Radiation protection and decision-making on cleanup of contaminated urban environments

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Abstract. The system of radiological protection for interventions should be applied to determine an optimised cleanup strategy for environments contaminated from nuclear or radiological accidents. The *decision-aiding process* of justification and optimisation of radiological protection achieved by cleanup of contaminated environments is presented. In addition, a methodology is presented for deriving generically optimised reference levels for cleanup of urban and semi-urban environments, based on dose reduction and monetary costs of the cleanup measures. These generic reference levels are compared to international recommended reference levels for protection of the public against prolonged exposure and international recommended reference levels for remediation of areas contaminated by past activities and accidents.

The necessary inputs to the optimisation of an *overall health protection*, of which radiological protection only forms one part, are briefly discussed. The experience in the former Soviet Union after the Chernobyl accident was that social and psychological factors formed an important input to decisions on the introduction of countermeasures in contaminated territories. To achieve an *optimised* overall health protection of the affected population, it might be necessary, therefore, to include measures to reduce e.g. anxiety and to gain reassurance of the affected population, in addition to measures for reducing the radiation detriment. This *decision-making process* would be much wider than the decision-aiding process of justification and optimisation of radiological protection alone. The process of decision-making will therefore require inputs from experts in radiation protection as well as from experts in social sciences and probably from the affected population, the so-called *interested parties* or *stakeholders*.

The role of radiological protection experts, experts in social sciences and stakeholders in the decision-making process is discussed. It is concluded that the radiological protection framework should neither include stakeholder involvement nor socio-political and psychological factors. Otherwise, the radiation protection community would enter the field of decision-making. This would be conceptually wrong, as the radiation protection community has no mandate to make societal decisions. Consequently, stakeholder inputs, radiological protection inputs and social inputs to the decision-making process on cleanup of contaminated environments must be done in parallel to form an optimised overall health protection being the sole responsibility of the decision-maker.

1 Introduction

The term cleanup has essentially the same meaning as rehabilitation, reclamation, remediation, and restoration. Cleanup generally includes those measures that might be carried out to reduce the exposure from existing contamination through actions applied to the contamination itself *e.g.* removal of contaminated soil or sediments, decontamination of surfaces etc. However, cleanup could broadly be taken also to include dose reduction measures applied to the exposure pathways to humans, *e.g.* covering the contaminated material to reduce external exposure or radon exhalation, planting vegetation to reduce resuspension, incorporating contaminated material into structures to prevent dispersion, or restricting particular uses of an area.

2 Radiological protection achieved by cleanup

Although the formulations of the optimisation principle differ for practices and interventions (constrained versus unconstrained optimisation), the practical implementation of optimisation of cleanup is essentially the same process, whether it is considered in the context of the continuing operation of a practice, as part of decommissioning of a practice, or for intervention. In all cases, it includes an evaluation of the different options available and how exposures might be reduced, and choosing the course of action which results in the greatest net benefit, considering all of the relevant factors that influence costs and benefits. These benefits and costs may accrue to directly affected populations, both now and in the future, as well as to other parts of society.

2.1 Justified cleanup strategies

Clean-up of contaminated land will introduce some benefit to the affected populations. The components of benefit will include, e.g. averted dose and decrease in anxiety. With no cleanup introduced, the beneficial aspects of cleanup will all be negative. After a cleanup has been implemented some of these negative benefits have been reduced or even removed but other negative benefits, *e.g.* monetary costs and disruption and positive benefits, *e.g.* reassurance have been introduced [1, 2]. Clean-up is justified when the net benefit, B, is positive:

$$B = \sum_i b_i(\text{after cleanup}) - b_i(\text{before cleanup}) = \sum_i \Delta b_i \ \ (> 0) \tag{1}$$

where b_i are the benefit components.

The application of the justification principle to cleanup situations requires prior consideration of the benefit that would be achieved by the cleanup and also of the harm, in its broadest sense, that could result from it. It is emphasized that justification must consider also non-radiological risks as well as radiological risks, *e.g.*, chemical risks, and risks from industrial and transportation operations. Each of the benefit components, b_i, has to be expressed in the same units. These units must be in like quantities or values. For example, since costs are expressed in monetary terms, equivalent monetary values may be assigned to other parameters. However, it is the relative values placed on the components and their weighting one to another that is important, rather than the absolute unit in which they are quoted. Alternatively, other units may be used, *e.g.* dimensionless quantities normally used in multi-attribute utility analysis.

2.2 Optimised cleanup strategy

When the performance and costs of all the protection options has been assessed, a comparison is needed to define the optimum protection option. Normally, there would be a range of justified cleanup options for which the net benefit would be positive. The optimum cleanup option would be the one for which the net benefit is maximized. There might be justified options with a lower residual dose than at the optimum. This is due to the fact that some of the negative benefit components entering the optimisation process would have a higher weighting than the averted dose.

Most of the methods used in optimisation of protection tend to emphasize the benefits and detriments to society and the whole exposed population. For cleanup of contaminated land, society usually requires that the same level of protection be provided regardless of the source of exposure. Therefore, cleanup criteria that do not differ depending on whether the situation is deemed to fall within the category of practices or intervention are desirable, but may not always be possible.

2.3 Derivation of reference levels for cleanup

An optimum reference level for cleanup operations depends on many factors. For illustrative purposes it has been assumed here that the most important are the avertable individual annual doses to the population, ΔE_{an}, and the monetary costs of the cleanup operation, C_{clean}.

The average cleanup efficiency, $\overline{\eta}$, is defined as the ratio of the avertable individual annual dose, ΔE_{an}, to the individual annual dose before cleanup, E_{an}:

$$\overline{\eta} = \frac{\Delta E_{\mathrm{an}}}{E_{\mathrm{an}}} \tag{2}$$

The cleanup costs per unit area, C_{clean}, can be expressed as:

$$C_{\mathrm{clean}} = C_{\mathrm{waste}} \cdot \gamma + C_{\mathrm{lab}} \cdot \varepsilon + C_{\mathrm{equip}} \cdot \delta \tag{3}$$

where:

- C_{waste} is the cost per unit mass of produced waste,
- γ is the waste produced per unit area,
- C_{lab} is the labor cost per unit time,
- ε is the working time spent per unit area,
- C_{equip} is equipment cost per unit time, and
- δ is time of equipment use per unit area.

The parameters w, ε, and δ, would all depend on the cleanup efficiency, η. The cleanup costs would depend on the type of area contaminated as the cleanup procedures would be different for the different areas. Examples of cleanup in urban areas would include street sweeping, firehosing, asphalt planing, removal of vegetation and removal of soil. The cleanup costs also involve the disposal of waste which could be the dominating cost in the cleanup of large areas. The total costs of soil and turf removal have been estimated to be of the order of US \$ $0.5 \cdot 10^6$ - $1 \cdot 10^6$ per km^2 [3].

Taking into consideration only the avertable dose to the population, the doses to the workers engaged in the cleanup and the monetary costs of the cleanup operation, the following factors would enter the justification/optimisation process for determining a reference level for cleanup:

- the number of people living in the contaminated area, N_{pop}
- the collective dose to the affected population, $S_{\mathrm{pop}} = E_{\mathrm{an}} N_{\mathrm{pop}}$
- the size of the contaminated area, A

- the monetary cost of the cleanup per unit area, C_{clean}
- the number of workers performing the cleanup, N_{work}
- the individual doses to workers carrying out the cleanup, E_{work}
- the collective dose to the workers carrying out the cleanup, $S_{\mathrm{work}} = E_{\mathrm{work}} N_{\mathrm{work}}$
- the average efficiency of the cleanup operation, $\overline{\eta}$, or the average cleanup reduction factor, $\overline{f} = 1/(1-\overline{\eta})$
- the equivalent monetary cost of averting a unit collective dose, α

The avertable detriment, ΔY_{pop}, expressed in monetary terms, of the avertable collective dose to the population, ΔS_{pop}, can be calculated from the equivalent monetary cost of averting a unit collective dose, α, as $\Delta Y_{\mathrm{pop}} = \alpha \Delta S_{\mathrm{pop}}$. The condition for a cleanup operation to be justified is that the avertable detriment (being the benefit) to the population from the cleanup, ΔY_{pop}, be larger than the sum of the detriment of the collective dose to the cleanup workers and the cost of the cleanup operation:

$$\alpha\,\Delta S_{\mathrm{pop}} \geq \alpha\, S_{\mathrm{work}} + C_{\mathrm{clean}}\, A \tag{4}$$

$$\alpha\, S_{\mathrm{work}} + C_{\mathrm{clean}}\, A \approx C_{\mathrm{clean}}\, A$$

The detriment of the collective dose to cleanup workers will normally be marginal compared to the other cleanup costs and therefore the term, $\alpha\, S_{\mathrm{work}}$, in the equation above has been disregarded.

The individual annual dose to members of the affected population, E_{an}, from activity deposited in urban and semi-urban environments will, as an approximation, be proportional to the surface contamination density at each surface type of which only four have been considered here. Other relevant media for urban environments would include, *e.g.* concrete surfaces. The annual individual doses would thus be proportional to:

$$E_{\mathrm{an}} \propto w_{\mathrm{soil}} \cdot \nu_{\mathrm{soil}} + w_{\mathrm{grass}} \cdot \nu_{\mathrm{grass}} + w_{\mathrm{house}} \cdot \nu_{\mathrm{house}} + w_{asphalt} \cdot \nu_{\mathrm{asphalt}} \tag{5}$$

where:

- w_{surface} is the occupancy at a given surface type, and
- ν_{surface} is the relative deposition velocity for that surface type

When the cleanup efficiency for the different surfaces is η_i, the annual average individual dose to the affected population after cleanup, $E_{\mathrm{an,\,clean}}$, is assumed to be proportional to:

$$E_{\mathrm{an,\,clean}} \propto (1-\eta_{\mathrm{soil}})\, w_{\mathrm{soil}}\, \nu_{\mathrm{soil}} + (1-\eta_{\mathrm{grass}})\, w_{\mathrm{grass}}\, \nu_{\mathrm{grass}} + (1-\eta_{\mathrm{house}})\, w_{\mathrm{house}}\, \nu_{\mathrm{house}} + (1-\eta_{\mathrm{asphalt}})\, w_{\mathrm{asphalt}}\, \nu_{\mathrm{asphalt}} \tag{6}$$

The average dose reduction factor, $\overline{f}$, by cleanup of the different surfaces can then be described as:

$$\overline{f} = \frac{1}{1-\overline{\eta}} = \frac{E_{\mathrm{an}}}{E_{\mathrm{an,\,clean}}} = \frac{\sum_i w_i\, \nu_i}{\sum_i (1-\eta_i)\, w_i\, \nu_i} \tag{7}$$

If the time period over which the collective dose is accumulated is T, the avertable collective dose, ΔS_{pop}, over the same time period is related to the annual individual effective dose, E_{an}, as:

$$\Delta S_{\mathrm{pop}} = N_{\mathrm{pop}} \int_0^T \Big(E_{\mathrm{an}}(t) - (1 - \overline{\eta}) \cdot E_{\mathrm{an}}(t) \Big) \mathrm{d}t \tag{8}$$

A justified reference level expressed as an annual individual effective dose, E_{an}, before cleanup can be found from the following considerations. The avertable collective dose over time, T, with cleanup will determine the annual individual dose before cleanup, E_{an}, as:

$$\alpha\, \Delta S_{\mathrm{pop}} = \alpha\, N_{\mathrm{pop}}\, \overline{\eta}\, E_{\mathrm{an}}\, T \tag{9}$$

$$\alpha\, \Delta S_{\mathrm{pop}} \geq C_{\mathrm{clean}}\, A$$

assuming a fairly constant value of $E_{\mathrm{an}}(t)$.

With a population density $P_{\mathrm{pop}} = N_{\mathrm{pop}}/A$, and an average cleanup efficiency, $\overline{\eta}$, a justified reference level, $(E_{\mathrm{an}})_{\mathrm{just}}$, can be found from Eq. (10) as:

$$\Big(E_{\mathrm{an}}\Big)_{\mathrm{just}} = \left(\frac{C_{\mathrm{clean}}}{\overline{\eta}}\right) \cdot \left(\frac{1}{\alpha\, P_{\mathrm{pop}}\, T}\right) \tag{10}$$

Each identified cleanup option would have its own reference level. If the actual annual dose is less than the reference level, the specific cleanup option would not be justified.

The optimised reference level among the justified reference levels for different cleanup options might be taken as the one with the minimum cleanup cost to efficiency ratio, $(C_{\mathrm{clean}}/\overline{\eta})_{\mathrm{min}}$:

$$\Big(E_{\mathrm{an}}\Big)_{\mathrm{opt}} = \left(\frac{C_{\mathrm{clean}}}{\overline{\eta}}\right)_{\mathrm{min}} \cdot \left(\frac{1}{\alpha\, P_{\mathrm{pop}}\, T}\right) \tag{11}$$

Other attributes than monetary costs and dose reduction might have an equally important weight and these factors should be included in the decision-making process on selecting the reference level for an optimised overall health protection.

For assumed cleanup efficiencies, η_i, of soil removal, grass cutting, firehosing of houses and asphalt planing, the total cleanup cost per unit area can be determined as:

$$\begin{aligned} C_{\mathrm{clean}} = {} & x_{\mathrm{soil}}\, C_{\mathrm{clean,\,soil}} + x_{\mathrm{asphalt}}\, C_{\mathrm{clean,\,asphalt}} + x_{\mathrm{house}}\, C_{\mathrm{clean,\,house}} + \\ & x_{\mathrm{grass}}\, C_{\mathrm{clean,\,grass}} \end{aligned} \tag{12}$$

where x is the fraction of the given surface.

Cost values for different cleanup operations can be found in a UK study, which gives a review of the various methods to remove activity from buildings and land surfaces [3]. The study considers monetary costs, cleanup rates for land and buildings, waste disposal implications, and personnel and resource requirements. The cost values used in the present calculations have been normalized to a GNP per capita of 25,000 US Dollars for Western European countries in 1996. The values of the parameters and their distributions as used in the calculations are shown in Table 1.

Table 1. *Parameter values and their distribution as used in the calculations of reference levels for cleanup of urban and semi-urban environments.*

Parameter	Uniform distribution	Log-normal distribution	
		Central value	Standard deviation
Soil removal costs, GNP km^{-2}			
Waste disposal	24 - 40	32	10
Wages	0.8 - 1.6	1.2	0.4
Grass cutting costs, GNP km^{-2}			
Waste disposal	16 - 24	24	7
Wages	1.2 - 2.4	2	0.6
Firehosing costs, GNP km^{-2}			
Waste disposal	0.2 - 0.6	0.4	0.1
Wages	6 - 12	8	2.4
Asphalt planing costs, GNP km^{-2}			
Waste disposal	32 - 48	40	12
Wages	8 - 16	12	3.6
Population density, urban, km^{-2}	300 - 600	450	200
Population density, semi-urban, km^{-2}	100 - 200	150	60
Relative deposition on roads, ν_{road}	0.2 - 0.5	0.30	0.08
Relative deposition on houses, ν_{house}	0.05 - 0.2	0.12	0.03
Relative deposition on grass, ν_{grass}	0.8 - 1.2	1.0	0.20
Relative deposition on soil, ν_{road}	0.8 - 1.2	1.0	0.20
Fraction of houses, x_{house}			
Urban	0.50	0.50	-
Semi-urban	0.30	0.30	-
Fraction of roads, x_{road}			
Urban	0.25	0.25	-
Semi-urban	0.25	0.25	-
Fraction of soil, x_{soil}			
Urban	0.20	0.20	-
Semi-urban	0.30	0.30	-
Fraction of grass, x_{grass}			
Urban	0.05	0.05	-
Semi-urban	0.15	0.15	-
Occupancy factor house, w_{house}	0.85	0.85	-
Occupancy factor road, w_{road}	0.05	0.05	-
Occupancy factor soil, w_{soil}	0.05	0.05	-
Occupancy factor grass, w_{grass}	0.05	0.05	-
Soil removal efficiency, η_{soil}	0.5 - 0.8	0.7	0.14
Grass cutting efficiency, η_{grass}	0.2 - 0.6	0.4	0.06
Firehosing efficiency, $\eta_{\text{firehosing}}$	0.1 - 0.5	0.3	0.03
Asphalt planing efficiency, η_{asphalt}	0.6 - 0.9	0.8	0.12
Cost of unit dose reduction, α, GNP Sv^{-1}	0.4 - 1.6	1	0.3
Integration time T, years	30 - 300	200	50

Justified values of the annual individual dose before cleanup have been calculated from Eq. (10) as shown in Table 2. The parameters entering Eq. (10) have been assigned either a uniform or a log-normal distribution and the distribution parameters are shown in Table

1. Latin Hypercube Sampling technique were used with 100,000 trials for each distribution and environment type. The distribution of the resulting reference level for cleanup of a semi-urban environment applying uniform parameter distributions is shown in Fig. 1.

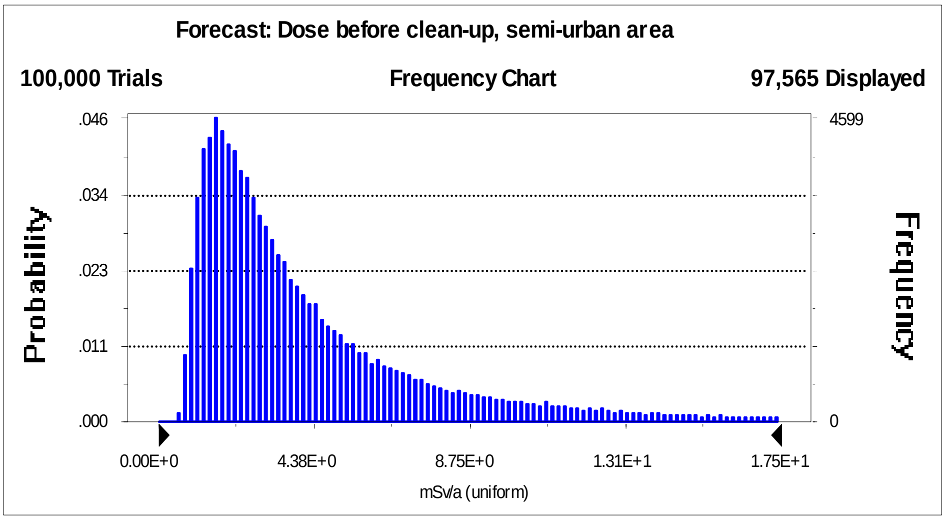

Figure 1. *Distribution function of the calculated reference level for cleanup of a semi-urban environment. The distribution functions for the parameters have all been assumed to be uniform with parameter values as shown in Table 1.*

The reason why the results in Table 2 for semi-urban environments are 3 - 4 times higher than for urban environments is mainly due to the difference in population density. For more densely populated environments, the avertable collective dose by cleanup per unit reduction in dose rate will result in a correspondingly higher avertable collective dose over the time period considered.

If the actual annual dose level (from all relevant exposure pathways) exceeds the minimum justified reference level, $(E_{\text{an}})_{\text{just}}$, before cleanup is implemented, cleanup would be justified.

Table 2. *Minimum justified reference levels in mSv/a above which cleanup is justified based on avertable collective dose and monetary costs of the cleanup of urban and semi-urban areas.*

Area type	Distribution	Percentiles			Mean	Median
		2.5%	50%	97.5%		
Urban	Uniform	0.3	0.9	5.0	1.4	0.9
	log-normal	0.2	0.7	2.3	0.9	0.7
Semi-urban	Uniform	1.0	3.2	17	4.6	3.2
	Log-normal	0.8	2.5	7.6	3.0	2.5

The generic reference levels shown in Table 2 are generally in good agreement with the recommendations from ICRP and IAEA presented in section 2.4.

2.4 International recommendations

The *existing annual dose* can conceptually be used as a generic reference level for intervention. This quantity is made up of all the existing and persisting annual doses incurred by individuals and, therefore, it is constituted by many different components of prolonged exposure. These include external exposure to long-lived radionuclides (and their progeny) in soils, strata and building materials (including exposure to radon and other radionuclides in the ambient), internal exposure due to the incorporation of those radionuclides into the body as a result of inhalation of resuspended materials and ingestion of contaminated foodstuffs. Both the ICRP and IAEA have recommended generic reference levels in terms of a total annual dose for intervention in prolonged exposure situations, including cleanup.

International Commission on Radiological Protection (ICRP)
ICRP has re-emphasized that generic reference levels in terms of an existing annual dose should be viewed as a *consequential* derivation from the principles of the System of Radiological Protection for intervention and as *complementary*, rather than *alternatives*, to those principles [4]. Their use should not preclude the application of these principles to any dose component of the existing annual dose that is controllable, particularly if it is a dominant component.

ICRP has recommended that an existing annual dose approaching about 10 mSv may be used as a generic reference level below which intervention is not likely to be justifiable for some prolonged exposure situations. Below the level of existing annual dose for which intervention is not likely to be justifiable, protective actions to reduce a dominant component of the existing annual dose are still optional and might be justifiable.

Should intervention be considered justifiable, the form, scale and duration of the protective actions should be optimised taking into account all factors involved, including the avertable individual and collective annual doses.

International Atomic Energy Agency (IAEA)
IAEA has recommended that for contamination resulting from past activities and accidents, the required level of remediation shall be established on a site-specific basis and in accordance with the radiation protection principles that apply to intervention situations. Consequently, remediation measures and protective measures to be implemented thereafter shall be justified and optimised [5, 6].

IAEA recommends a generic reference level for aiding decisions on remediation to be an annual effective dose of 10 mSv from all sources including natural background. This will normally be assessed as the average dose in an appropriately defined critical group. Regardless of this, remediation measures might be justified below this generic reference level and national authorities may define a lower level for identifying sites that might need remediation. The use of generic reference levels should not encourage a 'trade-off' of remedial measures among the various components of the existing annual dose.

3 Decision-making overall health protection

In many intervention situations like cleanup of environments contaminated by a nuclear or radiological accident, there are considerations, which may not be objectively related to radiological protection, that may also need to be taken into account in making decisions about intervention. ICRP consider that these other considerations, which are mainly of a socio-political and cultural nature, may be taken into account in a decision-making process which should be wider than the decision-aiding process for the justification and optimisation of radiological protection, as all relevant attributes are included, not only radiological protection attributes.

3.1 Radiological protection attributes

Radiological protection attributes are defined as those which are related to the level of radiological protection achieved and they have been used in developing international numerical guidance on intervention levels for implementing countermeasures to reduce doses after a nuclear or radiological emergency [4]. Thus they include those attributes describing the dose distribution averted and those describing the costs and other disadvantages incurred in averting the doses. All these techniques have as their primary objective to clarify, for the people who have to decide on the intervention, the various attributes, to quantify them if this is reasonable and necessary, and to systematize the trade offs between the various attributes.

Attributes which would clearly be radiological protection related include those describing benefits from the countermeasure and those describing harm:

- the averted individual and collective risks for the members of the public,
- the individual and collective physical risks to the public caused by countermeasures,
- the individual and collective risks to the workers in carrying out the countermeasure, and
- the monetary cost of the countermeasure.

3.2 Non-radiological protection attributes

Non-radiological protection attributes are defined as those which are not related to the level of radiological protection achieved by protective measures. It is very difficult to generalise about these attributes, although they can have an important or even overriding influence on the decisions taken.

Most intervention is disruptive to normal social and economic life. Change may cause anxiety, which can be harmful to health and well-being. However, the absence of protective measures can also cause anxiety, which is often exacerbated by a lack of objective information. These effects are non-radiological, are not easily quantifiable, will vary markedly between countries, and in any case will normally have opposing influences on the choices of intervention levels. They include the following attributes:

- the perception of the hazard posed by the radiation from radioactive contamination,
- psychological impacts,
- the reassurance provided by the implementation of the countermeasure,
- the anxiety caused by its implementation,
- the individual and social disruption resulting from its implementation, and
- political considerations.

Although some of these attributes to a certain extent are related to the level of protection achieved they are all considered to be non-radiological protection attributes. The political input, however, is always deemed to include only non-radiological protection attributes.

3.3 The role of radiological protection in decision-making

Management of protective actions like cleanup of contaminated environments is not a radiological protection problem only as has been experienced in the former USSR following the Chernobyl accident [7]. The socio-psychological attributes are important and they may even be the dominating ones. Socio-psychological countermeasures are a new category of action, in the sense that social protection philosophy has not yet been developed to fully include their application in such situations, especially those following nuclear or radiological accidents [8].

Without the introduction of cleanup of contaminated environments, most attributes would quantify disadvantages, *e.g.* the existing individual and collective doses as shown in Fig. 2. The advantage of intervention is that it may reduce the disadvantageous attributes, for instance averting individual and collective doses, or even get rid of them. Cleanup may also introduce advantageous attributes, such us the reassurance produced by the intervention. Cleanup will also introduce new disadvantageous attributes, *e.g.* the costs, harm and inconveniences introduced by the cleanup measures as shown in Fig. 2.

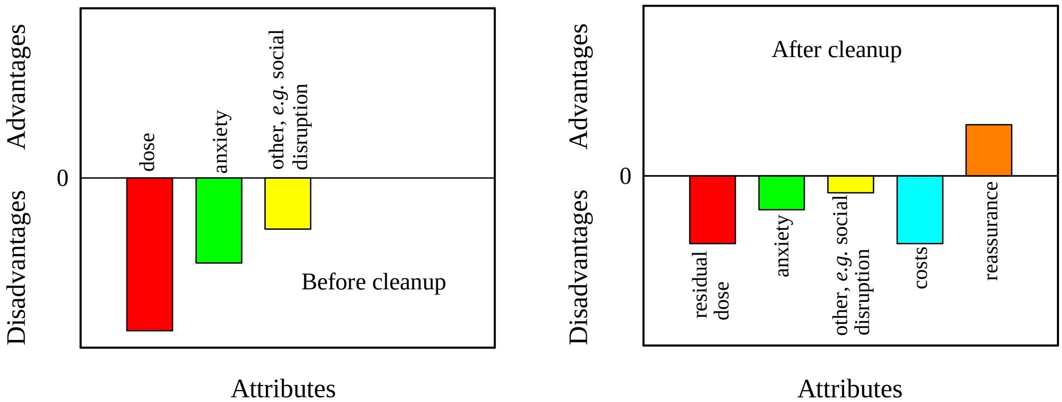

Figure 2. *A schematic view of the concept and application of justification of cleanup. The left-hand picture shows the situation before cleanup and the right-hand picture the situation after cleanup.*

The left-hand picture shows that, without cleanup, all key attributes can be considered disadvantageous. The right-hand picture shows that cleanup may reduce (or eliminate) some of the disadvantageous attributes, introducing new disadvantageous attributes (*e.g.* costs) and some advantageous attributes (*e.g.* reassurance). The factor 'other' is intended to cover the disadvantage of social disruption and political problems as well as other less quantifiable components. The attributes costs and reassurance are not shown in the left-hand figure as their value is zero without cleanup.

In analyzing the inputs to the decision, it is necessary to decide on the *relative importance* of each factor. These judgements have to be applied *irrespective* of the decision aiding technique used. In a complete analysis each of the attributes have to be expressed in the same units [9, 10]. These units can be dimensionless quantities (such as used in multi-attribute utility analysis), or values could be expressed in *equivalent years of life* *lost.* However, it is the *relative values* placed on the components and their *weighting* one to another that is important, rather than the absolute unit in which they are quoted. Explicit guidance is not provided on how psychological, social and ethical attributes should be included in the optimization of overall health protection. However, the optimization of radiological protection and psychological and social protection should probably not be carried out independently, as the overall health protection would depend on both radiological and non-radiological protection attributes as shown in Fig. 3.

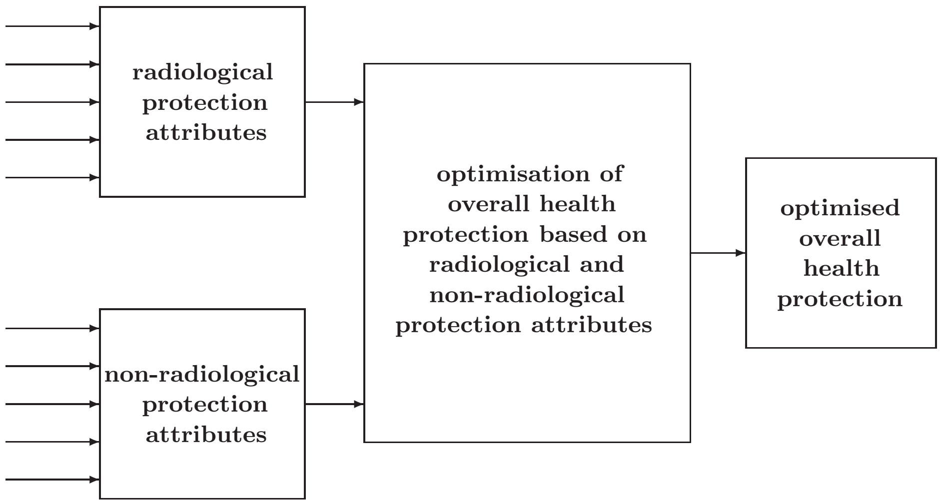

Figure 3. *Optimisation of overall health protection based on radiological and non-radiological protection attributes resulting in an optimised overall health protection after a radiological or nuclear emergency.*

Combining independent optimisation of radiological and non-radiological protection might lead to a sub-optimised overall health protection as shown below in Fig. 4.

The overall health consequences of a nuclear or radiological emergency include the increased stochastic risks directly attributable to the accident. They also include the perception of the hazard posed by radioactive materials dispersed in the environment and enforced changes of lifestyle which lead to increases in psychological strain in the affected population. Such increases may in turn lead directly or indirectly to increased illness.

In situations where a dose-reducing cleanup measure has already been implemented, and has been found to create so much strain that a net harm has been the result, *i.e.* the psychological harm introduced by this measure more than offsets the benefit of the dose reductions, it may be optimal not to reduce doses, or even increase doses, in order to reduce the strain and so provide an overall net benefit. For example, some relocation strategies in the former USSR moved people to areas with elevated radon levels such that their total annual radiation exposure after the countermeasure was greater than if they had remained in the contaminated areas. Such a strategy may result in improved overall health due to a reduction in perceived risk or due to the psychological benefit from the countermeasure that would more than offset the increased radiation risk.

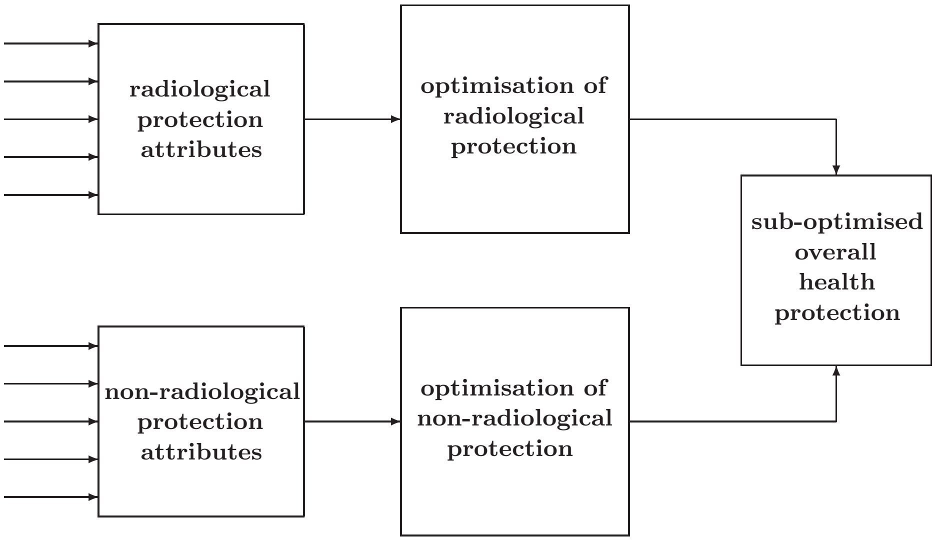

Figure 4. *Optimisation of radiological and non-radiological protection resulting in a sub-optimized overall health protection after a radiological or nuclear emergency.*

The decision-making process might include the participation of relevant stakeholders, rather than radiological protection specialists alone. Such a process may take account of attributes other than those directly related to radiological protection. The objective is that those concerned with the situation should be involved and be given the opportunity to participate in the decision-making process. The extent of stakeholder involvement will vary from one situation to another.

4 Discussion and conclusions

Generically justified reference levels for cleanup of contaminated urban and semiurban environments have been derived from cleanup efficiencies and monetary costs associated with the cleanup measures. The generic reference levels are expressed as an annual dose level, above which cleanup is justified and below which it is not. The methodology for determining reference levels includes uncertainty analyses in which distribution functions are assigned to the model parameters. *Minimum* reference levels for cleanup are found to be of the order of 1 - 10 mSv/a before cleanup is justified. Environments with a dose level of 10 mSv/a or greater would normally be subject to cleanup according to recommendations from ICRP and IAEA.

In the decision-making process on the introduction of protective actions in an existing exposure situation like long-term contamination of urban and semi-urban environments, many complex human, social and economic considerations will have to be taken into account by the responsible authorities. From the experience in the former USSR after the Chernobyl accident, countermeasures to mitigate socio-psychological impacts have obviously been needed. It has been suggested that such countermeasures should be included in the radiation protection framework. It has also been suggested that the radiation protection community in the future should involve interested parties, the so-called stakeholders, in the process of determining, or negotiating, the optimised level of protection in situations of public exposure.

ICRP has up until now considered that the justification and optimisation of radiological protection should be assessed by means of a *decision-aiding process* requiring a positive balance of all relevant attributes related to radiological protection. The result of such a decision-aiding process can be used as input into a wider *decision-making process* (not performed by the radiation protection community), which may encompass other considerations being mainly of a socio-political nature. Decision-making is an integral part of a more wide political system and decision-making should therefore *not* form an integral part of the radiation protection framework. Involving stakeholders in negotiating the optimisation of radiological protection would in fact mean that the radiation protection community would enter the field of decision-making. This seems to be wrong as the radiation protection community has *not* any mandate to make societal decisions.

Including socio-political aspects into the radiological protection framework as has been suggested would in fact be a dangerous path to enter. Radiological protection factors are related to the level of radiological protection achieved by protective measures. Socio-political factors would depend not only on the presence of radiation but to a large extent on other attributes, such as the attitude of the mass media, the political climate and the general level of information in the population. In order to achieve an optimised overall health protection, non-radiological protection factors should enter the optimisation process *in parallel* with radiological protection factors to form an overall optimised protection strategy. The optimisation of the overall health protection is alone the responsibility of the *decision-maker* with guidance from radiation protection experts as well as from experts in the fields of social sciences.

Finally, ethical aspects should be addressed in the decision-making process on cleanup of radioactively contaminated environments. Applying very large resources to reduce low radiation risks only marginally could remove resources that would be much more needed in the society for, *e.g.*, other health care purposes. The consequence of misallocation of resources might be a number of *non-saved lives* elsewhere in society that could be orders of magnitude larger than the marginally number of saved lives due to the reduced radiation exposure achieved by cleanup. This ethical aspect should be addressed *also* by the radiation protection community, which has an obligation to inform the decision-maker and stakeholders on these matters.

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