russian military installations close to the Norwegian border
- Finnish PWR-reactor
- nuclear power plant close to a big city (Copenhagen/Malmoe)
- accidents defined by Nordic authorities

Based on the analyses representative OILs can be selected for reference accidents.

6.1 Sheltering

Sheltering refers to staying inside or moving into dwellings or other buildings, closing doors and windows, and turning off any ventilation systems in order that individuals will inhale less radioactive material from the outside air, and also to reduce their direct exposure to airborne radionuclides and to short lived surface deposits. Sheltering can also be used as a means of controlling the population in order to facilitate other protective measures, such as evacuation and the administration of stable iodine. However, there is a limit to the time that the population can reasonably be expected to remain sheltered indoors, and 2 days should be the absolute maximum. In considering sheltering as a protective action, its effectiveness in averting radiation doses should be considered, since it can vary markedly.

During the early stages of an accident with a release of relatively short duration of mixed radionuclides into the atmosphere, and while the plume is passing, the dose from inhalation will usually be much larger than that from external radiation. Most buildings will reduce inhalation doses by a factor of two or so. However, the reduction of inhalation doses typically decreases rapidly after a few hours, and sheltering becomes less effective for protracted releases. External doses can be reduced by an order of magnitude or more for brick built or large commercial structures. Many open or lightweight buildings, however, provide less effective protection. Improvised respiratory protection can also reduce the inhalation of particulates by significant factors. However, this measure cannot be sustained comfortably for long; it would normally be recommended as a measure to be adopted when short trips outside are necessary. The relative merits of sheltering strongly depend on the timing of its introduction relative to the accident phase and the magnitude and radionuclide composition of the release. In any case, ventilation is necessary following a period of sheltering and after the plume has passed in order to reduce air concentrations of radionuclides, which will have risen inside the shelter, to the levels of the now relatively clean air outside.

The decision on sheltering can be based on measurements of either outdoor dose rate or activity concentration in air. OILs have been calculated from an IL of an avertable effective dose of 10 mSv in 48 hours from three pathways: external γ-exposure from plume and ground (cloud shine and ground shine) and inhalation of activity. The following 'default' parameter values have been used:

- location factor for cloud shine: 0.5
- location factor for ground shine: 0.1
- filtration factor for air concentration: 0.6
- breathing rate: 1 m^3/h
- deposition velocity: 0.01 m/s

Calculated values of avertable dose, ΔE, per unit operational quantity and of OILs are shown in Table 9.

Table 9. Calculated avertable doses per unit operational quantity and Operational Intervention Levels corresponding to an Intervention Level of avertable dose of 10 mSv in 48 hours.

Radionuclide	Avertable dose		IL = 10 mSv/48 h	
	ΔE / Q_r mSv (48 h)$^{-1}$ per kBq m^{-3}	ΔE / $\dot{E}_r$ mSv (48 h)$^{-1}$ per mSv h^{-1}	**OIL** (kBq/m^3)	**OIL** (mSv/h)
^{85}Kr	$2.21\cdot10^{-5}$	$2.40\cdot10^{1}$	$4.53\cdot10^{5}$	$4.17\cdot10^{-1}$
^{87}Kr	$3.36\cdot10^{-3}$	$2.40\cdot10^{1}$	$2.98\cdot10^{3}$	$4.17\cdot10^{-1}$
^{88}Kr	$8.40\cdot10^{-3}$	$2.40\cdot10^{1}$	$1.19\cdot10^{3}$	$4.17\cdot10^{-1}$
^{133}Xe	$1.20\cdot10^{-4}$	$2.40\cdot10^{1}$	$8.33\cdot10^{4}$	$4.17\cdot10^{-1}$
^{135}Xe	$9.60\cdot10^{-4}$	$2.40\cdot10^{1}$	$1.04\cdot10^{4}$	$4.17\cdot10^{-1}$
^{95}Zr	$2.26\cdot10^{-1}$	$1.88\cdot10^{3}$	$4.43\cdot10^{1}$	$5.32\cdot10^{-3}$
^{95}Nb	$9.91\cdot10^{-2}$	$7.62\cdot10^{2}$	$1.01\cdot10^{2}$	$1.31\cdot10^{-2}$
^{103}Ru	$8.89\cdot10^{-2}$	$1.19\cdot10^{3}$	$1.12\cdot10^{2}$	$8.43\cdot10^{-3}$
^{106}Ru	$5.56\cdot10^{-1}$	$1.68\cdot10^{4}$	$1.80\cdot10^{1}$	$5.94\cdot10^{-4}$
^{132}Te	$2.48\cdot10^{-1}$	$7.76\cdot10^{3}$	$4.03\cdot10^{1}$	$1.29\cdot10^{-3}$
^{131}I	$1.77\cdot10^{-1}$	$2.95\cdot10^{3}$	$5.66\cdot10^{1}$	$3.39\cdot10^{-3}$
^{133}I	$8.34\cdot10^{-2}$	$8.51\cdot10^{2}$	$1.20\cdot10^{2}$	$1.17\cdot10^{-2}$
^{135}I	$1.40\cdot10^{-1}$	$5.17\cdot10^{2}$	$7.17\cdot10^{1}$	$1.94\cdot10^{-2}$
^{134}Cs	$2.67\cdot10^{-1}$	$1.03\cdot10^{3}$	$3.74\cdot10^{1}$	$9.73\cdot10^{-3}$
^{137}Cs	$1.47\cdot10^{-1}$	$1.58\cdot10^{3}$	$6.82\cdot10^{1}$	$6.35\cdot10^{-3}$
^{140}Ba	$3.04\cdot10^{-1}$	$1.09\cdot10^{4}$	$3.29\cdot10^{1}$	$9.21\cdot10^{-4}$
^{140}La	$2.21\cdot10^{-1}$	$5.53\cdot10^{2}$	$4.52\cdot10^{1}$	$1.81\cdot10^{-2}$
^{141}Ce	$6.77\cdot10^{-2}$	$6.15\cdot10^{3}$	$1.48\cdot10^{2}$	$1.63\cdot10^{-3}$
^{144}Ce	$6.96\cdot10^{-1}$	$8.48\cdot10^{4}$	$1.44\cdot10^{1}$	$1.18\cdot10^{-4}$
^{238}Pu	$8.83\cdot10^{2}$	-	$1.13\cdot10^{-2}$	-
^{239}Pu	$9.60\cdot10^{2}$	-	$1.04\cdot10^{-2}$	-

6.2 Evacuation

Evacuation is used here to mean the urgent moving of people from their homes, or from places of work or recreation, for a limited period of time in order to avert short term exposures due to the accident. In most cases people will subsequently be permitted to return to their homes within a short period of time, typically a few days, if they are habitable and do not require prolonged cleanup operations. Because of the short period for which people are expected to stay away from their homes, they would usually be given temporary and minimal accommodation, such as in schools and other public buildings. However, if it becomes clear that the evacuation will last longer than a week, then they should be relocated temporarily to more substantial accommodation.

Evacuation can be implemented at various stages in the development of an accident. It is most effective (in terms of avoiding radiation exposure) if it can be taken as a precautionary measure before there has been any significant release of radioactive material. In developing plans, an assessment should be made and account should be taken of how a release might progress, particularly during the earlier stages of an accident, which will have considerable significance for the decision whether and how to effect precautionary evacuation.

Evacuation to minimal accommodation may be initiated or continued after the dispersion of the material released has terminated in order to avoid the possibility of exposure from deposited material (externally and also internally from resuspended material) which could be incurred in the short term (*ie* within a few days).

The decision on evacuation can be based on measurements of either outdoor dose rate or activity concentration in air. OILs have been calculated from an IL of an avertable effective dose of 100 mSv in 168 hours from three pathways: external γ-exposure from plume and ground (cloud shine and ground shine) and inhalation of activity. The following 'default' parameter values have been used:

- time-averaged location factor for cloud shine: 0.55
- time-averaged location factor for ground shine: 0.20
- time-averaged filtration factor for air concentration: 0.65
- breathing rate: 1 m^3/h
- deposition velocity: 0.01 m/s

Calculated values of avertable dose, ΔE, per unit operational quantity and of OILs are shown in Table 10.

Table 10. Calculated avertable doses per unit operational quantity and Operational Intervention Levels corresponding to an Intervention Level of avertable dose of 100 mSv in 168 hours.

Radionuclide	Avertable dose		IL = 100 mSv/168 h	
	$\Delta E\ /\ Q_r$ mSv (168 h)$^{-1}$ per kBq m^{-3}	$\Delta E\ /\ \dot{E}_r$ mSv (168 h)$^{-1}$ per mSv h^{-1}	OIL (kBq/m^3)	OIL (mSv/h)
^{85}Kr	$8.58 \cdot 10^{-5}$	$9.32 \cdot 10^{1}$	$1.17 \cdot 10^{6}$	1.07
^{87}Kr	$1.31 \cdot 10^{-2}$	$9.32 \cdot 10^{1}$	$7.66 \cdot 10^{3}$	1.07
^{88}Kr	$3.26 \cdot 10^{-2}$	$9.32 \cdot 10^{1}$	$3.06 \cdot 10^{3}$	1.07
^{133}Xe	$4.66 \cdot 10^{-4}$	$9.32 \cdot 10^{1}$	$2.15 \cdot 10^{5}$	1.07
^{135}Xe	$3.73 \cdot 10^{-3}$	$9.32 \cdot 10^{1}$	$2.68 \cdot 10^{4}$	1.07
^{95}Zr	$8.84 \cdot 10^{-1}$	$7.37 \cdot 10^{3}$	$1.13 \cdot 10^{2}$	$1.36 \cdot 10^{-2}$
^{95}Nb	$3.56 \cdot 10^{-1}$	$2.74 \cdot 10^{3}$	$2.81 \cdot 10^{2}$	$3.65 \cdot 10^{-2}$
^{103}Ru	$3.78 \cdot 10^{-1}$	$5.04 \cdot 10^{3}$	$2.65 \cdot 10^{2}$	$1.98 \cdot 10^{-2}$
^{106}Ru	3.08	$9.33 \cdot 10^{4}$	$3.25 \cdot 10^{1}$	$1.07 \cdot 10^{-3}$
^{132}Te	$7.86 \cdot 10^{-1}$	$2.45 \cdot 10^{4}$	$1.27 \cdot 10^{2}$	$4.07 \cdot 10^{-3}$
^{131}I	$8.96 \cdot 10^{-1}$	$1.49 \cdot 10^{4}$	$1.12 \cdot 10^{2}$	$6.69 \cdot 10^{-3}$
^{133}I	$3.13 \cdot 10^{-1}$	$3.19 \cdot 10^{3}$	$3.20 \cdot 10^{2}$	$3.13 \cdot 10^{-2}$
^{135}I	$4.04 \cdot 10^{-1}$	$1.49 \cdot 10^{3}$	$2.48 \cdot 10^{2}$	$6.69 \cdot 10^{-2}$
^{134}Cs	1.10	$4.24 \cdot 10^{3}$	$9.07 \cdot 10^{1}$	$2.36 \cdot 10^{-2}$
^{137}Cs	$6.58 \cdot 10^{-1}$	$7.08 \cdot 10^{3}$	$1.52 \cdot 10^{2}$	$1.41 \cdot 10^{-2}$
^{140}Ba	1.11	$3.97 \cdot 10^{4}$	$9.01 \cdot 10^{1}$	$2.52 \cdot 10^{-3}$
^{140}La	$6.72 \cdot 10^{-1}$	$1.68 \cdot 10^{3}$	$1.49 \cdot 10^{2}$	$5.95 \cdot 10^{-2}$
^{141}Ce	$3.63 \cdot 10^{-1}$	$3.30 \cdot 10^{4}$	$2.75 \cdot 10^{2}$	$3.03 \cdot 10^{-3}$
^{144}Ce	3.91	$4.76 \cdot 10^{5}$	$2.56 \cdot 10^{1}$	$2.10 \cdot 10^{-4}$
^{238}Pu	$4.98 \cdot 10^{3}$	-	$2.01 \cdot 10^{-2}$	-
^{239}Pu	$5.41 \cdot 10^{3}$	-	$1.85 \cdot 10^{-2}$	-

6.3 Relocation

Temporary relocation and/or permanent resettlement are two of the more extreme protective measures available to control exposures to the public in the event of a nuclear accident. Temporary relocation is used to mean 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) to avert exposures principally from radioactive material deposited on the ground and from inhalation of any resuspended radioactive particulate material. During this period, people would typically be housed in temporary accommodation. Permanent resettlement is the term used for the deliberate complete removal of people from the area with no expectation of return. This would typically require the construction of new accommodation and infrastructure in an area remote from the contaminated zones.

Temporary relocation should not be confused with evacuation, which refers to the urgent removal of people from an area to avert or reduce their exposure from an airborne plume or from deposited radioactive material. Accommodation following an urgent evacuation should typically be in local community centres and people will return to the area within a relatively short period of time (typically several days) provided that temporary relocation is not warranted. Thus, temporary relocation may be carried out as an extension to evacuation, or could be implemented at a later stage of the accident. During the period of temporary relocation, decontamination of land and property should be considered.

The decision on relocation can be based on measurements of either outdoor dose rate or surface contamination density. OILs have been calculated from an IL of an avertable effective dose of 10 mSv in a month from two pathways: external γ-exposure and inhalation of resuspended activity. The following 'default' parameter values have been used:

- time-averaged location factor for ground shine: 0.20
- resuspension factor: 10^{-7} m^{-1}
- breathing rate: 1 m^3/h
- time-averaged filtration factor: 0.65

Calculated values of avertable dose, ΔE, per unit operational quantity and of OILs are shown in Table 11.

The calculations indicate that the avertable dose per unit outdoor dose rate, $\Delta E/\dot{E}_r$, will be of the order of 100-200 $mSv \cdot month^{-1}$ per $mSv \cdot h^{-1}$ for β-/γ-emitting radionuclides with half-lives of *months to years*. For radionuclides with half-lives of *days* the value would be of the order 20-50 $mSv \cdot month^{-1}$ per $mSv \cdot h^{-1}$. For long-lived α-emitters with resuspension as the dominating exposure pathway the value of avertable dose per unit surface contamination density, $\Delta E/Q_r$, is of the order 30-50 $mSv \cdot month^{-1}$ per $MBq \cdot m^{-2}$.

Table 11. Calculated avertable doses per unit operational quantity and Operational Intervention Levels corresponding to an Intervention Level of avertable dose of 10 mSv in a month.

Radionuclide	Avertable dose		IL = 10 mSv/month	
	$\Delta E / Q_r$ mSv month^{-1} per kBq m^{-2}	$\Delta E / \dot{E}_r$ mSv month^{-1} per mSv h^{-1}	OIL (kBq/m^2)	OIL (mSv/h)
^{95}Zr	$4.27 \cdot 10^{-4}$	$1.22 \cdot 10^{2}$	$2.34 \cdot 10^{4}$	$8.19 \cdot 10^{-2}$
^{95}Nb	$1.96 \cdot 10^{-4}$	$1.09 \cdot 10^{2}$	$5.10 \cdot 10^{4}$	$9.19 \cdot 10^{-2}$
^{103}Ru	$1.22 \cdot 10^{-4}$	$1.11 \cdot 10^{2}$	$8.18 \cdot 10^{4}$	$9.00 \cdot 10^{-2}$
^{106}Ru	$6.67 \cdot 10^{-5}$	$1.39 \cdot 10^{2}$	$1.50 \cdot 10^{5}$	$7.18 \cdot 10^{-2}$
^{132}Te	$1.27 \cdot 10^{-4}$	$2.27 \cdot 10^{1}$	$7.87 \cdot 10^{4}$	$4.41 \cdot 10^{-1}$
^{131}I	$4.60 \cdot 10^{-5}$	$5.15 \cdot 10^{1}$	$2.17 \cdot 10^{5}$	$1.94 \cdot 10^{-1}$
^{133}I	$8.37 \cdot 10^{-6}$	5.97	$1.20 \cdot 10^{6}$	1.67
^{135}I	$6.45 \cdot 10^{-6}$	1.90	$1.55 \cdot 10^{6}$	5.27
^{134}Cs	$5.09 \cdot 10^{-4}$	$1.41 \cdot 10^{2}$	$1.96 \cdot 10^{4}$	$7.08 \cdot 10^{-2}$
^{137}Cs	$2.15 \cdot 10^{-4}$	$1.43 \cdot 10^{2}$	$4.65 \cdot 10^{4}$	$6.99 \cdot 10^{-2}$
^{140}Ba	$3.88 \cdot 10^{-4}$	$7.05 \cdot 10^{1}$	$2.58 \cdot 10^{4}$	$1.42 \cdot 10^{-1}$
^{140}La	$5.90 \cdot 10^{-5}$	$1.16 \cdot 10^{1}$	$1.69 \cdot 10^{5}$	$8.64 \cdot 10^{-1}$
^{141}Ce	$1.70 \cdot 10^{-5}$	$1.06 \cdot 10^{2}$	$5.87 \cdot 10^{5}$	$9.46 \cdot 10^{-2}$
^{144}Ce	$1.68 \cdot 10^{-5}$	$1.38 \cdot 10^{2}$	$5.95 \cdot 10^{5}$	$7.23 \cdot 10^{-2}$
^{238}Pu	$2.13 \cdot 10^{-3}$	-	$4.69 \cdot 10^{3}$	-
^{239}Pu	$2.32 \cdot 10^{-3}$	-	$4.31 \cdot 10^{3}$	-

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