INTERVENTION PRINCIPLES — THEORY AND PRACTICE

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Abstract

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After the Chernobyl accident, it became clear that some clarification of the basic principles for intervention was necessary as well as more internationally recognised numerical guidance on intervention levels. There was in the former USSR and in Europe much confusion over, and lack of recognition of, the very different origins and purposes of dose limits for controlling deliberate *increases* in radiation exposure for practices and dose levels at which intervention is prompted to *decrease* existing radiation exposure.

In the latest recommendations from ICRP in its Publication 60, a clear distinction is made between the radiation protection systems for a practice and for intervention. According to ICRP, the protective measures forming a program of intervention, which always have some disadvantages, should each be *justified* on their own merit in the sense that they should do more good than harm, and their form, scale, and duration should be *optimised* so as to do the most good.

Intervention levels for protective actions can be established for many possible accident scenarios. For planning and preparedness purposes, a generic optimisation based on generic accident scenario calculations, should result in optimised *generic* intervention levels for each protective measure. The factors entering such an optimisation will on the benefit side include avertable doses and avertable risks as well as reassurance. On the harm side the factors include monetary costs, collective and individual risk for the action itself, social disruption and anxiety. More precise optimisation analyses based on real site and accident specific data can be carried out and result in *specific* intervention levels.

It is desirable that values for easily measurable quantities such as dose rate and surface contamination density be developed as surrogates for intervention levels of avertable dose. However, it is important that these quantities should be used carefully and applied taking account of local conditions and the circumstances of the accident. Only with suitable models can they be accurately interpreted in terms of avertable individual or collective doses.

This paper will discuss the application of the basic radiation protection principles for intervention to develop generic intervention levels for different protection actions and how these levels can be converted to specific operational intervention levels reflecting site and accident specific factors. In addition, the factors entering the optimisation process will be discussed and also how the uncertainty associated with these factors will influence the optimised intervention levels. Finally, the use of intervention levels in the decision-making process after an accident is discussed.

1. INTRODUCTION

In the event of a nuclear accident or radiological emergency, there is a need for criteria for taking particular protective actions with the aim of avoiding or reducing radiation exposures to the population or to workers. Such criteria can be established on the basis of radiological protection principles for intervention situations. The effectiveness of measures to be taken to protect a general public will depend heavily upon the adequacy of emergency plans in which these criteria are specified. There is, therefore, an important role for planning in the establishment of *intervention levels* for different protective measures. It is of utmost importance that pre-established intervention levels form an integral part of an emergency response plan.

2. BASIC PRINCIPLES

2.1. Practices and interventions

In most situations in which there is a need to consider controls over people's exposure to radiation, the source of radiation is deemed to provide a net benefit to society, for which an increased radiation exposure can be justified. This is the case for all normal exposures as a result of industrial processes utilising radiation sources. These situations are defined as *practices* by the ICRP [7].

There are, however, a small number of situations in which the source of radiation exposure does not provide a net benefit. The aim of radiological protection in these circumstances is to reduce the exposure by taking some protective or remedial action. The two most easily identifiable examples of these situations are exposures resulting from the natural occurrence of radionuclides in the environment and exposures resulting from the release of radionuclides following an accident. These situations are defined as *intervention* by the ICRP [7].

Current radiation protection philosophy clearly distinguishes between a *practice*, which causes either actual exposures or probabilities of exposure and therefore will *add* radiation doses to the existing background, and *intervention* situations, in which radiation exposures can be reduced only by intervention in order to put exposed people in a better position. The radiation protection systems for practices and interventions are completely *separate systems*.

2.2. Principles for intervention

In existing exposure situations, i.e. existing at the time when control procedures are being considered, the choice of action is limited. The most effective action, that applied at the source, is rarely available and controls have to be applied in the form of intervention.

The system of radiological protection for intervention is based on the following general principles of *justification* and *optimisation*:

(a) *All possible efforts should be made to prevent deterministic effects.*

(b) *The intervention should be justified, in the sense that introduction of the protective measure should achieve more good than harm.*

(c) *The levels at which the intervention is introduced and at which it is later withdrawn should be optimised, so that the protective measure will produce a maximum net benefit.*

Dose limits used in the radiation protection system for practices do *not* apply in the case of intervention.

The process of justification and optimisation *both* apply to the protective action, so it is necessary to consider them *together* when reaching a decision. *Justification* is the process of deciding that the disadvantages of each component of intervention, i.e. of each protective action or, in the case of accidents, each countermeasure, are more than offset by the reductions in the dose likely to be achieved. *Optimisation* is the process of deciding on the method, scale and duration of the action so as to obtain the *maximum net benefit*. In simple terms, the difference between the disadvantages and the benefits, expressed in the same terms, e.g. monetary terms, should be positive for each countermeasure adopted and should be *maximised* by refining the details of that countermeasure's implementation.

The benefit of a particular countermeasure within a program of intervention should be judged on the basis of the reduction (*dose subtraction*) in dose achieved or expected by that specific countermeasure, expressed as an *avertable dose*.

2.3. Factors entering optimisation

The factors entering the optimisation process can be divided into those describing *benefits* from the countermeasure and those describing *harm*. In analysing the inputs to the decision on the introduction of countermeasures, it is necessary to decide on the relative importance of each factor. The most relevant factors are summarised below.

Benefit	Harm
Avertable individual risk	Individual physical risk
Avertable collective risk	Collective physical risk
Reassurance	Monetary costs
	Social disruption
	Individual disruption
	Countermeasure anxiety
	Worker risk

The weightings to be attached to each of these factors are necessarily subjective and it has been difficult to agree internationally upon their exact values. In any case the importance of some of the factors will vary with the site and nature of the accident, thus making it hard to generalise. Nevertheless, the dominant factors are those related radiological protection principles, and to psychological and political factors.

Socio-political and psychological factors indeed may well contribute to, or even dominate, some decisions. The competent authorities responsible for radiation protection should therefore be prepared to provide the radiation protection input (justification and optimisation of the proposed protective actions on radiological grounds) to the decision making process in a systematic manner, indicating all the radiological factors *already considered* in the analysis of the protection strategy. In the decision process the radiological protection and the political factors should *each* be taken into account *only once* to avoid the same political factors being introduced in several places.

2.4. Generic and specific intervention levels

In the management of accidents, there are two distinct phases in which optimisation of protective measures should be considered. In the phase of planning and preparedness, prior to any actual event, a *generic* optimisation of protective actions should be studied, based on a *generic* accident scenario. This should result, for each protective measure and each selected scenario, in an optimised *generic* intervention level, which is meant to be the first criterion for action to be used immediately and for a short time after the occurrence of an accident.

Some time after a real event, specific information on the nature and likely consequences of the accident would become available. In this case, a more precise and *specific* optimisation analysis can be carried out on the basis of actual data and efficiency of protective measures. This could result in a *specific* intervention level for each protective measure, to be used as a criterion in the medium and long term. However, in many cases the optimisation will be constrained by socio-political factors, which may make it difficult to alter the generic intervention levels unless there are overriding reasons.

3. SELECTION OF INTERNATIONAL GENERIC INTERVENTION LEVELS

3.1. Working Premises

Intervention levels for urgent and longer term protective actions can be based on the justification and optimisation principles and the following premises:

- national authorities will spend the same resources on radiation health risks as on other similar health risks;
- physical risks from the action are taken into account;
- disruption to individuals, such as livelihood or to resources, is considered;
- 'good' and 'harm' of psychological nature are excluded (although unpredictable, these are taken to result in a null net benefit);
- political, cultural, and other social factors (such as disruption) are excluded (because they will be considered separately).

The above relatively simple premises are considered appropriate to assist the selection of internationally applicable generic intervention levels. The premises have been used in Safety Series No. 109 [5] for the development of generic intervention levels. A variety of decision aiding techniques are available to assist in questions of social risk management, including cost-benefit theory, decision theory and social choice theory [9]. Cost-benefit theory was adopted in [5] as an appropriate rationale for assisting in the selection of generic intervention levels. This rationale was first adopted for the purposes of countermeasure decisions by [1]. The problem can be conceptualised in cost-benefit terms whereby the net benefit of a proposed action compared with taking no action can be expressed as:

$$B = \Delta Y - R - X - A_i - A_s + B_c \qquad (1)$$

where the six terms are expressions respectively of the radiological detriment averted by taking the action; the detriment associated with the physical risk of the action itself; the resources and effort need to implement the action; individual anxiety and disruption caused by the action; social disruption; and the reassurance benefit provided by the action. An intervention level (IL) for a countermeasure can be selected if principles (b) and (c) for intervention are satisfied. This can be achieved by conceptualising them as conditions that B must be greater than zero, and that $dB/d(IL) = 0$ respectively, and resolving the above expression accordingly.

3.2. Simplistic analysis

For clarity of expression and understanding a simplistic analysis was performed in the Annex of Safety Series No. 109 [5], expressing the terms in Eq.(1) in a way consistent with the premises described above. The two terms expressed quantitatively were the financial costs (X) and the radiological detriment averted ΔY). For illustrative purposes, the analysis for temporary relocation is considered below. The financial costs of temporary relocation can be expressed as the sum of one-off transport costs (away and return), loss of income per month, rental of substitute accommodation per month and depreciation/maintenance costs per month. The *average* cost per person was evaluated as between about \$400 and \$900 for the first month of relocation, and between about \$200 and \$500 for subsequent months [5].

The radiological detriment averted by temporary relocation was expressed simplistically in [5] as the product of the collective dose averted by the action and an ∀-value representing the resources allocated to averting unit collective dose. Several methods have been developed to assess how much value is placed by individuals and society on avoiding health detriment, including the human capital approach, legal compensation approaches, insurance premium analogies, implied or revealed preference approaches and willingness to pay approaches. There are flaws in all of these methods. Nevertheless it is possible to arrive at a credible range of values for α. The method used in [5] is based on the human capital approach used in [4] modified to take account of the 1990 Recommendations of the ICRP [7]. The average loss of life expectancy associated with 1 manSv of collective dose is estimated as 1 year. On a purely economic basis, a minimum value to be associated with a statistical year of life lost is the annual GDP per head. This was used in [5] to estimate a value for α of $20,000 per manSv saved. A factor of two uncertainty in the risk per unit dose was explicitly used in considering a range in the α-value from $10,000 to $40,000 per manSv. (NB All monetary costs are expressed for a highly developed country. The argument is not significantly different for less developed countries.)

On this basis the temporary relocation of people will be justified for more than one month if the avertable dose in that month exceeds IL_{rel}:

$$\frac{\$400 \text{ to } \$900 \text{ in first month}}{\$10{,}000 \text{ to } \$40{,}000 \text{ per manSv}} \approx \text{ten to several tens of mSv in the first month} \quad (2)$$

The optimum return time is when the avertable dose in a following month falls below IL_{rel}:

$$\frac{\$200 \text{ to } \$500 \text{ in the month}}{\$10{,}000 \text{ to } \$40{,}000 \text{ per manSv}} \approx \text{a few to a few tens of mSv in the month} \quad (3)$$

3.3. Sensitivity analysis

In support of the guidance in Safety Series No. 109 [5] more extensive sensitivity analyses were performed to consider explicitly the influence of the other relevant terms in Eq. (1). Moreover, several objections are raised and consequently modifications are often made to the basic value of α. Firstly, it takes no account of pain, grief and suffering associated with a premature death. Secondly, because people show an aversion to higher levels of individual risk, and because society is normally willing to allocate relatively more resources to protect people at higher risks, a modification is often used whereby α is increased according to the level of risk. Thirdly, an argument is made that because there is an inherent social time preference to speed up the receipt of desirable outcomes and postpone undesirable ones, a reduction factor should be applied to account for the delay between exposure and the occurrence of the effect. These three factors, which in some way counteract each other, could be assessed by willingness to pay methods. An example is given below of the influence the second two factors have on the range of intervention levels for temporary relocation.

Several national authorities provide guidance on the use of multipliers (so-called ∃-term) to apply to a baseline α-value to account for the level of individual dose received. [3] presents several schemes for such ∃-terms. One formulation can be expressed as:

$\beta = \beta_0 E^{\nu}$ where β_0 and ν are parameters (4)

Moreover a discount factor, F_d to account for the time delay between the dose received and the time of appearance of a cancer can be applied, of the form $(1+r)^{-T}$ where r is a discount rate (typically between 0 and 10% per annum) and T is the time delay. The detriment saved by invoking a countermeasure can be expressed then as :

$$\Delta Y = \alpha_o \beta_o F_D \left(E_{tot}^{v+l} - E_{res}^{v+l}\right) \qquad (5)$$

where E_{res} and E_{tot} are the total doses received with and without the countermeasure. Temporary relocation, for example, can be suspended when :

$$\frac{\mathrm{d}\Delta Y}{\mathrm{d}t} = -C_{rel} = -\alpha_o \beta_o F_D (v+l) E_{res}^{v} \dot{E} \qquad (6)$$

where C_{rel} is the cost per person per month of continuing relocation. This can be solved depending on the relationship between the residual dose, E_{res} and the optimum dose rate for return, $\dot{E}$. Various functional forms and source term characteristics were considered in support of Safety Series No. 109 [5]. Considering as an example a release of a single nuclide with an effective removal rate constant, 8, the optimum dose rate for return can be evaluated as:

$$IL_{ret} = \left(\frac{C_{rel} l^{v}}{a_o b_o F_D (v+l)}\right)^{\frac{l}{v+l}} \qquad (7)$$

A parameter uncertainty analysis was carried out to evaluate the likely range of values within which a generic intervention level might reasonably lie, and to identify which

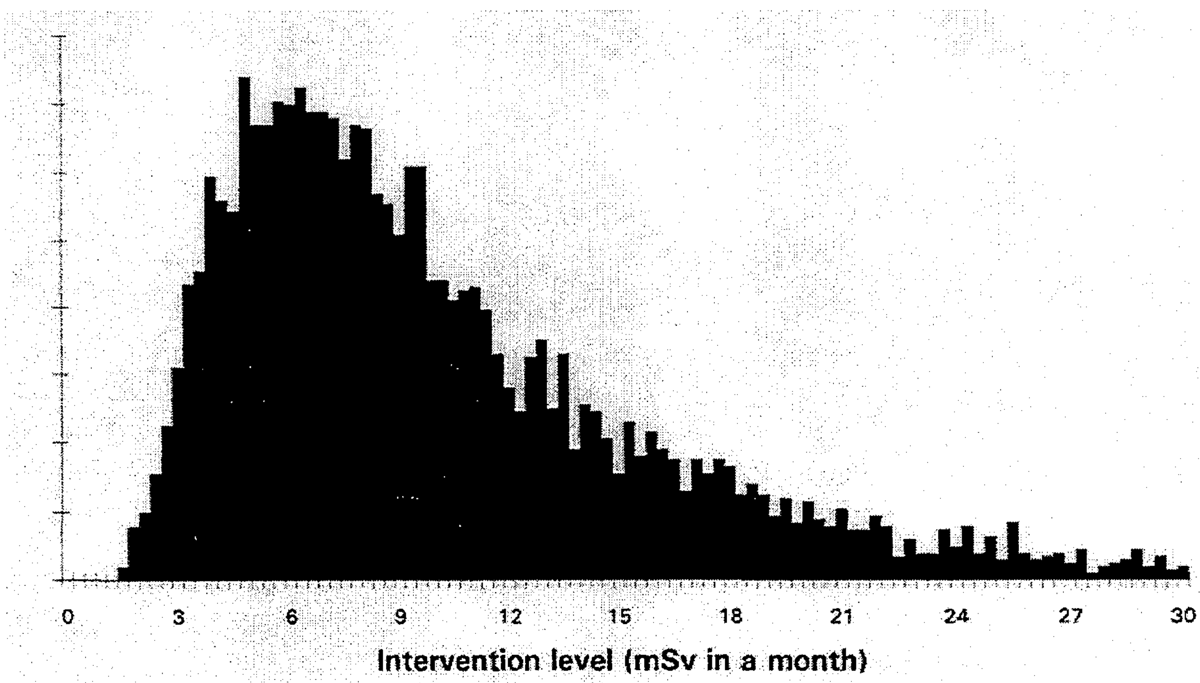

FIG. 1. Subjective expression of uncertainty in the generically optimised intervention level for return to an area from which people have been relocated. The probability distribution has been calculated using the program CRYSTAL BALL [CB93] from subjective expressions of uncertainty in the input parameters for Eq. (7).

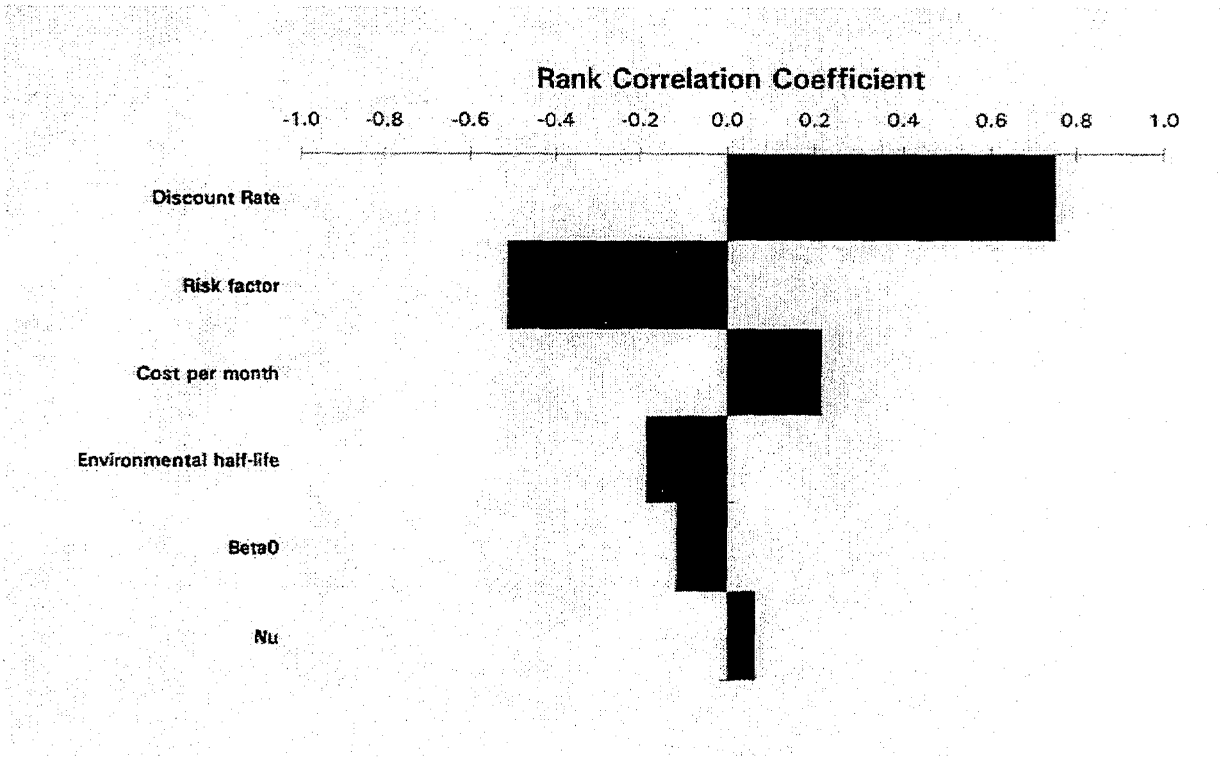

FIG. 2. The rank correlation coefficients between the uncertainty in the generically optimised intervention level and the uncertainty in the input parameters. The graph indicates that the uncertainty in the discount rate and the radiation risk factor are dominant.

parameter uncertainties influence most strongly the selection of a generic value. The results are illustrated in Figs. 1 and 2, and indicate that the range of values derived from the simplistic approach are not drastically different from those obtained by a more sophisticated approach. This analysis and others underpinned the final selection of the values that appear in Safety Series No. 109 [5], which also took into account qualitative factors.

3.4. Temporary and permanent relocation

Permanent relocation of a population can also be used as a protective measure where this action can be justified and optimised in accordance with the principles for intervention. Because the penalties associated with this action are of a one-off nature, the intervention level for permanent relocation is expressed in terms of total dose averted rather than avertable doses per month of temporary relocation. In addition to this criterion for permanent relocation based on avertable dose, there is a limit to the period of any temporary relocation that can normally be tolerated. The maximum length of this period is dependent on many social and economic factors. An argument based on economic grounds shows that continuing temporary relocation costs will begin to exceed permanent relocation costs between about one and five years. However social factors would indicate that the period of temporary relocation should be no more than a year or so.

The final guidance of the International Basic Radiation Safety Standards [6] is as follows:

The generic optimised intervention levels for initiating and terminating temporary relocation are 30 mSv in a month and 10 mSv in a month, respectively. If the dose accumulated in a month is not expected to fall below this level within a year or two, permanent resettlement with no expectation of return to homes should be considered. Permanent resettlement should also be considered if the lifetime dose is projected to exceed 1 Sv.

4. PRACTICAL USE OF INTERVENTION AND ACTION LEVELS

Intervention Level and Action Level are terms used for levels at which action is taken. The meaning of these terms have been differentiated in [6].

- Intervention Level is the level of avertable dose at which specific protective or remedial action is taken in a chronic or emergency exposure situation.
- Action Level is the level of dose, dose rate or activity concentration above which unspecified remedial or protective actions should be carried out in chronic or emergency exposure situations.

In other words, *Intervention Levels* refer to avertable doses by specific protective measures like relocation whereas *Action Levels* refer to several (unspecified) measures like agricultural countermeasures or radon reducing measures in houses [6].

Because of the inherent difficulty of forecasting doses that could be averted, there is a merit in establishing surrogate quantities that can be more readily addressed from conditions pertaining when decisions need to be made. For urgent decisions early on in the course of an accident, these conditions will primarily relate to conditions in the plant. Later on, operational quantities that can easily be measured will be of use, including air concentration, surface contamination density and dose rates. The relationship between these quantities and the avertable dose will vary considerably with the circumstances of the accident and nature of contamination. The operational quantities would, therefore, be both accident and site specific but would still be inextricably linked to the avertable dose.

OPERATIONAL INTERVENTION LEVELS

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*:

$$\Delta E_{c,r,p} = E_{r,p} - E_{c,r,p} \qquad (8)$$

where $E_{r,p}$ is the dose without any countermeasure and $E_{c,r,p}$ is the dose after implementing the countermeasure, *c*. 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*:

$$\Delta E_{c,r} = \sum_p \Delta E_{c,r,p} \qquad (9)$$

If the radionuclide specific intervention level of avertable dose for the countermeasure, *c*, is IL_c, then the operational quantity, *q*, is the operational intervention level, $OIL_{c,r,q}$, for countermeasure, *c*, and radionuclide, *r*:

$$\Delta E_{c,r}(q = Q_r) = IL_c \Rightarrow OIL_{c,r,q} = Q_r \qquad (10)$$

The intervention level in terms of avertable dose would determine the operational intervention level as follows:

$$OIL_{c,r,q} = \frac{IL_c}{\sum_p \Delta E_{c,r,p}(q=1)} \quad (11)$$

It should be recognised that in the calculation of $\Delta E_{c,r,p}(q = 1)$, site specific parameters like location factors, filtration factors and indoor/outdoor occupancy have to be used.

RELOCATION

The avertable individual effective dose, ΔE, from relocation in a time period,)*t*, would be the sum of the external effective (-dose and the committed effective inhalation dose from resuspended radioactive material on the ground. The avertable individual doses in a month following the measurements of outdoor dose rate would - for ß-/γ-emitting radionuclides with a half-life of *months to years* like ^{103}Ru, ^{134}Cs and ^{137}Cs - be of the order of:

$$\sum_p \Delta E_{r,p}(q=1) \approx 200 \frac{\text{mSv month}^{-1}}{\text{mSv h}^{-1}}$$

The generic optimised intervention level for relocation, IL_{rel}, has been selected to be 30 for the first month and 10 mSv•month^{-1} in subsequent months [8, 5]. The operational intervention level for a continuing relocation after the first month, OIL_{rel}, for long-lived radionuclides can then be calculated as:

$$OIL_{rel} = \frac{IL_{rel}}{\sum_p \Delta E_{c,r,p}(q=1)} = \frac{10 \text{ mSv month}^{-1}}{200 \text{ mSv month}^{-1} / \text{mSv h}^{-1}} = \underline{50 \text{ :Sv h}^{-1}}$$

In areas that have been contaminated with long-lived radionuclides, there would be an increasing residual dose after return to the area from a temporary relocation with increasing effective half-life of the deposited radionuclides. If the effective removal half-life were greater than about 6 years, the residual lifetime dose corresponding to a return criterion of 10 mSv/month would be greater than 1 Sv.

DECONTAMINATION

Decontamination of urban areas serves three main purposes: (1) reduce the individual doses to people living in the area, (2) accelerate the return time for people who have been relocated temporarily, and (3) avoid permanent resettlement. The optimum intervention criteria for clean-up operations would depend on many factors all of which are not easily quantifiable. The most important factors are the avertable individual doses to the population,)E_{pop}; the efficiency (fraction of activity removed or dose rate reduction factor) of the decontamination, *f*; the individual doses to the workers engaged in the clean-up, E_{work}; and the monetary costs of the cleaning operation, C_{clean}. The clean-up costs would include costs of labour, use of equipment, replacement of building materials, waste disposal etc.

Two different situations are considered here. Firstly, a residential area accidentally contaminated in which people can continue to live without any restrictions, and, secondly, a residential area accidentally contaminated from which people have been relocated temporarily.

NON-RELOCATED AREAS

Clean-up in non-relocated areas is justified if the monetary value of the avertable individual doses, ΔE_{pop}, by the clean-up exceeds the sum of the monetary value of the collective dose to the clean-up workers and the cost of the clean-up operation:

$$\alpha\ \Delta E_{pop}\ N_{pop}\ \geq \alpha\ E_{work} N_{work} + C_{clean} N_{pop} \qquad (12)$$

Assuming that the clean-up operation is implemented during a time period that is much less than the effective environmental removal half-life, $T_{1/2}$ (corresponding to an effective environmental removal rate constant of the contaminant 8), and that the time-averaged location factor for occupancy and shielding is L, the total avertable individual doses from the deposited activity can be expressed as:

$$\Delta E_{pop} = \frac{\dot{E}\, L\, f}{\lambda} \qquad (13)$$

Decontamination is thus justified if the outdoor dose rate, $\dot{E}$, at the time of decision of decontamination is greater than the Operational Intervention Level for clean-up, OIL_{clean}:

$$OIL_{clean} = \dot{E} = \frac{\lambda}{L f}\left(\frac{N_{work}}{N_{pop}} E_{work} + \frac{C_{clean}}{\alpha}\right) \approx \frac{\lambda\, C_{clean}}{L f \alpha} \qquad (14)$$

The approximation can be made because the clean-up cost component, $C_{clean}N_{pop}$, normally is much greater than the equivalent cost of collective dose to the clean-up workers, $\forall_{work}N_{work}$.

AREAS FROM WHICH PEOPLE HAVE BEEN RELOCATED

Clean-up of areas from which people have been relocated is justified if the saved relocation costs by an accelerated return is larger than the sum of the monetary value of the collective dose to the clean-up workers and the cost of the clean-up operation:

$$C_{rel} N_{pop} \Delta\tau \geq \alpha\, E_{work} N_{work} + C_{clean} N_{pop} \qquad (15)$$

where C_{rel} is the relocation cost per person and unit time. The condition for clean-up is further constrained by an acceptable temporary relocation time, which without clean-up should be less than T_{max}. This maximum temporary relocation time would not be exceeded if the dose rate at the time of decision can comply with:

$$\dot{E} < OIL_{rel}\, e^{\lambda T_{max}} \qquad (16)$$

where 8 is the effective removal rate constant. If the dose rate exceeds this value, people should be permanently relocated. The accelerated return time,)t, is related to the effective environmental half-life of the deposited activity, $T_{1/2}$, as)t = -ln(f)•$T_{1/2}$/ln(2). The clean-up operation is justified, for a given efficiency, f, when the effective environmental half-life, $T_{1/2}$, exceeds:

$$\mathrm{OIL}_{clean} = \mathrm{T}_{1/2} = -\frac{\ln(2)}{\ln(f)}\left(\frac{\alpha}{\mathrm{C}_{rel}}\frac{\mathrm{N}_{work}}{\mathrm{N}_{pop}}\mathrm{E}_{work} + \frac{\mathrm{C}_{clean}}{\mathrm{C}_{rel}}\right) \approx -\frac{\ln(2)}{\ln(f)}\frac{\mathrm{C}_{clean}}{\mathrm{C}_{rel}} \qquad (17)$$

EXAMPLES

The parameters are assumed to have the following values:

N_{pop} = 10,000 people $\quad$ V = \$ 20,000 per sievert

N_{work} = 100 workers $\quad$ L = 0.3

E_{work} = 20 mSv per worker $\quad$ f = 0.5

c_{clean} = \$ 200 per person $\quad$ c_{rel} = \$ 200 per person per month

which can be used to calculate OILs for clean-up.

NON-RELOCATED AREAS

The Operational Intervention Level for clean-up of non-relocated areas contaminated with ^{137}Cs for which the effective removal half-life is assumed to be about 10 years can be expressed in terms of an external outdoor (-dose rate from Eq. (17):

$$OIL_{clean} = \frac{0.693}{10 \cdot 365 \cdot 24 \cdot 0.3 \cdot 0.5}\left(\frac{100}{10{,}000}0.02 + \frac{200}{20{,}000}\right) = \underline{0.5\ \text{:Sv h}^{-1}}$$

This dose rate is equivalent to a surface contamination density with ^{137}Cs of 0.4 MBq/m^2 (10 Ci/km^2).

AREAS FROM WHICH PEOPLE HAVE BEEN RELOCATED

The Operational Intervention Level for clean-up of areas from which people have been relocated can be expressed in terms of effective removal half-life of the deposited activity from Eq. (14):

$$\text{OIL}_{\text{clean}} = -\frac{\ln(2)}{\ln(f)}\left(\frac{20{,}000}{200}\frac{100}{10{,}000}0.02 + \frac{200}{200}\right) = \underline{1\ \text{month}}$$

Clean-up of areas from which people have been relocated would thus be justified if the effective half-life of the deposited activity is greater than 1 month, *and* if the foreseen relocation time is less than the maximum acceptable relocation time, T_{max}. In those situations, the outdoor dose rate would be larger than the OIL_{rel} for relocation, but lower than a value which — during the time period T_{max} — would decrease due to decay and migration to a value lower than OIL_{rel}. When the effective half-life in the environment would be larger than about six years, permanent resettlement would become necessary if the dose rate at the time, T_{max}, would be equal to OIL_{rel}, because the residual lifetime dose then would exceed 1 Sv. If the clean-up could reduce the surface contamination density so the residual lifetime dose would become less than 1 Sv, permanent resettlement could be avoided.

5. CONCLUSIONS

Over the past decade considerable progress has been made in developing and clarifying internationally recognised principles for decisions on protective measures following nuclear or radiological emergencies, and in providing quantitative guidance for applying these principles. However, experience has shown that, in spite of these efforts, there remain discrepancies in the application of both principles and guidance.

An accident resulting in the dispersion of radioactive material to the environment requires measures to protect the general public against the exposure to ionising radiation from the released and dispersed activity. The effective implementation of these measures will be largely dependent upon the adequacy of emergency response plans. Such plans should specify intervention levels for the various protective actions, and detailed considerations of site specific and accident specific conditions should be taken into account at the planning stage when specifying these levels based on the justification/optimisation principles.

In theory, the optimum intervention level for each kind of countermeasure could take a range of numerical values, depending on the exact circumstances following the accident and on social, political and cultural factors that national authorities might need to consider. However, to avoid confusion, there are obvious advantages to have a single internationally accepted value for the appropriate level of protection instead of a range of values as have been recommended earlier by international organizations.

Generically optimised intervention levels based alone on the premises presented in this paper might be used with equal benefit both in developing countries and in more developed countries, even if there are large differences in the absolute cost levels for specific countermeasures between such countries. The reason for this is that the outcome of an optimisation normally is a cost ratio, which is much less sensitive to geographical location than the absolute cost values alone all of which are similarly related to the GDP of the country.

Measurable quantities can be applied as surrogates for intervention levels using models that link avertable doses with these quantities. Modelling of the various processes describing the exposure of man to environmental contaminants would include parameters such as type of radionuclides, environmental half-lives, transfer functions as well as location and filtering factors for housing conditions. The models may be of varying complexity but both models and parameter values used to determine avertable doses should be realistic and particular to the circumstances under consideration. Incorporation of pessimism should be avoided by using central values from the parameter ranges. The measurable quantities normally used as so-called operational intervention levels include dose rate and activity concentration in air, in foodstuffs and on ground surfaces. The operational intervention levels will be both accident and site specific as they are derived from dose models that include accident and site specific parameters. Operational quantities should therefore be used carefully.

In conclusion, generic optimised intervention levels and their derived operational quantities based on the principles given in this paper are judged to provide protection that would be justified and reasonably optimised for a wide range of accident situations although they can only be used as guidelines. Any specific optimisation would lead to intervention levels that might be either higher or lower than those emerging from a generic optimisation.

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