Basic Principles for Intervention after a Nuclear or Radiological Emergency

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Abstract. The current status of internationally agreed principles for intervention after a nuclear accident or radiological emergency and the international development of intervention guidance since the Chernobyl accident are reviewed. The experience gained after the Chernobyl accident indicates that the international advice on intervention existing at the time of the Chernobyl accident was not fully understood by decision makers neither in Western Europe nor in the former USSR and that the guidance failed to address adequately the difficult social problems which can arise after a serious nuclear accident. The radiation protection philosophy of today distinguishes between practices and interventions. The radiological protection system of intervention includes justification of the protective action and optimization of the level of protection achieved by that action. Dose limits do not apply in intervention situations. The inputs to justification and optimization studies include factors that are related to radiological protection, whereas the final decisions on introduction of countermeasures would also depend on other factors. The basic principles for intervention as recommended by international organisations are discussed in detail and the application of the principles on a generic basis is illustrated for long-term protective actions. The concepts of intervention level, operational intervention level and action level are presented and the relation between these quantities is illustrated. The numerical guidance on intervention in a nuclear accident or radiological emergency or a chronic exposure situation given by ICRP, IAEA and in the Basic Safety Standards is presented.

1 Practices and interventions

The latest recommendations from the International Commission on Radiological Protection [1] outline the systems of protection for *practices* and *interventions*. Human activities that *add* radiation exposure to that which people normally incur due to background radiation, or that increase the likelihood of their incurring exposure, are termed *practices*. The human activities that seek to reduce the existing exposure, or the existing likelihood of incurring exposure which is not part of a controlled practice, are termed *interventions*. The concepts of *dose addition* in a practice and *dose reduction* in an intervention are shown in Fig. 1.

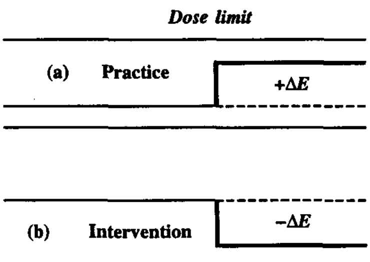

Fig. 1. Exposure situations for practices (a) and interventions (b). In a practice the dose increments $+\Delta E$ are controlled within the dose limit. In an intervention situation the dose decrement $-\Delta E$ or avertable dose is the result of the protective action.

For practices where the occurrence of the exposure is foreseen, the recommendations include the control of the source and limitation of exposure. Such situations include medical exposure, occupational exposure and exposure of the general public, and the system of protection includes the justification of the practice, optimisation of protection and imposition of overall dose limits.

In some situations the sources, the pathways and the exposed individuals are already in place when the decisions about control measures are being considered, and protection can therefore only be achieved by interventions, which always have some disadvantages. The system of protection for interventions include the justification of the intervention and the optimisation of the form, scale and duration of the intervention so as to maximize the net benefit.

The dose limits recommended by the Commission are intended for use in the control of practices. The use of these dose limits, or of any other pre-determined dose limits, as the basis for deciding on intervention might involve measures that would be out of all proportion to the benefit obtained and would then conflict with the principle of justification. The two different protection systems for practices and interventions are shown in Fig. 2.

Practice	Intervention
Each practice should be justified	Each protective measure should be justified
The doses *adding up* in a practice should be kept as low as reasonably achievable	The level of protective measures resulting in *dose subtraction* should be optimized
The *sum* of doses in a practice should be kept below specified dose limits	

Fig. 2. Systems of radiation protection for practices and interventions. The major differences between the two systems are that dose limits do not apply in the system of interventions and that different dose quantities apply.

2 Basic principles for intervention

An intervention should be *justified* in the sense that the introduction of protective measures should achieve *more good than harm*, and the level at which an intervention is introduced, and the level at which it is later withdrawn, should be *optimized* so that it will produce the maximum net benefit, i.e. *do the most good.*

A. JUSTIFICATION AND OPTIMIZATION OF PROTECTIVE ACTIONS

The avertable dose by the protective action, ΔE, can be found as the difference between the dose *without* any actions, and the dose *after implementation* of a protective action. The process of justification and optimization *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 (avertable dose) likely to be achieved.

Optimization 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 setting the details of that countermeasure.

Each of the factors describing the net benefit achieved by the protective measure have to be expressed in the same units. These units can be dimensionless quantities as used in multiattribute analysis, or values could be expressed in equivalent years of lost life. Normally in cost-benefit methods values are expressed in monetary units. However, it is the relative values placed on the components and their weighting one to another that is important, rather than the absolute unit. The use of a particular currency is relatively unimportant, as all terms could be evaluated as fractions of a country's gross national product (GNP) per head to allow for differences per head between countries.

If a protective measure were introduced at time t_1 and lifted at time t_2, the avertable dose, ΔE would be equal to the time-integral of the dose per unit time, $\dot{E}(t)$, over this time interval, τ.

The avertable effective dose, ΔE, and the effective dose per unit time, $\dot{E}$, are shown in Fig. 3.

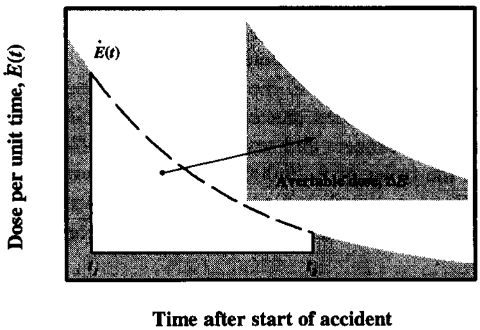

Fig. 3. Avertable dose, ΔE, when the protective measure is introduced at time t_1 and lifted again at time t_2.

B. INTERVENTION LEVELS

Intervention levels refer to the dose that is expected to be averted (avertable dose) by a *specific countermeasure* over the period it is in action. If an intervention level is exceeded, *ie*, if the expected avertable individual dose is greater than the intervention level, then it is indicated that the specific protective action is likely to be appropriate for that situation. Intervention levels (ILs) are specific to accident situations. The intervention level is defined as [5]:

> *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

Recommended intervention levels from the IAEA and ICRP for the major protective actions in a nuclear emergency are shown in Table 1 [2,3,5]. These recommendations are based on generic optimization as shown below.

Table 1. Summary of Recommended intervention levels from ICRP Publication 63 and IAEA Safety Series No. 109.

Protective measure	IAEA generically optimized intervention levels	ICRP range of optimized values
Sheltering (less than 1 day)	10 mSv	5 - 50 mSv
Administration of stable iodine	100 mGy to thyroid	50 - 500 mSv to thyroid
Evacuation (less than 1 week)	50 mSv	50 - 500 mSv
Temporary relocation	initiate at 30 mSv in a month and suspend at 10 mSv in a month	almost always justified at a dose level of 1 Sv 5 - 15 mSv/month as an optimized range
Permanent resettlement	if lifetime dose would exceed 1 Sv	

The optimized intervention level could either be expressed as an *individual dose, $\dot{E}$,* averted per unit time or as a *collective dose, S,* averted per unit mass of a given foodstuff, both given at the end of the interval, τ, for which the countermeasure, introduced at time t_1, would have to be in action [2,3,4]:

$$\dot{E}(t_1+\tau) = \frac{c}{\alpha} \quad \text{or} \quad S(t_1+\tau) = \frac{b}{\alpha}$$

The costs parameters in the above expressions, c (cost per unit time of implementing a given countermeasure), b (cost per unit mass of restricting a given foodstuff) and α (monetary value of a unit dose averted) are likely to be similarly correlated to national wealth and thus susceptible to a relatively large variation between countries. However, their ratios would in general be much less sensitive to geographical location than either of the cost parameters alone.

The monetary value of a unit dose, α, would be related to the risk per unit dose, R, and the statistical loss of life expectancy, ΔL, per radiation induced cancer as $\alpha = R\ \Delta L\ GNP$, with some allowance for loss of quality of life for non-fatal cancers and severe hereditary effects. For rich developed countries the value of GNP is of the order of \$ 25,000 year^{-1} which would give a reference value of α of \$ 25,000 per sievert. For less developed countries α-values would be correspondingly lower. Generically optimized intervention levels would, however, be more or less country independent.

C. OPERATIONAL INTERVENTION LEVELS

Because of the inherent difficulty of forecasting doses that could be averted, there is a merit in establishing surrogate quantities such as *dose rate in air*, *surface contamination density* and *activity concentration in air*. 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.

The term "*operational intervention level (OIL)*" is reserved for quantities that can be more easily assessed at the time of decision on intervention such as dose rate, activity concentration, surface contamination density, etc. OILs are related to the dose that could be averted by a *specific protective action* like evacuation, relocation and banning of foodstuffs.

In general terms, the avertable dose, ΔE, from *all exposure pathways* by implementing a given countermeasure can be expressed by a measurable quantity, q. The operational intervention level can be determined from the intervention level (IL) as follows:

$$OIL = \frac{IL}{\sum_{pathways} \Delta E(q=1)}$$

It should be recognised that in the calculation of $\Sigma\Delta E(q=1)$, summed over all pathways, p, site specific parameters like location/filtration factors and indoor/outdoor occupancy have to be used. For long-lived γ-emitting radionuclides like $^{137}Cs/^{134}Cs$ the value of $\Sigma\Delta E(q=1)$ would be approximately 200 mSv·month^{-1}/mSv·h^{-1} for a time-averaged location factor of 0.3, q being the outdoor dose rate. The OIL_{rel} for relocation corresponding to an IL of 10 mSv·month^{-1} can thus be calculated from the above formula to be about 50 µSv·h^{-1}. When the outdoor dose rate from long-lived γ-emitting radionuclides therefore exceeds 50 µSv·h^{-1}, it is indicated that temporary relocation might be needed.

D. ACTION LEVELS

Action levels refer to different protective measures or strategies of actions like agricultural countermeasures or radon reducing measures in houses and they relate to the residual dose without remedial actions. The action level is defined as [5]:

> *Action level* is the level of *dose rate* or *activity concentration* above which *remedial actions* or *protective actions* should be carried out in *chronic* or *emergency exposure* situations

Action levels are levels above which remedial actions are taken and below which they are not. An action level is set such that the dose averted by taking the remedial action is always worthwhile in terms of the costs and other disadvantages involved. Justified action levels would begin at the minimum value of the avertable individual dose at which the remedial action is just beginning to do more good than harm.

The action level can thus be defined as the lowest level at which remedial actions to reduce doses are justified and optimized. The equivalent definition would be that the action level is equal to the maximum acceptable level of dose attributable to the contamination without any protective actions taken. If an action level is exceeded, it is indicated that some form of remedial action specific to the situation considered is likely to be appropriate. Action levels have, therefore, the same character as operational intervention levels. The concept of an action level is illustrated in Fig. 4.

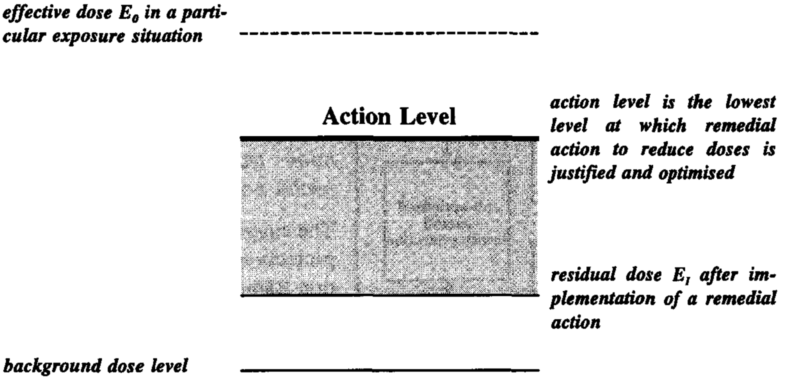

Fig. 4. The action level (AL) is the maximum acceptable residual dose without a remedial action which is equivalent to the minimum avertable dose by that action. The avertable dose in the figure is given as $\Delta E = E_0 - E_r$.

Action levels would also be used for the reduction of radon in dwellings. Recommended action levels from ICRP for radon in dwellings are shown in Table 2 [6]. The action level for remedial actions relating to chronic exposure situations involving radon in workplaces is a yearly average concentration of ^{222}Rn of 1,000 $Bq \cdot m^{-3}$ in air.

Table 2. Action levels for radon in dwellings.

Annual dose (mSv)	3 - 10
Concentration ($Bq \cdot m^{-3}$)	200 - 600

Table 3. Action levels for chronic exposure of single organs ($Gy\ y^{-1}$).

Bone marrow	0.4
Lens of the eye	0.1
Gonads	0.2

Different tissues have a wide range of sensitivity for radiation induced deterministic effects. Threshold dose rates for deterministic effects under conditions of prolonged exposure over many years have been used in the Basic Safety Standards (BSS) [5] as action levels for chronic exposure. The values for permanent sterility, for clinically significant depression of the blood-forming process and for opacities sufficient to cause impairment of vision are shown as action levels in Table 3 [1,5].

3 Unresolved issues

Following a nuclear or radiological emergency, especially in the later phases, many complex human, social and economic considerations will have to be taken into account by the responsible authorities. The decisions and protective actions taken may themselves induce social and psychological impacts. Internationally, the application of different intervention levels in similar circumstances resulting from a single accident would cause much confusion in the public mind. At the national level, taking decisions about lines of demarcation between those areas where protective measures are applied and those where they are not, might create anxiety or even fear by people living on the 'safe' side of the demarcation line.

From the experience in CIS following the Chernobyl accident, countermeasures to mitigate social-psychological impacts have obviously been needed and they have been identified to be a new category of action. It has even been argued that radiation protection philosophy has not yet been developed to fully include these countermeasures, as being reflected in Fig. 5, but that the two 'lines' of optimization should be merged into one system of 'radiation protection'.

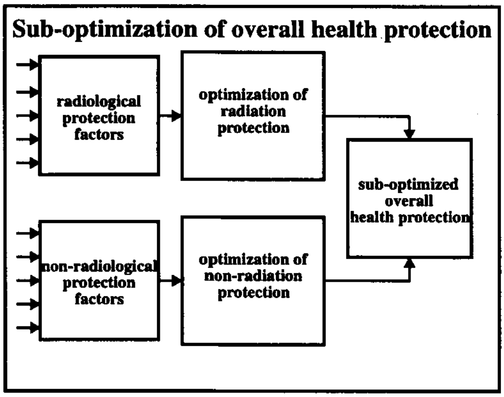

Figure 5. Sub-optimization of overall health protection where radiological protection and non-radiological protection factors each are used for separate optimizations leading to a sub-optimized overall health protection.

The suggestion to include non-radiological protection factors in the radiation protection framework seems awkward. Radiation protection factors are related to the level of protection achieved including those factors describing the dose distribution averted and costs and other disadvantages incurred in averting doses. The level of socio-psychological impact would depend not only on the presence of radiation but to a large extent on other non-radiological protection factors, such as the attitude of the mass media, the political climate and the general level of information in the population. Non-radiological protection factors would also be different from country to country, and would probably be highly dependent on the existing political situation. To include socio-psychological factors in the radiation protection framework would thus give very random levels of 'radiation protection'.

Therefore, to achieve an optimized overall health protection, non-radiological protection factors should enter the optimization process in parallel with radiological protection factors to form an optimized countermeasure strategy as shown in Fig. 6.

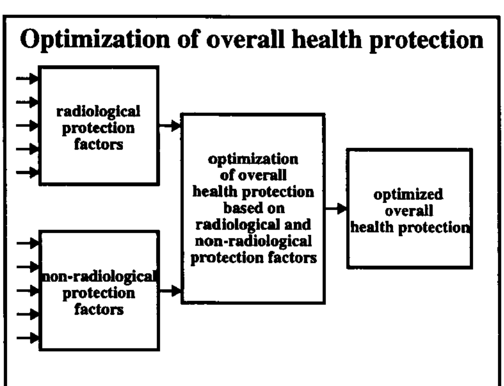

Figure 6. Optimization of overall health protection where radiological and non-radiological protection factors are included simultaneously in the optimization process.

Optimization of overall health protection would thus be the responsibility of the decision maker with guidance from radiation protection experts as well as experts in the fields of social and psychological sciences. Optimization of overall health protection is therefore a discipline for decision makers and not an extension of the radiation protection philosophy. It is also of great importance that decision makers present the optimized protection strategy to the public in a transparent way so that all the factors and their relative importance in reaching the optimized strategy are revealed.

4 Summary

The distinction between practices and interventions has created some confusion. The fact that dose levels for introduction of protective measures have been interpreted as doses *received* and not as doses *averted* is, however, awkward and prone to suggest to people that the levels are dose limits. The experience after the Chernobyl accident was that many actions taken led to an unnecessarily large expenditure of national resources, and many instances occurred of contradictory national responses. Therefore, there was a strong need for a simple set of internationally consistent intervention levels and action levels and for clear guidance on application of the principles in planning and preparedness for response to nuclear accidents or radiological emergencies.

Intervention levels have therefore been established by ICRP and IAEA for both short-term and longer-term countermeasures. These intervention levels are expressed in terms of dose *averted* by the specific action. Since the dose that will be averted cannot easily be estimated in the period immediately after the accident, derived quantities of *operational intervention levels* (*OILs*) or *action levels* (*ALs*) can be established (dose rate or activity concentration, for example). The appropriate protective action will be invoked if these levels are exceeded, but the action will normally not be taken if they are not.

There are still unresolved issues for different intervention situations, especially for long-term exposure situations; these issues would involve both optimization of radiation protection and optimization of overall health protection:

- So far, no international agreed numerical guidance have been established on action levels for protection of populations against different chronic or semi-chronic exposure situations from natural and artificial radionuclides in the environment (except for radon in dwellings).
- Clean-up levels for residues from previous events or past practices, *eg*, uranium mining and milling, might - due to their origin from intervention optimization - result in a lower level of protection than for still operating practices of a similar type because of the dose constraints for practices. It would be peculiar to operate with different levels of protection in two similar situations and, obviously, optimized action levels for such intervention situations might have to be constrained to an equal protection level as in the similar practice.
- Interaction between radiological and non-radiological factors in decision making has been identified to be an important issue. Both radiological and non-radiological factors will influence the level of protective actions being introduced. From the experience in CIS following the Chernobyl accident, the need for social-psychological countermeasures is obvious. However, the quantification of non-radiological protection factors needs further development.
- It has been suggested that the inclusion of socio-psychological factors into the intervention decision making framework should be as a part of the radiation protection framework. This suggestion seems awkward as the level of socio-psychological impact would depend not only on the presence of radiation but to a large extent on other non-radiological protection factors, such as the attitude of the mass media, the political climate and the general level of information in the population. Inclusion of socio-psychological factors in the radiation protection framework would therefore give very random levels of 'radiation protection'.
- Non-radiological protection factors such as public anxiety and risk perception will play a legitimate role in the decision making. These factors should be addressed by the decision maker and *not* by the radiation protection community. The optimization of overall health protection is thus the responsibility of the decision maker. It is of great importance that the decision maker present the protection strategy to the public in a transparent way so that all factors and their relative importance in reaching an optimized strategy are revealed.

There are at least two areas where the radiation protection community should clarify its recommendations in the years to come. Firstly, convincing guidance needs to be prepared for the 'grey area' of similar intervention/practice situations for which the optimized level of radiation protection of populations might be different. Secondly, only radiological protection factors should be included in generically optimized intervention levels. The socio-psychological and political factors should be included by *the decision maker* in the optimization of overall health protection based on inputs from radiation protection experts and from experts in the fields of social and psychological sciences.

5 References

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