DECISION ANALYSIS FOR CLEANUP STRATEGIES IN AN URBAN ENVIRONMENT

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Abstract

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The values entering the decisions on protective actions, as concerning the society, are multidimensional. People have strong feelings and beliefs about these values, some of which are not numerically quantified and do not exist in monetary form. The decision analysis is applied in planning the recovery operations to clean up an urban environment in the event of a hypothetical nuclear power plant accident assisting in rendering explicit and apparent all factors involved and evaluating their relative importance.

1. INTRODUCTION

A comprehensive overview of the important methods to clean up large areas contaminated as a result of a nuclear accident is available in the literature (IAEA, Le, Ro). The successful implementation of actions, however, requires good planning including the identification of multidimensional values entering the decision. These values, expressed as objectives, criteria or performance measures, will necessarily be a part of the final decision making following radiological emergencies. The aim of the identification of values and the assessment of their relative importance on decisions is to create better alternatives for decisions and to define decision problems that are more appealing than those that confront us.

Research over the past 30 years has transformed the abstract mathematical discipline of decision theory to a potentially useful technology known as *decision analysis*, which can assist decision makers in handling large and complex problems and the attendant flows of information (Fr, Go, Wi). Decision analysis is not intended to solve problems directly. Its purpose is to produce insight and understanding, so that the decision maker can make better decisions. This report provides an application on how techniques of decision analysis can be used when planning cleanup measures in urban environment.

2. DECISION MODEL

For the purpose of the analysis it was assumed that a hypothetical core-damaging accident had happened at a Finnish nuclear power plant and, as a result, a few percent of the fission products had been released to the environment. It was further assumed that the accident had happened in summer time in dry atmospheric conditions. The contamination levels and the areas were evaluated with the OIVA software package (Fig. 1, La). The range of values corresponds the deposition onto infinite grass surface where all the deposited matter is on the grass cover. The mean values were estimated taking into account typical differences in deposition on various urban surfaces.

The distribution of the deposited material onto different surfaces and the contribution that each surface has to the dose was considered in developing decontamination strategies. The most cost-effective techniques given in the literature to decontaminate each surface were then selected to achieve effective dose reduction (Le, Ro). In addition, the postponement of the cleanup and the width of the area to be cleaned up will affect the net benefit to be obtained.

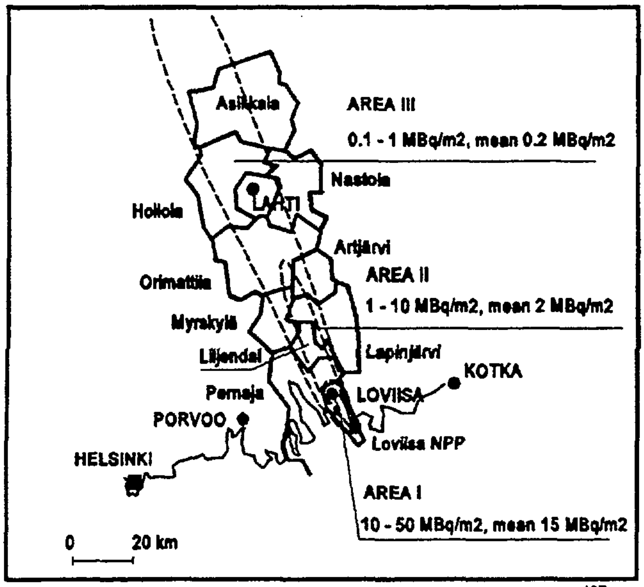

Figure 1. The map showing the distribution of the ^{137}Cs contamination after a hypothetical reactor accident. The mean values are relevant in urban environment.

The effect of the width of the area is studied with moderate and extensive decontamination alternatives. In extensive decontamination the area was chosen to be twice as large as that of moderate decontamination. To form the policy of the protection seven strategies were defined (Table I).

TABLE I. STRATEGIES FOR RECOVERY OPERATIONS IN URBAN AREAS DEFINED IN TERMS OF THEIR EFFECTS ON THE AREAS I, II AND III.

Strategy	Firehosing of roofs	Firehosing of walls	Sweeping of streets	Cutting trees	Grass cutting	Scraping/ clean soil	No action
1	I, II, III	I, II, III	I, II, III	I, II, III		I, II, III	
2	I, II, III	I, II	I, II, III	I, II	III	I, II, *III*[a]	
3	I, II	I	I, II	I	II	I, *II*[a]	III
4[b]	I, II	I	I, II	I	II	I, *II*[a]	III
5			I, II, III		I, II, III		
6	I		I		I	*I*[a]	II, III
7							I, II, III

a) Only the nearest surroundings of the houses are scraped
b) Decontamination is started one month after the fallout.

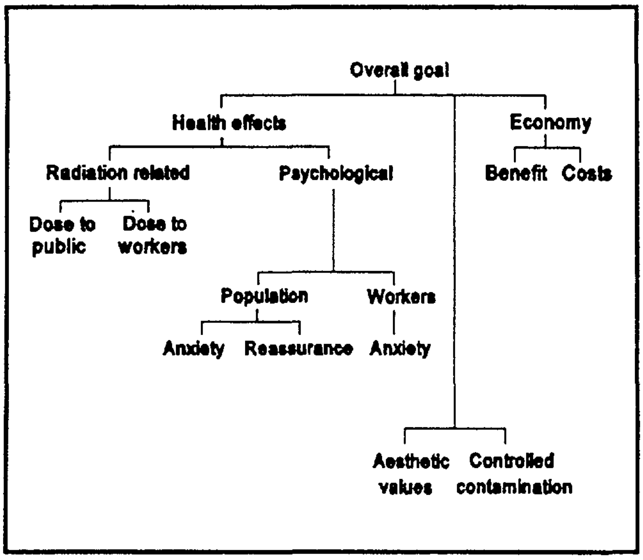

Figure 2. Hierarchy of attributes used in the decision model.

Although we have defined alternatives above, it is useful to iterate between articulating values and creating alternatives. *Alternatives are relevant only because they are means to achieve values*. Since environmental values are multidimensional, different kinds of objectives will necessarily be involved in any decision following radiological emergencies. Some of the objectives might be directly measured on a numerical scale and some should be further divided into sub-objectives in order to be measurable. This kind of a numeric variable is called an attribute, and it is used to measure performance of actions in relation to an objective. An *attribute hierarchy* (*value tree*) can be useful in defining attributes and objectives (Fig. 2). The attributes used in the analysis are defined as follows:

Dose to the public. Because the dose of the population is not known on an individual basis, the value of this attribute is assessed as the projected (residual) collective dose to the public (manSv).

Dose to the workers. Projected collective dose to the workers carrying out the recovery operations (manSv).

Anxiety of the population. Psychological stress could lead to health effects of a comparable nature to those arising from the contamination. A majority of the population in a contaminated area may show varying degrees of stress reactions in response to an accident, but stress could also be the consequence of a protective action. The accident will be realized through protective measures and it will be felt more severe if numerous and aggressive measures are taken, e.g., removing soil and trees in living environment (direct rating).

Reassurance of the population. In the long term, appropriate and reasonably extensive actions will offer reassurance to the population to live safe in the affected area. Especially measures that the population could implement by itself are the most effective in reducing stress (direct rating).

Anxiety of the workers. Working in the contaminated area will cause stress among workers when intervening (direct rating).

Aesthetic values. Decontamination methods such as digging, scraping and especially felling down trees would result in the reduction of contamination, but at the same time, decrease the aesthetic value of the environment. The reduction would also take place near disposal sites and around power stations burning radioactive wood (direct rating).

Controlled contamination. The contamination is brought under control and its circulation in the environment is prevented by collecting and disposing it (direct rating).

Costs. Cleanup would cause monetary costs to individuals, industry and society. The question of reimbursing individuals for any remedial actions would also arise. If any compensation is paid, either in full or in part, it would mean that the costs to individuals would now be costs to society. The costs that are taken into account include the costs of the removal of contamination, transportation and disposal of waste (MFIM).

Economic benefit. The economic impact of an accident may not be entirely negative. The activities may have positive effect on the economy, such as manufacturing and trading decontamination equipment and generation of employment. Unfortunately no models exist that would enable the consideration of full economic activities and therefore the assessment of benefit was based on expert assessment (Ni) and on the calculated benefit of burning the chipped wood. (MFIM).

The measurement of the quantifiable attributes is easy, because we can identify the variables representing them. However, for attributes, such as reassurance and aesthetic values, it is more difficult to find proxy attributes or variables that can be quantified. *Direct rating* can be used with unquantifiable attributes. In this technique, the most preferred option for, e.g., reassurance, is given a value of 100 and the least preferred option the value of zero. The other options are ranked between zero and 100, according to the strength of preference for one option over another in terms of reassurance. Although this technique seems robust, it should be emphasized that there are methods of checking the consistency of the numbers elicited. Also, numbers do not need to be precise. The choice of action is generally fairly robust and substantial changes in the figures are often required before another option is preferred. The assessed values of attributes for each strategy are given in Table II (1 USD = 5 FIM).

TABLE II. VALUES OF THE ATTRIBUTES FOR STRATEGIES DEFINED IN TABLE I

Strategy	Dose to public (manSv)	Dose to workers (manSv)	Benefit (MFIM)	Costs (MFIM)	Anxiety of population (score)	Reassurance (score)	Anxiety of workers (score)	Aesthetic values (score)	Controlled contamin. (score)
1[a]	1180	15	140	690	0	90	0	0	100
2[a]	1340	10	30	120	10	100	50	70	80
3[a]	1700	8	10	60	50	50	70	90	30
3[b]	1360	16	17	110	40	60	60	80	50
4[a,c]	1810	2	10	60	30	40	80	80	40
5[b]	1430	1.8	1.8	3.7	60	40	60	100	60
6[b]	1870	1.1	1.5	3.4	80	30	90	100	20
7	2670	0	0	0	100	0	100	100	0

a) Moderate decontamination
b) Extensive decontamination
c) Decontamination is started one month after the fallout.

The reduction in the dose through cleanup is assessed based on calculations done by Andersson and Roed with the URGENT software package (Le) and on real statistics obtained in the defined fallout areas. The dose predictions for over 70 years were done by the ARANO software package (Sa). The dose to each worker group in each work phase was calculated separately; firehosing of roofs and walls, sweeping of streets, removal of vegetation and soil, transportation and disposal of waste. The software package MATERIA was used to assess the individual doses to workers during transportation and disposal (Ma). The monetary costs of actions were calculated using Finnish statistics and information collected in another study (Le). The scales for unquantifiable attributes were developed judgementally. A higher score represents more preferred actions.

Before we can combine the values for different attributes in order to obtain a view of the overall benefits offered by each strategy, we have to assess the weights on attributes. They represent the judgement of the decision maker on the relative importance of the levels of attributes. For example, how much he/she is ready to accept dose to workers to avoid a certain dose to the population. When assessing a trade-off value, it should be noted that the importance of an attribute is not only dependent on its conceptual value, such as health, but also on its *length of scale*, such as the number of cancer cases. *Swing weighting* is applied in the analysis as an assessment method for scaling constants. The decision maker is asked to compare a set of pairs of hypothetical actions which differ only in their values along two attribute scales until an indifferent pair of options is found. Based on the swing weighting assessments the following weights are obtained (Table III).

TABLE III. WEIGHTS OF ATTRIBUTES

Attribute	Costs	Dose to public	Benefit	control. contam	Reassu-rance	Aesthetic values	Anxiety of popul.	Anxiety of work.	Dose to workers
Weight	56	13	11	8	5.6	4	2.8	0.28	0.1

3. ANALYSIS OF THE MODEL

At this stage we are in a position to aggregate the values to find out how well each strategy performs overall. The *additive model* was applied simply to add together the weighted value scores of an action (weighted attribute values on each strategy) to obtain the benefit. Additive model, although robust, was considered here to be useful to gain an understanding of values. The overall scores and ranking of strategies are given in Table IV. Strategy 5[b], sweeping of streets and grass cutting extensively in the whole contaminated area is just optimal.

TABLE IV. OVERALL SCORES FOR THE ANALYSIS

Strategy	1[a]	2[a]	3[a]	3[b]	4[a,c]	5[b]	6[b]	7
Overall score	0.37	0.74	0.70	0.71	0.68	0.79	0.72	0.63
Rank	8th	2nd	5th	4th	6th	1st	3rd	7th

a) Moderate decontamination
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It is wise to be sceptical about the ranking of the actions, if the variation of figures used in the analysis is not analysed by means of a sensitivity analysis. We have to examine the robustness of the choice of a strategy in the light of changes in the figures. In many cases sensitivity analysis shows that the data need not to be accurate. If this is the case, then it would be a waste of effort and time to elicit the numbers accurately. There are several techniques described in the literature for performing a sensitivity analysis. The most straightforward analysis, applied here, examines the effects of varying one parameter at a time.

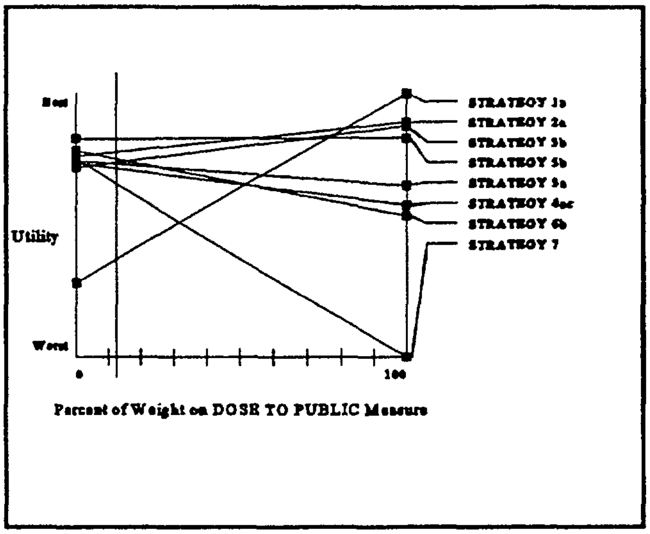

Figure 3. Sensitivity analysis on collective dose.

As an example of the sensitivity analysis performed is the analysis on the weight of collective dose (Fig. 3). The weight on dose is about 13% of the total weight in the model and this value is marked with the vertical line in the Figure 3. The overall score for each strategy against the percentage of total weight on dose are plotted with a line. The highest line segments gives the maximum utility, and hence the line with the highest intersection with the vertical line shows the optimal strategy, i.e., strategy 5^b; sweeping streets and grass cutting in the whole area.

As the weight on dose is below 50% strategy 5^b is optimal, but above 50% strategy 2^a and then strategy 1^a (80%) will be the best course of action, respectively. Besides the range (0 – 50%) gives the accuracy needed in weighting the dose attribute, it also reflects the required accuracy in the dose calculation because the 'length' of an attribute scale is taken into account when assessing the trade-off. The accuracy in assessing the trade-off between collective dose and costs attributes was also studied by changing the trade-off value, increasing the '-value' in radiation protection terminology from 100,000 FIM/manSv to 300,000 FIM/manSv. At this breakeven point strategy 2^a is optimal.

The analysis suggests that the best course of action is strategy 5^b. There should be modifications done in strategy 2^a or changes in numbers or trade-offs before this action will become more attractive. As is shown in Figure 3 strategies 3, 4, 6 and 7 can never be optimal considering the values and the trade-offs used in the analysis.

4. CONCLUSIONS

The decision analysis performed suggests that grass cutting and sweeping of streets would be the best course of action to be taken in the analysed situation. The extensive decontamination, e.g., cutting down trees and removal of soil is not appropriate considering the contamination level and the large area to be cleaned up. Although the less quantifiable factors appeared to be less important in an analysed situation considering the values and trade-offs used, they certainly have a valuable role to play in gaining insight in decision making.

There are different preferences connected to the values of attributes. Therefore, *the values of attributes and trade-offs are subjective*, not objective. Expressing the value may be both unpleasant and difficult, but often it is very crucial when assessing an intervention level. Since the values are subjective, no universal values exist. The values are related to the unique problem, and in addition, they change according to opinions and resources. Careful structuring of the problem is necessary to identify the underlying multidimensional values, attitudes to risk and trade-offs related to the problem. To create more insight, more research is needed, specially on the less quantifiable factors.

The analysis represented above is based on a hypothetical accident. In a real problem, depending on prevailing circumstances, more strategies would have to be considered. Also, the factors entering the decision depend on the situation. Thus, the results of the performed analysis could not be applied in a real situation as such, but the actions and factors should be revised and the calculations redone. The strategies found appropriate in the analysed situation might turn out not to be the most preferred for the real problem, however, they might well indicate the course of actions to be considered.

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