Demands to and Experience with the Decision Support System RODOS for Off-site Emergency Management in the Decision Making Process in Germany

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ABSTRACT

Emergency situations, man-made as well as natural, can differ considerably. However, they share the characteristic of sudden onset, involve complex decisions and necessitate a coherent and effective emergency management. In the event of a nuclear or radiological accident in Europe, the real-time on-line decision support system RODOS provides support from the early phase through to the medium and long-term phases.

This paper describes the demands to a Decision Support System from a user-centred view as well as experiences gained from conducting moderated decision making workshops based on a hypothetical accident scenario focusing on the evaluation of long-term countermeasures using the simulation capabilities of the RODOS system and its recently integrated evaluation component Web-HIPRE, a tool for multi-criteria decision analysis (MCDA).

Keywords

Decision Support System, Multi-criteria Evaluation, Sensitivity Analysis, Stakeholder Involvement, Decision Making Process.

INTRODUCTION

One of the major observations following the nuclear accident from Chernobyl was that decision making has to be harmonised. This was the case within Europe but also evident in individual countries in particular in Germany with the responsibilities subdivided between national and state (German Länder) authorities. Initiatives emerged to overcome this problem, among others the development of a Decision Support System (DSS) for the application in whole Europe, RODOS (Realtime Online Decision Support System for nuclear emergency management). Consequently, Germany became the first country where RODOS was installed in one central location for the common use by national and state authorities.

RODOS as a computerised tool consists of various components to answer the many questions which might arise from the request of the decision making team. However, such a system has to focus on the needs of the decision making process. Therefore, the evaluation tool Web-HIPRE was recently implemented into RODOS providing support for the emergency management team in evaluating the overall efficacy of possible countermeasure and remediation strategies. This new evaluation tool in RODOS has been tested in a set of workshops in Germany to demonstrate its capabilities and to gather feedback whether or not such a tool could be applied in the decision making process in Germany in nuclear emergencies.

There are many papers focusing on the needs in off-site emergency management discussing the demands from the various viewpoints of an International, European, national or regional authority (Kelly and Hohenberg, 2004). As became apparent in the workshops, there is no need to repeat the theoretical considerations to stimulate the improvement of such a system. Instead, the authors want to focus on the needs and demands with respect to operational applicability of those leading authorities involved in off-site emergency management in Germany. Looking at the system from the viewpoint of a German user, several aspects of the system do not need to be taken into account here. For example the aquatic environment which can be considered by RODOS is not used in Germany and therefore will be not considered in this paper.

REQUIREMENTS FOR OFF-SITE EMERGENCY MANAGEMENT AND SUPPORT PROVIDED BY RODOS FROM THE POINT OF VIEW OF A GERMAN USER

Basics

The first requirement clearly states that a DSS should be installed centrally and that all the authorities involved in the decision making process should have access to the results provided by the system. Furthermore, all information available from many sources should be collected in this system and processed to provide a consistent analysis of the radiological situation. Analysing the radiological situation is the first step, but based on this information the next important step has to follow: taking decisions to protect the population. Decisions will not only be based on the actual situation but have to take into account also the development of the situation in the future as only this can guarantee to some extend, that the time dependency is considered.

For this time dependency the accident evolvement is treated as a succession of different phases. Actions may start before any release (pre-release or threat phase) by preventive measures. After a release has occurred it can be distinguished between the early or release phase (contaminated atmosphere), the late or post-release phase (long-lasting contamination of the environment) and the final long-term phase (rehabilitation of contaminated areas). While the transition from early to late phase is relatively clearly defined by the end of the deposition, the transition stage from late phase to long-term phase is much broader. Requirements for off-site emergency management partially differ during the consecutive phases of a nuclear emergency, but nevertheless share some common issues (Gering et al, 2004).

Pre-release phase

Requirements

In the pre-release phase, very little information is available for decision making. Only in-plant information is accessible to estimate whether a release is likely to occur, its severity and possibly when the release might start. On the other hand, protective actions can be carried out most successfully before the release has started. Once the radioactive cloud has started to spread out, there is little time for actions except to shelter the population.

Therefore, most important is the knowledge of the potential radiological source term and to perform atmospheric dispersion calculations with prognosticated weather for the next hours to collect all the necessary information if there is a need to initiate early countermeasures.

What RODOS offers

RODOS provides atmospheric dispersion calculations based on numerical weather prediction data obtained automatically from the national weather service or – as it is the case in Germany – send in on request. The data cover the area of about 200 x 200 km with the nuclear power plant in the centre and a resolution of 7 by 7 kilometres. Updates will be delivered at least twice a day and one prognostic data set contains hourly data for 48 hours. A meteorological pre-processor calculates the local wind field and the necessary boundary layer parameters applying a mass-consistent wind field model. Based on the prognostic calculations, RODOS assesses contaminations and doses and estimates the timing and the extend and duration of countermeasures in accordance with the dose or contamination limits in Germany; in the pre-release phase these countermeasures are mostly limited to early measures such as sheltering, distribution of stable iodine and evacuation.

Parallel to the development of the RODOS system, software tools have been developed under the ASTRID and STERPS projects (ASTRID and STERPS standing for “Development of a methodology and of a computer tool for source term estimation in case of nuclear emergency in a light water reactor” and “A rapid response source term indicator based on plant status for use in emergency response” respectively), which enable, in the event of an emergency situation in a light water reactor, the monitoring of the progression of an accident from the moment it is detected, to forecasting the future behaviour of the reactor and estimating the ongoing and the potential releases as a function of time (Schulte et al., 2002). An interface between these tools and the RODOS system has been successfully tested.

Release phase

Requirements

As soon as a release starts, the fast analysis of the radiological situation is of highest priority. Analysis consists of the information on the source term – available if the release is measured by the stack monitors - and on the radioactive contamination in the surroundings of the Nuclear Power Plant (NPP). Information is mainly available from fixed gamma dose rate monitors, in addition meteorological data from the local tower and sodar can be used to perform diagnostic atmospheric dispersion calculations. As models are uncertain, there is a clear need to compare measurements and model simulations and to have a tool which combines both to the best available estimation of the radiological situation. Only the assimilation of measurements and simulations can assure that decisions are taken on the basis of all information available and not only on partial information from either side. Information has to be made available as soon as possible, i.e. model runs and also data acquisition, transfer and processing have to be achieved within minutes.

What RODOS offers

As the use of local meteorological data was a key objective from the user, the so-called “Automatic mode of operation” was introduced into the RODOS system. Within this mode, local meteorological data as well as stack emission data are used to perform diagnostic atmospheric dispersion calculations. In addition, automatic prognostic calculations are performed every 30 minutes, covering the next 24-hour time period and providing information to all important countermeasures, in particular to those relevant for the early phase of an accident. The only interaction with the system by the operator is the input of a potential source term, if not monitored by detectors in the stack.

Having experienced this mode in many national and international exercises, the German users of the system requested as further improvement that the start of the RODOS system in the Automatic mode and its basic input should be facilitated in a way that it can be triggered by sending a simple message to the system, e.g. by the emergency management personnel on-call from a remote computer or a mobile phone. This would assure that if the accident happens out of office hours, the system could provide first results already when the emergency management team arrives and starts working.

Data assimilation tools performing during the release phase are under development combining monitoring results and diagnostic information from the atmospheric dispersion calculations. However, these tools are at the moment not operational for the release phase and still have to proof their applicability in an emergency situation.

Post release phase

Requirements

The main aim in decision making in the later phase is to establish again save living conditions for the population including any remediation action necessary to achieve this objective. As soon as the release has stopped and the radioactive cloud has left the area under observation, mainly information for two different aspects are necessary:

- Lift/prolongation of actions initiated earlier
- Initiation of longer term actions such as relocation, decontamination and agricultural countermeasures

In particular in the beginning of the post release phase when more and more measurements are available but still gaps have to be filled with results from models, data assimilation is the most important tool to provide a consistent analysis of the radiological situation. At that time data purely based on atmospheric dispersion calculations is no longer sufficient as basis for decision making. Decisions will be taken in this phase mainly based on measurements, however simulation models are still required to estimate the evolution of the radiological situation in future. This is in particular important for inhabited areas in which save living conditions have to be established and thus decontamination might be necessary and in agricultural areas where production of clean food has to be assured.

There are obvious differences in decision making in the early and the later phases of an accident. In the early phase the key objectives are radiological aspects, in particular to save lives and to prevent deterministic health effects. These objectives will never be altered by e.g. taking into account the resources spent to achieve this goal.

In the later phases more and more countermeasure options become available and it is important to consider not only the radiological aspects but also to compare and evaluate the benefits and drawbacks of different countermeasure and remediation strategies from a wider perspective (e.g. costs, effort, feasibility, public acceptance, psychological and political implications, preferences or values of decision makers, etc).

What RODOS offers

The analysis and the future evolution of the contamination in the environment can be assessed inside RODOS either based on measurements, on atmospheric dispersion calculations and for the first time based on data assimilation tools which combine measurements and predictions for agricultural areas. Even in a pre-operational stage, the data assimilation tools for the late phase have demonstrated their usefulness in the preparation of the 4th DSSNET exercise (where DSSNET stands for “Improvement, extension and integration of operational decision support systems for off-site nuclear emergency management”) (Ehrhardt, 2004).

Several food chain modules are implemented in RODOS providing information for semi-natural and agricultural environments. These models are the basis for the simulation of the various countermeasures in inhabited or agricultural areas. Up to 12 individual agricultural countermeasures – some of them can be combined – and up to 14 alternatives for decontamination and temporary or permanent relocation are available for the simulations in the later phase. The relative merits and disadvantages of the different countermeasure options can be assessed and presented to the emergency management team.

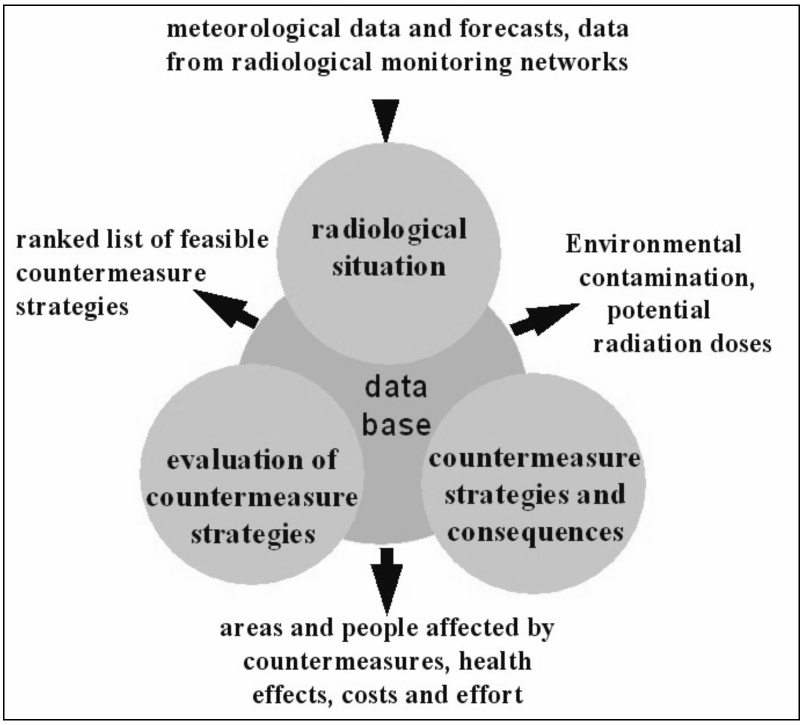

Figure 1: Information processing in the RODOS system

EVALUATION OF ALTERNATIVES

To summarise so far, the RODOS system provides coherent decision support at all levels ranging from largely descriptive reports, such as maps of the predicted, possible and, later, actual contamination patterns and dose distributions, to a detailed evaluation of the benefits and disadvantages of various countermeasure strategies and their ranking according to the societal preferences as perceived by the decision makers (see Figure 1). It is also able to perform ”what-if” calculations, allowing investigation of how the situation may develop under different scenarios.

Since decision making in emergency management involves resolving many conflicting objectives, setting priorities, and perhaps most importantly, bringing the various perspectives of the many stakeholder groups into some form of consensus multi-criteria decision analysis (MCDA) is vitally important to ensure transparency during the decision making process (Belton and Stewart, 2002), (French, 2000), (Hämäläinen, 2003), (Sinkko, 2004), (Geldermann and Rentz, 2004). Using modern decision analytic techniques (MAV/UT - multi-attribute value and utility theory), RODOS provides support for the emergency management team in evaluating the overall efficacy of possible countermeasure and remediation strategies applying the recently integrated evaluation tool Web-HIPRE.

A set of workshops were initiated to demonstrate the capabilities of the module and to gather feedback whether or not such a tool will be applied in Germany; and if there was positive feedback to which extend the tool has to be further developed and/or customised. Within a series of scenario focused decision making workshops organised across Europe, two workshops were performed in Germany, one focusing on the evaluation of countermeasures and clean-up actions in inhabited areas (see: Geldermann et al., 2005), the other focusing on evaluating agricultural countermeasure and remediation strategies.

Short description of Web-HIPRE

Various software tools for MCDA are available today. A modified version of Web-HIPRE, a Java-based software for decision analytic problem structuring, multi-criteria evaluation and prioritization (Hämäläinen and Mustajoki, 1998), (Mustajoki and Hämäläinen, 2000), has been integrated into RODOS as Evaluation Subsystem (ESY) in order to provide a transparent and coherent evaluation of alternative countermeasure and remediation strategies after a nuclear or radiological accident (Geldermann et al., 2005). Web-HIPRE offers both Multi-Attribute Value Theory (MAVT) and Analytic Hierarchy Process (AHP) elicitation methods for decision support (Salo and Hämäläinen, 1997), (French and Xu, 2004). Furthermore, it provides the possibility of illustrating the composite priorities and performing a sensitivity analysis, i.e. an examination of the robustness of the choice of an alternative when the weight of an objective is varied. "Composite priorities" denote the overall values of the different alternatives under consideration.

An "Explanation Module" (Papamichail, 2000), (Papamichail and French, 2003), that produces reports to explain the results of the decision analysis, was integrated into Web-HIPRE in order to enhance the understanding of the evaluation process, thus contributing to the direct involvement of the decision makers with the aim of forming an audit trail for the decision making process and increasing the overall acceptance of the entire system.

The Scenario focused Workshops

The parties involved in nuclear emergency management have different views and responsibilities (Carter, 2004), (French and Geldermann, 2004), (Hämäläinen et al., 2000), (Sinkko, 2004), (Geldermann et al., 2005). Decision makers (DMs) are those responsible for the decision. Stakeholders share, or perceive that they share, the impacts arising from a decision and therefore they claim that their perceptions should be taken into account. Experts provide economic, engineering, scientific, environmental and other professional advice. Analysts are concerned with the synthesis of the DMs' and stakeholders' value judgements and the experts' advice (Belton and Stewart, 2002). In addition, they guide and assist the DMs and know how to operate the MCDA algorithms.

Moderated workshops on "Decision analysis of long-term countermeasures after an accidental release of radionuclides" were organised by the Federal Office for Radiation Protection (BfS), Freiburg, Germany, the Forschungszentrum Karlsruhe (FZK), Karlsruhe, Germany and the French-German Institute for Environmental Research (DFIU) of the University of Karlsruhe (TH), Karlsruhe, Germany. The participants, including officials and experts from regional, state and federal authorities, represented the different stakeholder and expert groups in emergency management in Germany.

The first workshop, held in November 2003, focussed on a scenario for inhabited areas. During the second workshop, held in Mid-August 2004, agricultural countermeasures were discussed. One of the aims was to prepare a decision tree to be used during the international DSSNET emergency exercise 2004 (Ehrhardt et al., 2004).

Scenario description

The scenario for inhabited areas and the agricultural scenario were treated separately as the contamination pattern needed to effectively discuss the countermeasures for inhabited areas is very different to the one needed for agricultural measures. For the scenario for inhabited areas relatively high contamination in one city was chosen and countermeasures such as decontamination, relocation or temporary evacuation were discussed. A low to intermediate contamination of a larger area with important food production e.g. milk provided the scenario to discuss agricultural countermeasures and remediation strategies such as disposal of food, feeding of cows with uncontaminated feed and processing of milk.

Nevertheless in both cases the contamination situation was assumed to be caused by a hypothetical serious accident at a nuclear power plant in Northern Germany, which caused an immediate shutdown of the reactor. A few hours after the accident the fictitious release of radioactive material into the atmosphere started and lasted over a period of a few hours. According to historical weather conditions the radioactive cloud was blown over a city of 28000 inhabitants in the scenario for inhabited areas. In the agricultural scenario the radioactive cloud passed mainly agricultural areas and radioactive material from the cloud deposited onto the ground. Both scenarios included heavy precipitation and even thunderstorms resulting in local inhomogeneities of the ground contamination. It was assumed in both cases that about 50% of the plant inventory of radioactive noble gases and about 0.1% of the plant inventory of radioactive iodine and radioactive aerosols were released during the accident. In the near range (up to 1 km from the NPP) the dose rate reached up to 1000 μSv/h (micro Sievert per hour), while at distances larger than 25 km the dose rate varied between 0.01 and 50 μSv/h, corresponding to ground concentrations of up to several thousand kBq/m^2 (kilo Becquerel per square meter) for radioactive iodine and aerosols.

It was assumed that all necessary immediate and early countermeasures were taken in selected affected areas. These included distribution of stable iodine to children and adults, sheltering or evacuation. Also the closure of green houses and animal stables and the coverage of agricultural areas with vegetables, fruit and herbs, and of open storage for animal feed and foodstuffs were recommended.

For the scenario for inhabited areas the city was explicitly divided in zones of different dose levels. Calculations for the agricultural countermeasures were based on maximum permitted levels of radioactive contamination in feed- and foodstuffs; the countermeasures were calculated in those areas where the predicted contamination would exceed these limits.

Decision analysis in the workshops

The analysis and structuring was done in moderated discussions. The workshop participants determined the relevant decision criteria from the list of criteria available in RODOS or prepared by BfS. In the scenario for inhabited areas they also selected the strategies (combination of countermeasures in different zones) to be evaluated. One example of the criteria provided is the avoided individual dose for children, another is the necessary number of workers needed to conduct a measure. Additional important criteria which were not provided were identified and values denoted by the group such as acceptance of the public, of affected producers and of trade and industry.

Collecting, structuring and assorting of information during the discussion provided deeper insight and lead to shared understanding. The structuring and modelling process resulted in a decision tree which, for instance for the agricultural scenario, shows the ”total utility“ (of an “Alternative” resp. a measure) as the top criterion (overall goal) being split up into the criteria ”radiological effectiveness“, “resources”, ”impact” and “acceptance”, each of which is split up again (cf. Figure 2).

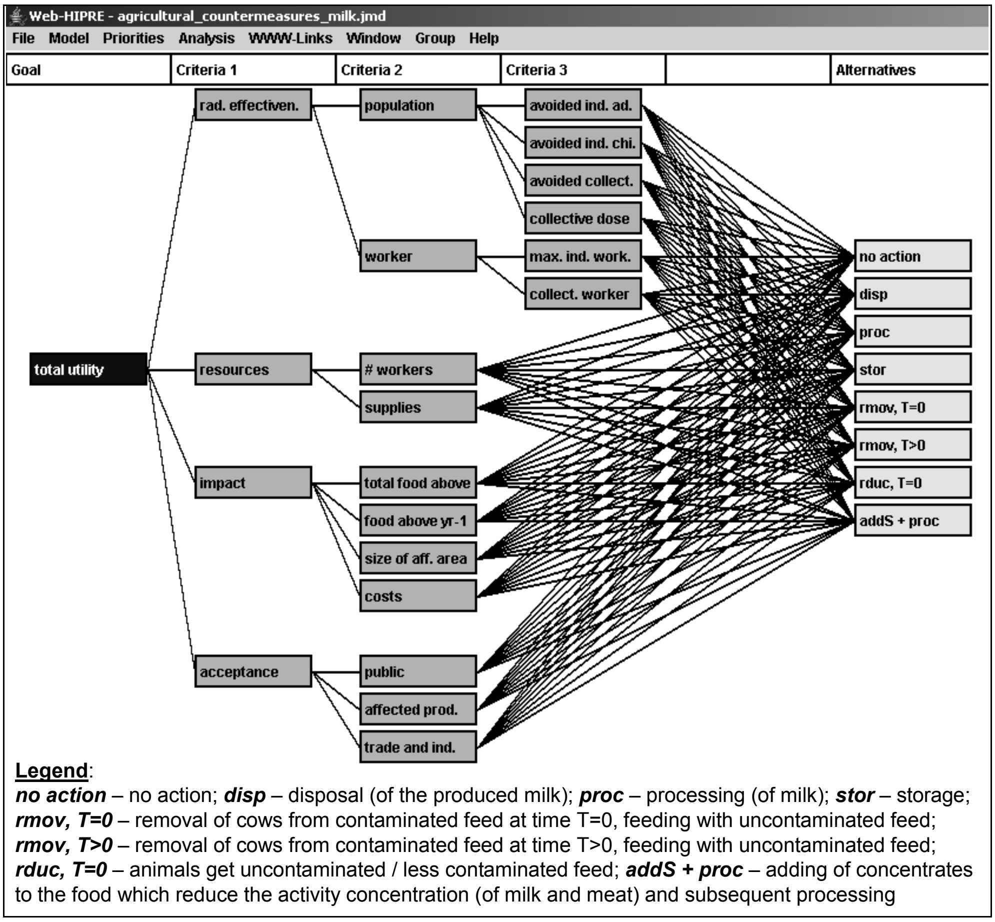

Figure 2: Decision tree (in Web-HIPRE) of the agricultural scenario

A first step of the preference elicitation is the weighting of the criteria of the decision tree, followed by the definition of the value functions and their shape for each individual attribute. After the preference elicitation the composite priorities were calculated and illustrated by Web-HIPRE (cf. Figure 3). These show the overall ranking and the contributions of the criteria to the choices of the countermeasure or remediation strategies for the weightings and value functions fed into Web-HIPRE. E.g. in case of the agricultural scenario (cf. Figure 3), the criterion “acceptance” provides a large contribution to the good overall performance of both of the (according to the analysis) two best alternatives (“rmov, T=0” and “disp” standing for “removal of cows from contaminated feed at time T=0, feeding with uncontaminated feed” and “disposal of the produced milk” respectively) whereas “impact” is the most important factor in differentiating between them.

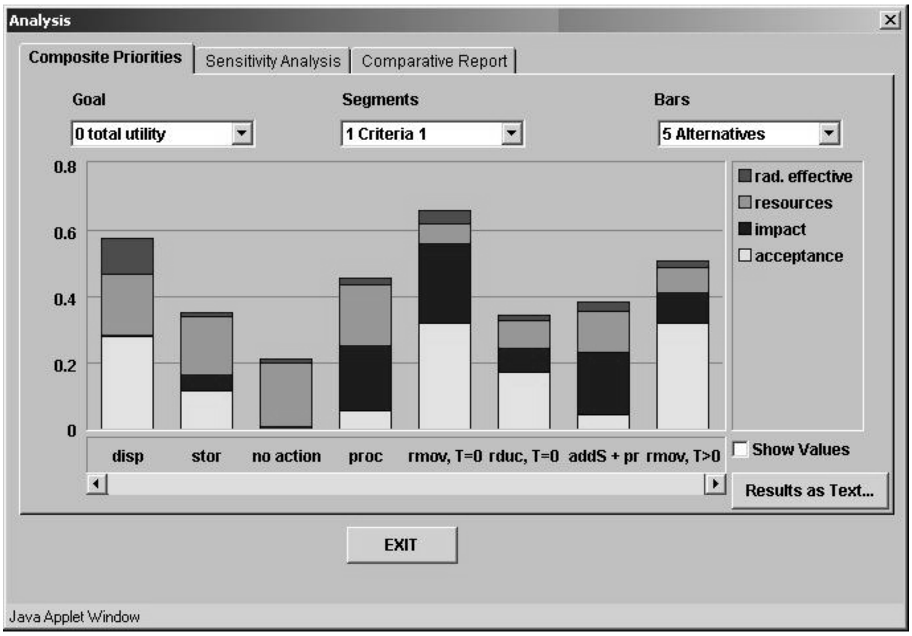

Figure 3: Composite Priorities (overall values) of the alternatives evaluated in the agricultural scenario

In addition, the sensitivity analysis allows the examination of the robustness of an alternative relative to changes of the weight assigned to one criterion, for example "acceptance" (cf. Figure 4). Moreover, the sensitivity analysis graph shows the range of weights for one such criterion for which an alternative is the most preferred. For instance, under the assumptions made in the second workshop, Figure 4 shows that the weight for "acceptance" can be changed by approximately 26 % without changing the optimality of "rmov, T=0". For a further reduction of the weight, "proc" standing for "processing of milk" turns out to be the best choice.

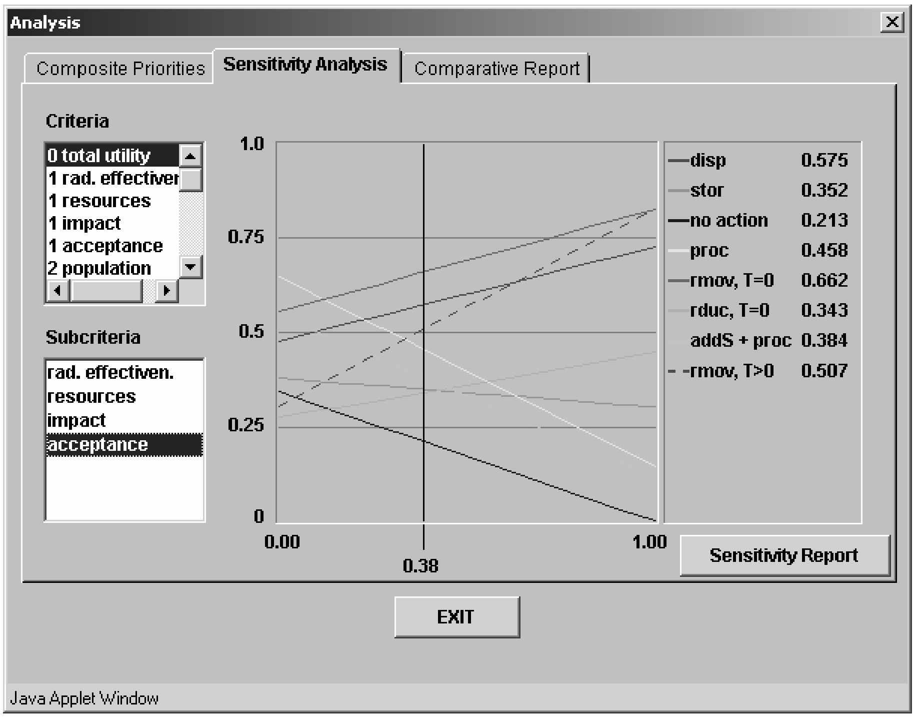

Figure 4: Sensitivity Analysis on the weight of acceptance within the agricultural scenario

Finally, the explanation module was used to generate comparative reports as well as sensitivity analysis reports to provide the results of the decision analysis in natural language format. In particular, in the second workshop, a comparative report for "rmov, T=0" and "disp." (cf. Figure 5) allowed to gain deeper insight into the factors differentiating between the two alternatives.

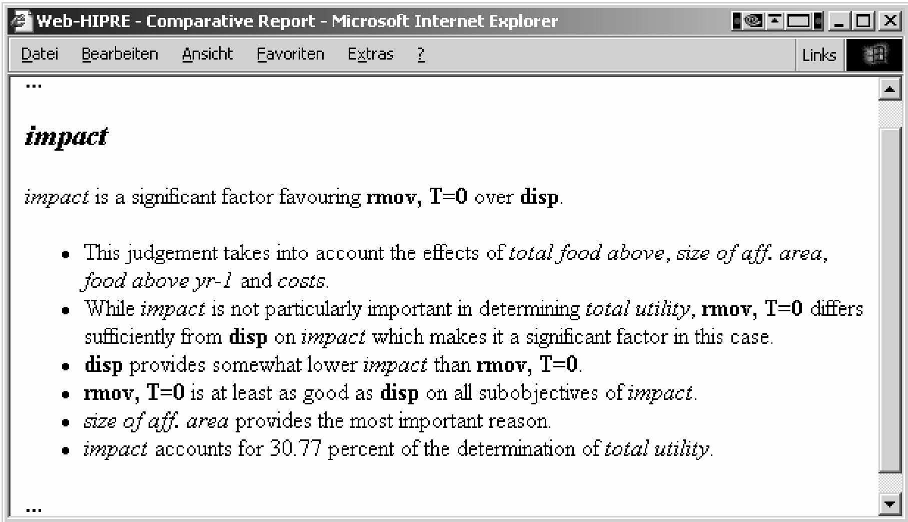

Figure 5: Extract of a comparative report

FEEDBACK AND WHAT WE HAVE LEARNED FROM THE WORKSHOPS

The application of the RODOS system including Web-HIPRE in the workshops has highlighted the potential of the system and also its needs for further improvements. The feedback from the attending experts was positive and the application of the evaluation tool Web-HIPRE was well accepted. The general tendency of the response was that the workshops were considered to be very useful for training purposes and that decision analysis helps to ensure the transparency of decisions and to understand the opinions and views of other participants. Particularly the sensitivity analyses and to some extend also the comparative and sensitivity analysis reports were perceived as a valuable benefit for decision making.

Later phase countermeasures in both the scenario for inhabited and agricultural areas together with remediation strategies have not been discussed previously in a similarly composed group of people coming from various levels of decision competence and diverse background of expert knowledge. It should be noted that the composition of the participants in the workshop may differ from the group of stakeholders and experts in case of a nuclear emergency. Likewise it cannot yet be concluded that the tool and method totally fit into a real emergency management decision process. However, the fact that the composition of an emergency management team cannot be fully predicted points up the necessity of a transparent decision support system and the capability of forming an audit trail for decision making processes.

Although the RODOS results provided a very valuable starting point, the information available did not match all the needs of the workshops, especially in the case of the scenario for inhabited areas. Sensible combinations of different countermeasures and decontamination techniques as well as a user selection of those areas, where these measures should be simulated/evaluated were the most important deficiencies. The importance of a wide range of results and information of high quality and high transparency as the basis of the decisions became evident. This includes not only radiological data, but also background information like population densities etc., where a high quality and clear definition of the underlying data and model assumptions is required as basis for decision making.

The participants identified as major drawback of the method that the tools used were not able to reflect the sequential and iterative process of decision making in real life. They noted that in a real emergency, decisions on countermeasures would be taken sequentially, with the iteration of including up-to-date measurements for each new decision. This led to the most challenging request for the further development of the longer-term countermeasure simulation models to include capabilities to define more complex strategies. A strategy has to include different types of measures applied at different times, but partly overlapping in time and possibly different in individual areas. Furthermore, it was highlighted, that the input parameters of a decision making model may be subject to uncertainties. Thus, sensitivity analyses are important for the robustness of a decision and advanced multi-criteria methods that take approaches for uncertainty modelling and sequential decision making into account are required.

Nevertheless the attending officials and experts saw a large benefit in adding transparency into the decision making process and providing information on the robustness of the decision examined in the sensitivity analyses. To further evaluate the robustness of the decisions and to facilitate the use of Web-HIPRE, more workshops with their structured and facilitated way for stakeholder involvement are necessary, especially for agricultural countermeasure and remediation strategies.

To summarise, multi-criteria decision analysis was considered to be a suitable framework for supporting, structuring and documenting decision processes and for providing transparency within emergency management. To ensure that the recommendations will result in model improvement, corresponding tasks were defined within the EC's 6th Framework Programme under the integrated project EURANOS.

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