STRUCTURING STAKEHOLDERS' INVOLVEMENT IN RADIOLOGICAL CRISIS MANAGEMENT:
A multicriteria decision aid approach for countermeasure evaluation

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Abstract: Stakeholders represent a valuable source of knowledge, which should be used in steering the emergency response during a radiological crisis. This can be achieved in a multi-criteria decision aid framework, the potential benefits of which are highlighted in the paper: consideration of all relevant factors, problem structuring, better insight in the decision process, and support for decision-makers to justify the chosen countermeasure strategies.

1. INTRODUCTION

The lessons learned from the aftermath of several nuclear events which happened over the last decades, ranging from nuclear power plant accidents to loss of radioactive sources, have emphasized the need to develop better structured and coherent procedures for decision-making regarding protective actions for the population and the environment.

Since the hazard is due to radioactivity, decisions have firstly to be justified on radiological grounds (e.g. averted doses). In practice there are also other driving factors that are equally important, as remedial actions may have their own drawbacks, such as additional health risks, considerable economical costs, anxiety and severe social disruption. Moral and ethical values of decision-makers and stakeholders are as important as the technical issues involved in evaluating the consequences of an accident (Hämäläinen, 2000a). Since the Chernobyl accident, the importance of non-radiological aspects received increasing attention in international research projects on off-site emergency management (French et al, 1992, French et al, 1993, Hämäläinen et al, 1998 and Hämäläinen et al, 2000a) and, more recently, in the European Commission projects for site restoration (STRATEGY) and extending the stakeholders' involvement (FARMING). Knowledge related to the non-radiological aspects can be best acquired from the interaction with relevant stakeholders, notably those involved in production, processing and distribution of food products, emergency workers, consumers and public at large. The various stakeholders involved in the decision process usually have different objectives and conflicting value systems.

How can the stakeholders' values, often expressed in qualitative terms (e.g. public acceptance, stress etc), be assessed and included into an information (decision-support) system will be tackled in the next section of the paper.

As the nuclear emergency management is a complex problem characterised by multiple attributes, it is natural to explore the use of multi-criteria decision aid (MCDA) in helping the decision makers to clarify and evolve their judgements and evaluations. This type of analysis offers a suitable framework with potential benefits, especially in the area of training and planning processes. MCDA techniques offer cognitive methodologies that can be used to structure the stakeholders' involvement in the decision process. The stakeholders' values in a MCDA model may be expressed either through a set fundamental objectives, in multi-attribute utility theory (Keeney, 1992), or a set of consistent evaluation criteria, in outranking methods (Roy, 1996).

In the next section we analyse the information requirements, stakeholders' specific issues and the information flow in the countermeasure evaluation process. In the last section we investigate potential directions of application of specific MCDA tools for evaluation of agricultural countermeasures during a nuclear emergency crisis.

2. INFORMATION REQUIREMENTS AND MANAGEMENT

2.1 Information required by the decision maker

The decision maker is the particular stakeholder who plays a critical role in the evolution of the decision process, in which he expresses and can impose his preferences.

In the case of the Belgian radiological emergency plan the "Emergency Director" is the one who decides and co-ordinates the protective actions. He is chairman of the decision cell and bases his decisions on the advice coming from the evaluation and the socio-economic cells.

Consequently, we will use the term decision advisers for people involved in preparing the decision making, but without effectively having decision power.

In this context, an information system needs to provide the decision advisers with a description of the different countermeasures that can be taken and the motivations supporting them, and to recommend the optimal strategy for a particular situation. The decision advisers can then inform the members of the decision cell about the benefits and the drawbacks of their strategic choices in a better structured and logical manner. The main information requirements concern the benefits and the side effects of possible countermeasures, in terms of feasibility, applicability, costs, health and social effects, public perception and, in general, the consequences of taking or not taking a certain countermeasure, as well as the consequences of taking no action.

The usefulness of decision analyses in evaluating and comparing protective actions strategies in nuclear emergency management has been confirmed as far as exercises and training are concerned. The role of such analyses in a real crisis is still a subject of debate (see for example Ahlbrecht et al 1997, Hämäläinen et al, 2000a). However one has to keep in mind that in case of crisis, decisions are made under conditions of stress, which narrow the perceptual scan and may cause a fixation on inappropriate decisions and a reduction of the working memory capacity. In addition, consistency in decision making is essential if public confidence is to be gained and maintained.

Given the difficulty arising from the fact that decision-makers do not know or fully understand how models actually work, it is essential that the assumptions are made explicit and that the factors addressed in such models correspond to the wishes of the people involved in the decision-making process. Otherwise they may see the models as inadequate, regardless of their level of sophistication. In any case, the decision cannot be made solely on the basis of a software selection. Personal responsibility and common sense are more important (Clarke, 2002).

2.2 Stakeholders' issues

The topic of stakeholders' involvement in nuclear emergency management has been mainly addressed through:

i) *Decision conferences*, i.e. facilitated workshops suitable for a limited number of participants and comprising the use of multi-attribute decision analytic models. They were exercised within the radiation-protection community either as 2-days decision conferences (French et al, 1993 and French, 1996), or as "spontaneous decision conferencing" events where time restrictions (on the order few hours) are imposed (Hämäläinen et al, 1998). Generic value trees are constructed based on a brain-storming approach and multi-attribute value/utility analyses are carried out in order to rank the different (limited number of) strategies considered. This technique has proved to be effective in stimulating discussions and eliciting issues for the resolution of complex problems.

ii) *Decision interviews*. In this case value elicitations are carried out with the stakeholders on an individual basis, by computer supported interviews, in addition to traditional questionnaires (Hämäläinen et al, 2000b). Similarly to i), value trees are derived and multi attribute value/utility analyses are performed.

iii) *International projects and workshops*. In the FARMING network, several rural and rural waste management strategies were screened from the stakeholders' point of view, in order to make this information more realistic and country-specific. The starting point for this study was the countermeasure templates resulting from another international project, STRATEGY. In Belgium, the stakeholders group (Vandecasteele et al, 2003) was structured with a balanced representation of various governmental and non-governmental bodies from more than 20 organizations having concerns and/or responsibilities in the management of a radiological crisis. This included representatives of the Ministries of Agriculture and Environment, the federal agencies for nuclear control and for safety and control of the food chain, the farming unions, the meat and cereal products sector, the milk and water industry, the food industry federation, the retail sector and consumers. The FARMING experience in Belgium revealed that in addition to the characteristics of the agriculture and the political environment, one also has to take into account the past experiences of food chain contamination crises. This explains why some countermeasures aiming at reducing the contamination in food products were considered hardly acceptable by the stakeholders, if at all, even when supported by scientific and technical arguments.

This kind of workshop leads to an improved understanding and common problem definition, decreasing in this way the contradictions between opposing stakeholders.

If data related to radiological effects of food countermeasures, such as averted doses, come from radiological experts, an important knowledge comes from the other stakeholders in what regards:

- Feasibility: e.g. clean grazing is a countermeasure which is theoretically very efficient in reducing the quantity of contaminated milk, but it is not practicable in Belgium due to the intensive cattle breeding;
- Constraints of different types such as legal, economical, availability of resources (man power and tools);
- Costs, including costs for countermeasure implementation, loss of production, compensation, waste disposal;
- Consumers/producers/public acceptance. It is considered that psychological stress can lead to health effects of a comparable nature to those arising from the contamination and at the same time reduces the quality of life significantly (French et al, 1993);
- Social disruption or reassurance;
- Ethical and environmental issues.

The stakeholders' feedback can also be used to assess the correctness, robustness, availability of the information collected in crisis centres for more general crisis response purposes.

2.3 Structure of the information system

The information system architecture which we propose contains several important components: i) an interface with the GIS databases available in the crisis centres; ii) a simple interface to calculation models for input data regarding the content of specific nuclides in various agricultural products; iii) a database of potential countermeasures and information about their efficiency, feasibility, constraints, cost, consequences and side effects evaluation (including the feedback from stakeholders and experts); iv) a filtering tool to assess potential actions, depending e.g. on the nuclide composition of the release, available resources, etc; v) a multi-criteria decision aiding tool.

A similar architecture was proposed within the framework of the European decision support system RODOS, for off-site management of nuclear emergencies, (French, 1996), but from a somewhat different perspective. For example, in that case, the selection of potential food chain countermeasure strategies, as well as an important evaluation step were made outside the MCDA model, which leads to a reduction in flexibility.

The task of modelling food-chain dose estimations is presently performed by a number of models, including some developed at a European level in the framework of decision support systems for off-site nuclear emergency management. Based on such calculations and taking into account prescribed Food Intervention Levels, various actions (countermeasures) can be taken.

Application of countermeasures might be first needed to reduce the radiological risk for people living on the plume trajectory or consuming plant and animal products from the contaminated zones. But remediation actions are also necessary to restore as quickly as possible normal life in the affected regions, allowing unrestricted activities and production of clean produces, as well as to re-insure the local population.

3. MULTICRITERIA DECISION-AID FRAMEWORK

In an emergency situation where intervention is considered, countermeasures to be implemented have to be justified and optimised. From a variety of countermeasures, single or combined, the optimal strategy has to be chosen. The problem is inherently a multi-criteria one, for which the complexity increases due to the fact that countermeasures do not only have to be scientifically founded, and feasible from the technical and economical points of view, but also socially and psychologically acceptable by the concerned stakeholders. In the following we discuss the formulation of the decision problem.

i) Actors.

As briefly mentioned in section 2.1, in the context of the Belgian radiological emergency plan, the decision maker, also called the "Emergency Director" is the Minister of Interior or his representative. He is chairman

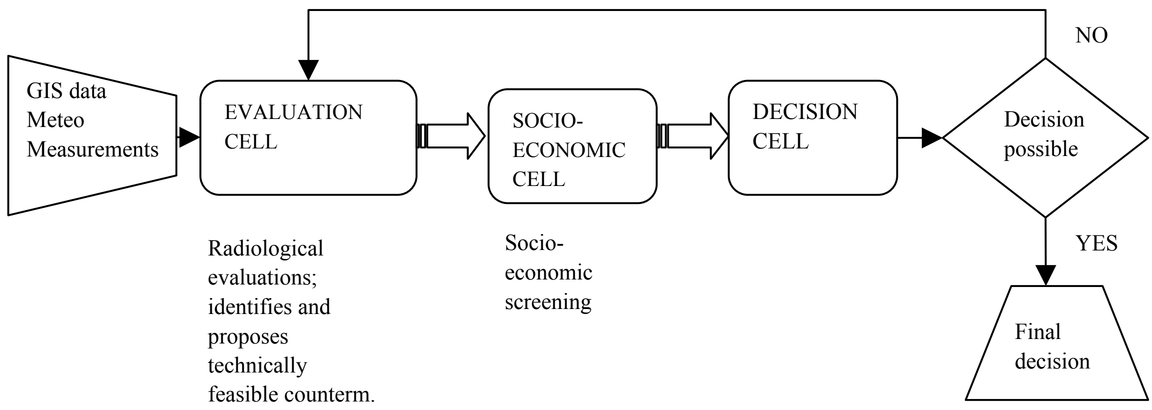

Figure 1: Countermeasure evaluation process

of the decision cell, i.e. the Federal Co-ordination Committee.

The decision cell is advised by the evaluation cell, mainly in charge with radiological and technical aspects and by the socio-economic cell (see also Figure 1).

In addition, various stakeholders have a direct or indirect impact on the efficiency of the chosen strategies.

ii) Actions.

An (individual) potential action could be defined by specifying a rural countermeasure and an associated rural waste disposal option. In practice, however, we are interested in countermeasure strategies, i.e. combinations of individual countermeasures.

The problem increases in complexity if the optimal time and the duration for the application of each selected countermeasure is also taken into consideration and optimised. In nuclear emergency management, decisions have far-reaching consequences, yet they often have to be made under time pressure and conditions of uncertainty. Also in case of food countermeasures, time may become an important issue. For example in case of milk, the large amounts produced daily vs. the limited storage facilities of diaries make it necessary to rapidly take a decision for management of contaminated milk (processing, disposal, etc).

iii) Criteria.

Different criteria may be considered: radiological (averted doses), health related (number of cancer incidents), social (acceptability), economic (costs for implementation, compensation and waste management).

iv) Methods.

Cost-benefit methods alone are not sufficient because of the 'softer and intangible' aspects, which are hard to quantify, like the psycho-sociological ones. Besides, putting an economic value to life is questionable from an ethical point of view.

On the other hand, MCDA methods offer a clearer illustration of the different kinds of information that go into decision-making, providing thus a good basis for training and discussions. Being able to handle conflicting objectives, trade-offs in criteria performance and constraints, they can guide the decision making process, by taking into account the balance between all relevant factors.

The first step is normally to apply or develop a cognitive procedure that describes in a formalized and systematic manner the various actions that can be taken, the relations between them and their consequences, expressed in quantitative and qualitative terms. This is a pre-requisite for the second step, the development of a selection procedure for actions, given the chosen attributes or family of evaluation criteria.

Depending on the way the decision aiding is envisaged, in our case one could be interested to either rank all (feasible) actions from best to worst, or to choose the best action or the smallest subset of "best" actions, in the case that some are indifferent or incomparable.

Concerning the first approach it has been argued that for decision systems which provide a ranking of alternatives there will be a temptation for the decision-maker to simply adopt the top-ranking countermeasure without questions (Kelly et al, 1997). The purpose of decision systems is nevertheless to support the decision maker, and not to supplant him.

The main application of multi-criteria decision analyses in nuclear emergency management explores the use of multi-attribute utility theory (MAUT). The interested reader can refer to French et al (1992, 1993 and 1996) and Hämäläinen et al (1998 and 2000a) for details. In this type of approach, a value tree is built by considering all factors that have an impact on the decision, including not only averted doses and cost, but also socio-psychological and other factors. The leaf attributes are the ones to which scores or values are attached. Consequently, the score or value of a tree node situated at a higher level is evaluated as a weighted sum of the values of the nodes branching from it. The method was tested in several exercises and it contributed to reaching a shared understanding between the people involved in decision making and the radiation-safety experts and to the identification of the most important attributes. Some drawbacks were nevertheless mentioned, one being related to the informational burden of adjusting associated parameters (weights). Also, when it comes to attributes like the socio-psychological ones, the process of giving weights to these non-quantifiable factors appeared questionable to the participants in exercises, partly due to difficulties in understanding and interpreting them in the same way (Hämäläinen et al, 1998).

Another approach, which has the advantage of allowing the evaluation of combinations of individual countermeasures, is due to Perny and Vanderpooten (1998). They have developed a multi-objective linear programming interactive procedure. Each objective function (cost, averted dose and acceptability) is defined as a linear function of variables representing the amounts of food product processed by an individual countermeasure on a certain area. The set of feasible strategies is explored either by restricted search (specifying constraints), partial search (if the user imposes certain values on some decision variables), or focused search (by specifying aspiration levels).

Here we must mention that the optimisation of countermeasure strategies has also been studied by means of a cost-benefit analysis (method that doesn't belong to the decision aiding class), by Cox and Crout (2003). They optimise the application thresholds for individual countermeasures, which may be given e.g. as Bq/kg or Bq/m^2. This has the advantage of reducing the dimensionality of the problem in a natural way, as one doesn't need to consider explicitly all possible combinations of countermeasures.

In the above MCDA approaches the qualitative attributes were quantified by giving them certain scores. The outranking methods (Vincke, 1992, Roy, 1996) are attractive alternatives, which allow the direct use of a preference relation for qualitative attributes. They also relax the key assumptions of the additive MAUT approach, i.e. comparability between any two actions, transitivity of preference and preferential independence of any subfamily of criteria (or attributes).

The basic principle of outranking is the "democratic principle of majority, without strong minority". In other words, an alternative *a* is preferred to an alternative *b*, if *a* performs better than *b* on a majority of criteria and there is no criterion for which *b* is strongly better than *a*.

The choice of an outranking approach may be motivated by at least some particularities of our decision problem:

- the units of the evaluation criteria (e.g. averted dose, cost, and public acceptance) are heterogeneous and coding them into one common scale looks difficult and not entirely natural;
- the compensation issues between gains on some criteria and losses on other criteria are not quantifiable;
- the process of weighting and judging is in general a more qualitative than quantitative procedure;
- preference or veto thresholds may need to be taken into account.

Several outranking methods are at hand (Vincke, 1992), depending on the formulation of the decision problem and the type of preference model chosen. Although they have a different meaning than in MAUT, in outranking methods we may still have to handle the problem of setting the weights for the different criteria. The development of robust methods can help in counteracting procedural biases. A robust outranking method has the property that its solutions, derived from different admissible method-specific parameter sets, do not contradict each other. However, in case the parameters for a given method are uniquely determined, no contradiction can appear between different solutions, and thus the method would be considered robust. To counterbalance the risk of having a solution which depends more on the method than on the particular decision problem, another interesting property may be studied, namely the neutrality. A study of robust and neutral methods for aggregation of individual preferences may be found in Vincke (1999).

4. CONCLUSIONS

Throughout the paper several issues were highlighted:
(i) the requirements expected from an information system for decision-support in the area of food countermeasures in the event of a nuclear emergency;
(ii) the importance of using the stakeholders' feedback in the decision-making process;
(iii) directions for use of multi-criteria decision aid techniques; this approach is well suited for the purpose of training new people entering the field and for organising revisions of the stakeholders' involvement process, as both the information and the people involved change rapidly.

By structuring the decision process we also gain a permanent update and learning capability of enhancing the emergency preparedness.

REFERENCES

Ahlbrecht, M., Borodin, R., Borzenko, V., Ehrhardt, J., French, S., Shershakov, V., Sohier, A., Trakhengerts, E., Verbruggen, A., 1997. Decision support issues in

RODOS: The needs of the decision makers, *Rad. Prot. Dos*, **73** (1-4), 81-84.

Clarke, R.H., 2002. ICRP Past, Present and Future: Quo Vadis ICRP 60, *Strahlenschutzpraxis*, **1**, 45-48, ISSN 0947-434 X.

Cox, G.M., Crout, N.M.J., 2003. A methodology for the selection and optimisation of countermeasure strategies. *STRATEGY Report*, www.strategy-ec.org.uk/outputs/ouputs.html.

French, S., Kelly, G.N., Morrey, M., 1992. Decision conferencing and the International Chernobyl Project, *J. Radiol. Protect.*, **12**, 17-28.

French, S., Walmod-Larsen, O., Sinkko, K., 1993. Decision Conferencing on Countermeasures after a Large Nuclear Accident, Risoe-R-676(EN) Report, Risoe National Laboratories, Roskilde, Denmark.

French, S., 1996. Multi-attribute decision support in the event of a nuclear accident*, J. Multi-Crit. Decis. Anal.*, **5**, 39-57.

Hämäläinen, R.P., Sinkko, K., Lindstedt, M.R.K., Amman, M., Salo, A., 1998. RODOS and decision conferencing on early phase protective actions in Finland. *STUK-A 159 Report*, STUK - Radiation and Nuclear Safety Authority, Helsinki, Finland, ISBN 951-712-238-7.

Hämäläinen, R.P., Lindstedt, M.R.K., Sinkko, K., 2000a. Multi-Attribute Risk Analysis in Nuclear Emergency Management, *Risk Analysis*, **20** (4), 455-468.

Hämäläinen, R.P., Sinkko, K., Lindstedt, M.R.K., Amman, M., Salo, A., 2000b. Decision analysis interviews on protective actions in Finland supported by the RODOS system. *STUK-A 173 Report*, STUK - Radiation and Nuclear Safety Authority, Helsinki, Finland. ISBN 951-712-361-2.

Keeney, R.L., 1992. *Value-focused Thinking: A path to creative decision-making.* Harvard University Press, Cambridge, MA.

Kelly, G.N., Bäverstam, U., French, S., Weiss, W., 1997. Summary and Conclusions, *Proc. IV Int. Workshop on Decision Support for Off-Site Emergency Management*, *Rad.Prot.Dosim* **73** (1-4), 298-308.

Perny, P., Vanderpooten, D., 1998. An interactive multiobjective procedure for selecting medium-term countermeasures after nuclear accidents, *J. Multi-Crit. Decis. Anal.* **7**, 48-60.

Roy, B., 1996. *Multicriteria Methodology for Decision Aiding*. Kluwer Academic.

STRATEGY Countermeasure Compendium. http://www.strategy-ec.org.uk/output/outputs.htm

Vandecasteele, C., Hardeman, F., Pauwels, O., Bernaerts, M., Carlé, B., Sombré, L., 2003. The FARMING experience in Belgium. *WISDOM International Workshop on "Extending the Involvement of Stakeholders in Decisions On Restoration Management"*, New College, Oxford, U.K., 15-17 Sept. 2003.

Vincke, P., 1992. *Multicriteria Decision Aid*, J. Wiley and Sons, Chichester.

Vincke, P., 1999. Robust and neutral methdos for aggregating preferences into an outranking relation*, Eur. J. Oper. Res.*, 112, 405-412.