Approaches to visualisation of uncertainties to decision makers in an operational Decision Support System

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Abstract

Decision making in case of any emergency is associated with uncertainty of input data, model data and changing preferences in the decision making process. Uncertainty handling was from the beginning an integral part of the decision support system RODOS for the off-site emergency management following nuclear or radiological emergencies. What is missing so far is the visualisation of the uncertainties in the results of the model calculations.

In this paper we present the first attempt to visualise uncertain information in the early and late phase of the decision making process. For the early phase, the area of sheltering was selected as example. For the later phase, the results of the evaluation subsystem of RODOS were selected being used for the analysis of remediation measures such as agricultural management options.

Both attempts are still under discussion but the presentation of the early phase uncertainty will be realised in the next version.

Keywords

Uncertainties, visualisation, decision support system, RODOS.

INTRODUCTION

Decision making in most areas of industry and society rely on computerised systems which collect and visualise the necessary data on the one hand but on the other hand provide means to analyse various alternatives related to their respective benefits and drawbacks. In the event of a nuclear or radiological emergency in Europe, real-time online decision support systems such as the RODOS system will support authorities and decision makers in selecting the 'best' possible option, so that the harm to the public is minimised (Ehrhardt and Weiss, 2000). RODOS provides decision making at all levels ranging from largely descriptive reports, such as maps of the contamination patterns and dose distributions, to a detailed evaluation of the benefits and drawbacks of various countermeasure or remediation strategies and their ranking according to the societal preferences as perceived by the decision makers (Ehrhardt and Weiss, 2000; French et al., 2000; Raskob et al., 2005). Figure 1 shows its conceptual structure with the main three subsystems: The "Analysing Subsystem (ASY)", the "Countermeasure Subsystem (CSY)" and the "Evaluation Subsystem (ESY)".

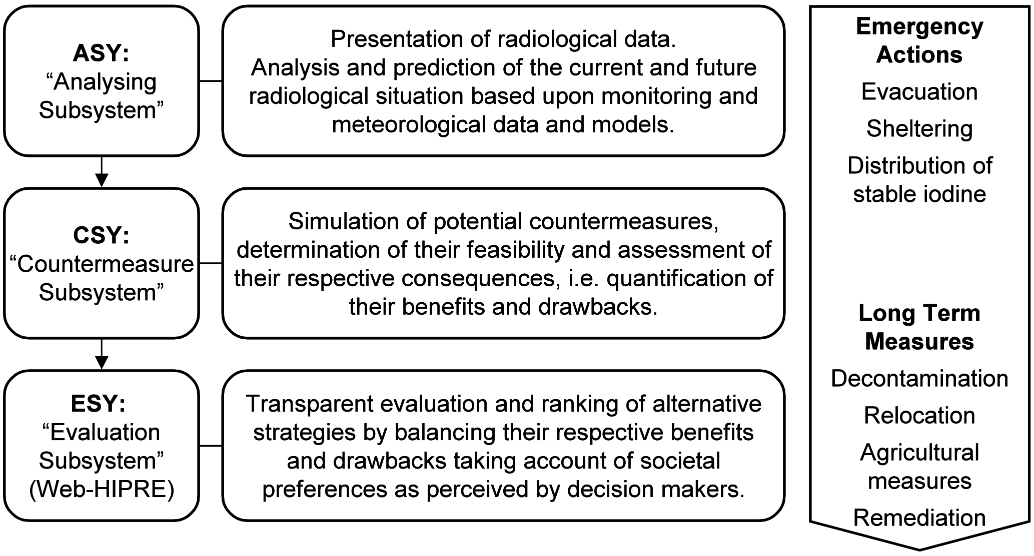

Figure 1: The conceptual structure of RODOS

The first step in the decision making process following a radiological or nuclear incident is the analysis of the actual situation which comprises the estimation of contamination levels in the environment. This can be either based on simulation models for the dispersion of radionuclides in the atmosphere, hydrosphere and the food chain or rely on monitoring results from fixed stations or mobile teams. Thus, the ASY consists of a model chain starting with models for calculating the atmospheric transport and dispersion in the near and far range, followed by a model for calculating the deposition to soil and plants, and finally food chain and dose models for simulating the transfer of radionuclides from the deposition into foods, as well as resulting radiation exposure. If needed a hydrological model chain (considering run-off of radionuclides from watersheds, transport in river systems, behaviour in lakes and reservoirs) can be inserted in between the deposition model and the food chain and dose models (cf. Gering, 2005). The prediction of the radioactive dispersion through the various pathways and thus the prediction of the radiation exposure of the population before and during the incident is one of the important tasks within the radiological and nuclear emergency management.

In the early phase, emergency management involves decisions on measures of disaster response, such as evacuation, sheltering or distribution of stable iodine tablets. Such measures are usually limited to areas within a few tens of kilometres around the release location. Since decisions on whether or not to implement such measures depend to a great extent on the spread of the radioactive plume and the estimated contamination levels, emergency management in the early phase is closely related to the predictions of the ASY (see Figure 1). In the longer term, more complex decisions on decontamination and remediation strategies, restricted access measures (e.g. relocation) and agricultural countermeasures are required (Bertsch et al., 2006; Geldermann et al., 2009). Many parties with different viewpoints are involved and many conflicting objectives must be resolved. Priorities must be set, and perhaps most importantly, a consensus must be found for the various perspectives of the many stakeholder groups. Both, the early and later phase emergency management are part of the calculations of the CSY (Countermeasure Subsystem). However, due to the higher complexity in the later phase, the ESY

(Evaluation Subsystem) was developed to support the evaluation of the alternative countermeasure and remediation strategies, whose potential benefits and drawbacks are quantified by the CSY (see Figure 1).

The decision making process supported by RODOS is subject to various sources of uncertainty whose handling is a fundamental part of good decision making. The occurring uncertainties can be classified in many different ways (see for example Morgan and Henrion, 1990; French, 1995; Gering, 2005; Geldermann et al., 2006). According to their respective source, a distinction can be made between “data uncertainties” (uncertainties of the input data to a model, also sometimes called “model forcing”), “parameter uncertainties” (uncertainties related to the model parameters, such as the weighting factors of a MCDA model) and “model uncertainties” (uncertainties resulting from the fact that models are ultimately only simplifications/approximations of reality (see French and Niculae, 2005)). Model uncertainties can have a significant impact on the results of the decision making process. However, they are difficult to quantify and can also be regarded as inherent to the nature of any model. Therefore we focus on data and parameter uncertainty in this paper. Parameter uncertainties are usually examined by means of (parametric) sensitivity analyses (Dinkelbach, 1969; Morgan and Henrion, 1990). The use of sensitivity analyses in the scope of nuclear emergency and remediation management, allowing to examine the effects of varying a weighting factor of a MCDA model, is for instance described in (Raskob et al., 2005; Bertsch et al., 2006; Geldermann et al., 2009).

However, the different types of uncertainty are of varying importance in the different phases of emergency management (see Figure 2). While in the early phase, the RODOS calculations, in particular the predictions of the ASY, are strongly affected by the uncertain input data (especially the source term and the wind fields), this source of uncertainty can be reduced in later phases when reliable measurements are available and integrated into the model calculations. Contrarily, the importance of the model parameters, especially the preference parameters, increases in later phases. In the early phase, preference parameters do not play such an important role since they are related to the ESY which is not primarily intended to be used in this phase. In the late phase, in which the ESY is intended to support decision makers in coping with complex decision situations, the uncertainties associated with the preference parameters which need to be elicited can have a significant impact on the outcome of a decision making process. Consequently, sensitivity analyses play an important role in the late phase providing support to investigate the stability of the results with respect to variations of the subjective preference parameters.

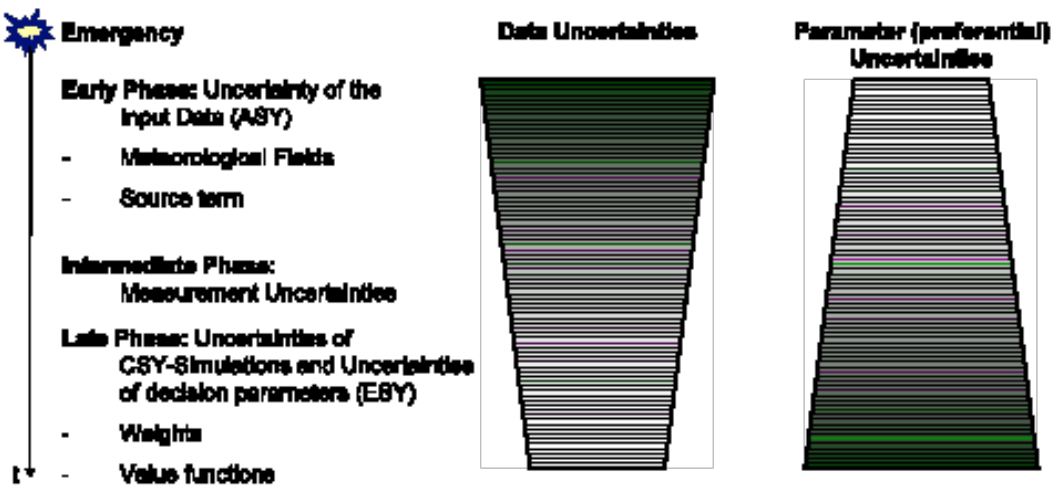

Figure 2: Importance of different types of uncertainty in different phases of emergency management

The objectives of this paper are to present a concept for handling the uncertainties in the ASY and ESY and the visualisation of their impact on decision making. As the uncertainties are different in the ASY and ESY, two different approaches and examples are presented. This paper is also issued to receive feedback as visualisation of uncertainties is not well appreciated by decision makers in the nuclear risk and emergency management – at least this is the result from many exercises in the German context – even if their importance is well understood (Gering, 2008).

Visualisation of uncertainties can be realised in various ways. The following techniques were identified as important for visualisation according to Griethe and Schumann (2005).

- Utilisation of free graphical variables such as colour, size, position, clarity, fuzziness, transparency and edge crispness
- Integration of additional graphical objects such as different images and uncertainty glyphs
- Use of animation to represent uncertainty in a dynamic way using parameters such as speed, duration, blinking and motion blur
- Interactive representation with direct interaction via mouse clicks with the user
- Addressing other human senses by the use of acoustic, e.g. pitch, volume or rhythm or haptic senses, e.g. touch or vibration

In our paper we focus on the usage of graphical variables such as colour codes and uncertainty probability images.

UNCERTAINTY HANDLING AND VISUALISATION IN THE ASY

Uncertainty handling in RODOS is thoroughly connected to data assimilation. Data assimilation was introduced in the system as in particular in the early phase of an emergency both the monitoring information and model predictions are available for analysing the situation. In most cases, these two types of information do not fit or even worth contradict each other. To avoid such a potential confusion, data assimilation methods for combining measured data with model predictions were developed. The aim is to smoothly change from pure model output to a description of the radiological situation mainly based on monitoring data and measurements and thus obtain a more consistent analysis of the radiological situation based on both monitoring and modelling. Data assimilation procedures are based on the Bayesian approach and thus require uncertainty handling as integral part of the methodology (Gering, 2005). Data assimilation techniques were first introduced in the atmospheric transport and dispersion models of the ASY sub-system and example calculations are used here in this paper.

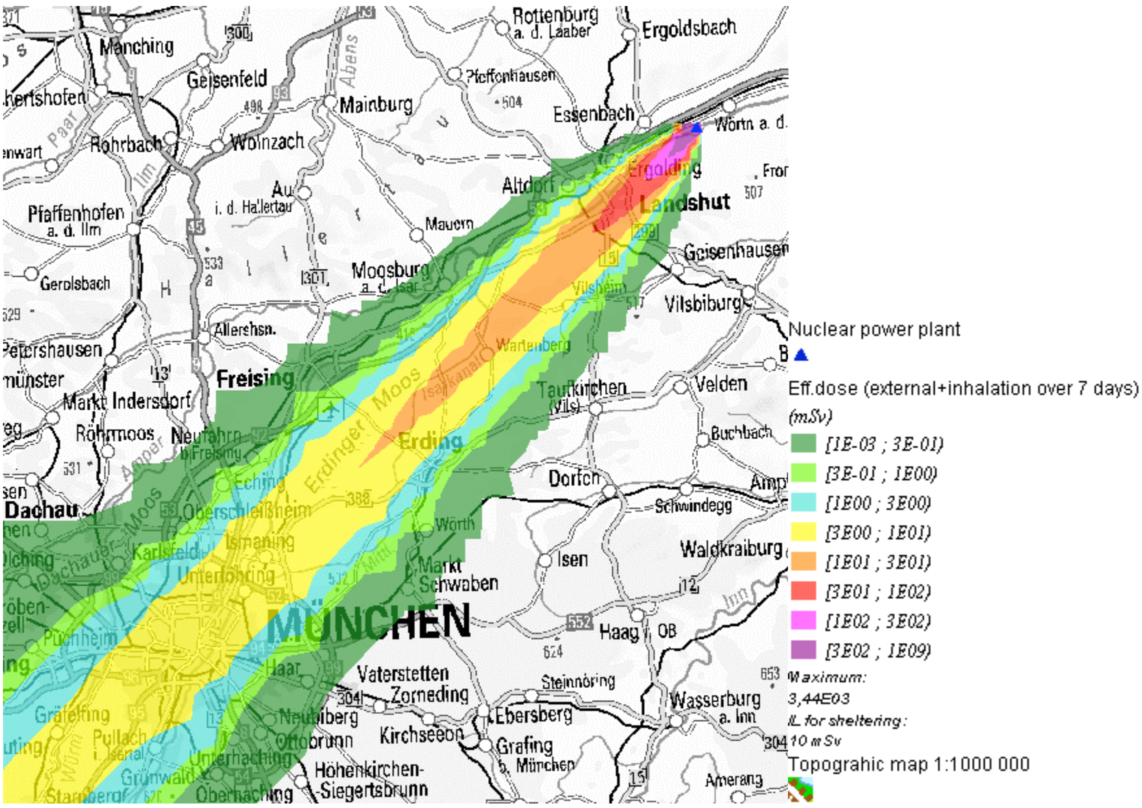

Figure 3: Illustrative atmospheric dispersion result of the ASY: Projected effective dose (external + inhalation over 7 days) in mSv at the end of the prognosis time interval for a hypothetical accident scenario

A typical result of the ASY is shown in Figure 3. On the basis of initial estimations of the source term and wind field data, the ASY predicts the atmospheric transport and dispersion of the radioactivity. These predictions constitute an important input for decisions on evacuation, sheltering or the distribution of stable iodine tablets in the early phase. Since the predictions are strongly affected by the uncertainties associated with the input data, a deterministic representation as in Figure 3 does often not provide a reliable basis for decision making. Consequently, an effective and easily understandable approach is needed providing a rapid overview of the uncertainties' impact on the results of the dispersion and based thereon the dose calculations as doses build the basis for any countermeasure simulation.

The main source of uncertainty for atmospheric dispersion modelling is the input data - here primarily the source term data - the effective release height and the wind field data. Dispersion parameters and plume rise parameters also contribute to the uncertainty of dispersion results, but typically to a lower extent. Bearing the complete RODOS model chain in mind, propagating these initial uncertainties through the models is a major challenge, especially for high-dimensional, non-linear models. Therefore, a Monte Carlo approach is chosen, in which probability distributions of variables are approximated by ensembles of values sampled according to their pre-defined probability distributions. The uncertainties of the model results can then be assessed by propagating these probability distributions through the model. This means, that multiple data sets (forming an ensemble) are calculated with the dispersion model, each based on a different set of variables sampled from the probability distributions. Consequently, each data set of such an ensemble can be seen as one potential result of the atmospheric dispersion calculation. The probability distributions of the variables considered was derived based on the findings of a European uncertainty study dealing with precurser of the current dispersion model in RODOS (Goossens L. H. J., Jones, J. A. and Ehrhardt, J, 2001).

In our example with a hypothetical release from a nuclear power plant in southern Germany, uncertainty modelling concentrates on two key variables of the input data for the dispersion model: source term and wind direction. A log-normal distribution is assigned to the source term, i.e. the quantity of released radioactive material, since a deviation of an order of magnitude is considered to be equiprobable in both directions. A normal distribution is assigned to the mean wind direction with a standard deviation of 30° (see Gering, 2005). The latter one should represent potential uncertainty in the wind directions for the weather forecast modelling. The normal distribution with a standard deviation of 30° for the wind direction was selected as best estimation of the uncertainty in prediction of wind direction. However, work is ongoing in the EURANOS project to estimate the uncertainty of the wind direction based on comparison calculations of numerical weather prediction data with measurements from three German power plants (see http://www.EURANOS.fzk.de). These results will replace the assumption with realistic information in future version of RODOS.

Typical realisations for three of these ensembles (out of the 100 ensembles used here) can be seen in Figure 4.

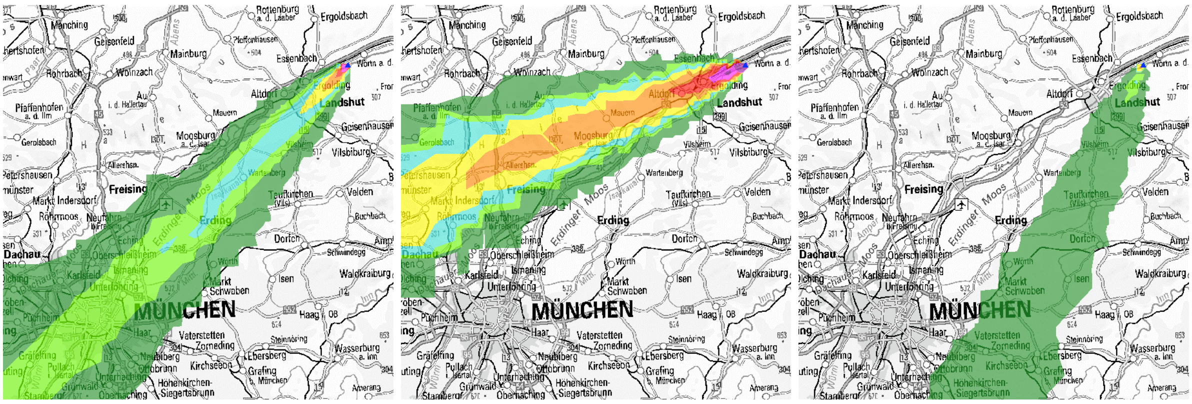

Figure 4: Different results of atmospheric dispersion calculations (Effective dose from external exposure and inhalation over 7 days in mSv as in fig.3; same legend as in Figure 3)

Individual realisations of the various parameter variations do not allow immediately to judge on the location and area of potential countermeasures such as sheltering. Therefore, a mathematical aggregation of the many ensembles seems to be necessary. One possible approach - aiming at providing a rapid overview of the situation in the light of data uncertainties - has been proposed in the scope of the ENSEMBLE project (cf. Galmarini et al., 2004a; Galmarini et al., 2004b). The basic idea of this approach is the colour coding of the percentage of individual dispersion results implying a contamination equal to or above a certain threshold value in a certain area. This approach was also introduced into RODOS within the model chain of the dispersion and early countermeasure models. The approach in RODOS gives results for the percentage of individual dispersion results leading to doses above a certain dose threshold in a certain area. Such a result can be interpreted as a probability that a dose threshold in a certain area can be exceeded. Figure 5 shows an example visualisation for the area and location of the countermeasure sheltering using the ensembles of which three are presented in Figure 4.

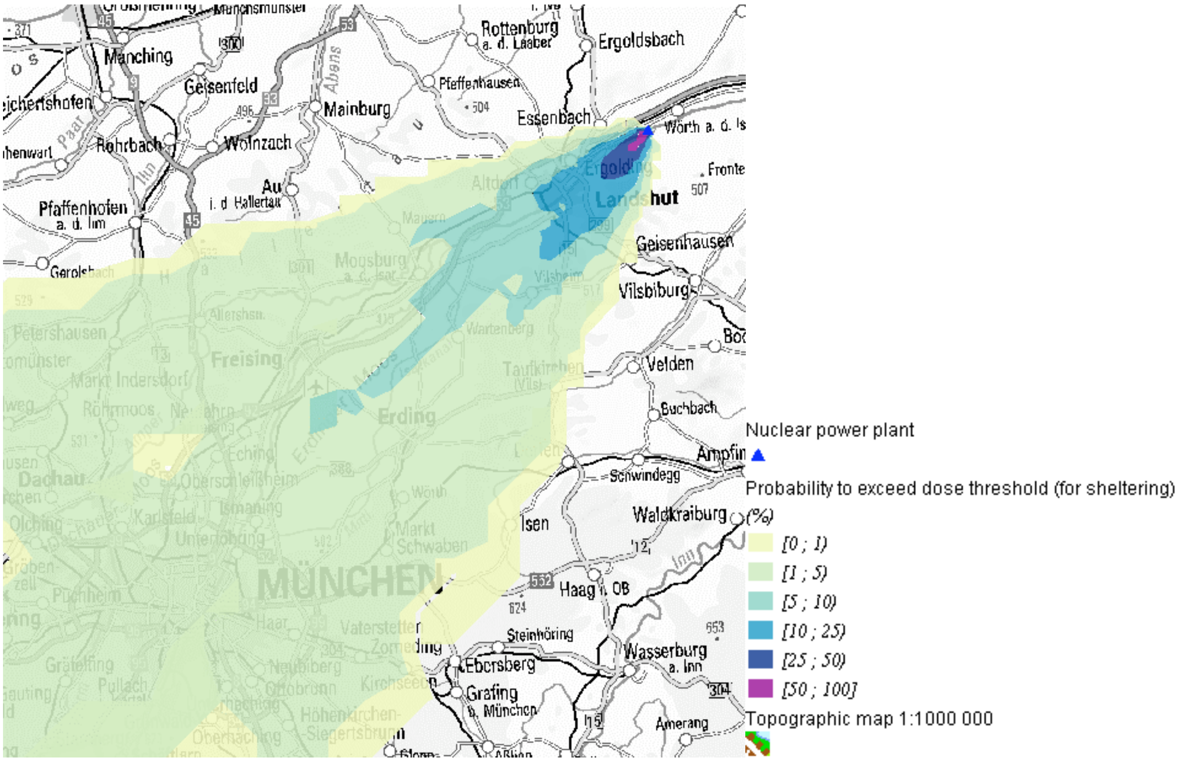

Figure 5: Proposed visualisation of the impact of data uncertainties on the area and location of early countermeasures (here the probability to exceed the dose threshold for sheltering)

Key information in this picture is the size and location area and the percentile of occurrence of this area under the given conditions. The large light green coloured area represents locations where the dose threshold was exceeded by at least one ensemble. Thus the 0-5% probability of exceeding the dose threshold result in large areas and represents the conservative or worst case assumptions – in terms of preparing for the emergency. The dark blue and violet colour defines the area where many ensembles exceed the intervention level. Thus selecting a probability of e.g. more than 50% exceeding the intervention level results in small areas and represents optimistic or best case assumptions.

UNCERTAINTY HANDLING AND VISUALISATION IN THE ESY

At the later stages of an emergency, decision making is not any longer driven by the urgency of the management actions since the immediate response measures, such as sheltering and evacuation, have been initiated or completed. Decisions in the later phase involve many parties who usually have different views, responsibilities and interests (e.g. French 2005, Geldermann et al. 2005). Know how from many disciplines such as economic, ecological, engineering and natural science has to be combined taking into account political and socio-psychological factors. This problem can be tackled with the help of multi-criteria decision analysis (MCDA) which on the one hand ensures a transparent and coherent discussion and on the other hand allows a structured evaluation and support of decision problems with multiple criteria (Clemen, 1996).

In the context of radiological and nuclear emergency management, the MCDA tool Web-HIPRE, which supports decision analytic problem structuring, multi-criteria evaluation and prioritisation, has been integrated into RODOS as evaluation subsystem (ESY) (Geldermann et al., 2005; Geldermann et al., 2006). The theoretical background of the tool is the multi-attribute value theory (MAVT, see Keeney and Raiffa, 1976). It provides and develops methods to structure and analyse decision problems by means of attribute trees and to elicit the relative importance of criteria in such a tree. In an attribute tree the overall goal or objective is divided hierarchically into lower level objectives (also called criteria) and – on the lowest level – measurable attributes. The essential interactive steps in a MAVT analysis are shown in Figure 6. All of these stages are user-friendly supported by Web-HIPRE (Hämäläinen and Mustajoki, 1998).

Figure 6: Steps in the MAVUT analysis

The ESY is based on the results of the simulation models from the ASY and the CSY. In the ASY, the atmospheric transport and dispersion models provides the information on the contamination of the environment which is used in the CSY to perform countermeasure simulations for either agricultural or inhabited areas. In the given example, the case study aims to find the best management option for the milk production problem following a release from a reactor in the north of Germany. This case study differs from the one presented for the ASY and details of the scenario can be found in Bertsch (2008). Options considered were:

- No Action: 'Do nothing'
- Disp: Disposal of the milk
- Proc: Processing of milk to further products
- Stor: Storage of milk
- Rmov, T=0: Move of the cows from the meadow to the stable before the release and feed with uncontaminated feed
- Rmov, T>0: "Move of the cows from the meadow to the stable two days after the release and feed with uncontaminated feed
- Rduc, T=0: Feed cows with contaminated feed but reduced amount of contaminants
- AddS+Proc: Adding sorbents + Processing of milk

The resulting attribute tree is presented in Figure 7. This figure also shows the top level criteria which are weighted by the preferences of the decision making team:

- Radiation effects,
- Resources,
- Impact and
- Acceptance by the population.

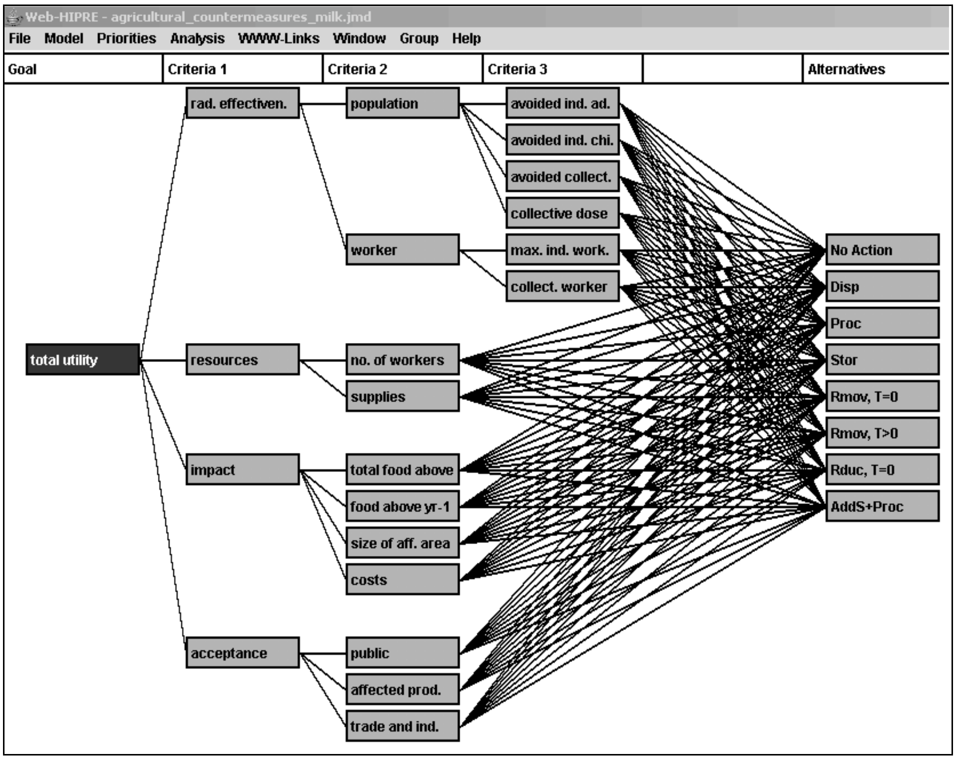

Figure 7: Attribute tree for the Web-HIPRE example

The ASY provides uncertainties in terms of many different ensemble realisations representing the uncertainties of the input data and parameters. These ensembles can be used in the CSY to perform countermeasure simulations. At present, the CSY sub-system of RODOS does not comprise its own uncertainty handling capabilities. Consequently, uncertainties of the CSY were not explicitly considered, but for each of the ensembles one countermeasure calculation was performed. The results were input to the ESY module Web-HIPRE.

Result visualisation is important for the understanding of the elicitation process and is realised as bar chart diagram in Web-HIPRE. There the contributions of the top level criteria to the overall performance of an individual countermeasure option are visualised. Including uncertainty information into this bar chart, the upper and lower probability bound was selected as that information which might best indicate the potential range of the impact of the uncertainties. Thus the 5% and 95% quantile, representing the worst case and best case scenarios, respectively, were added to the best estimate. For illustrative purposes, an example of such a graph is presented in Figure 8. A detailed description how uncertainty bands can be dealt with in MAVT can be found in Bertsch (2008).

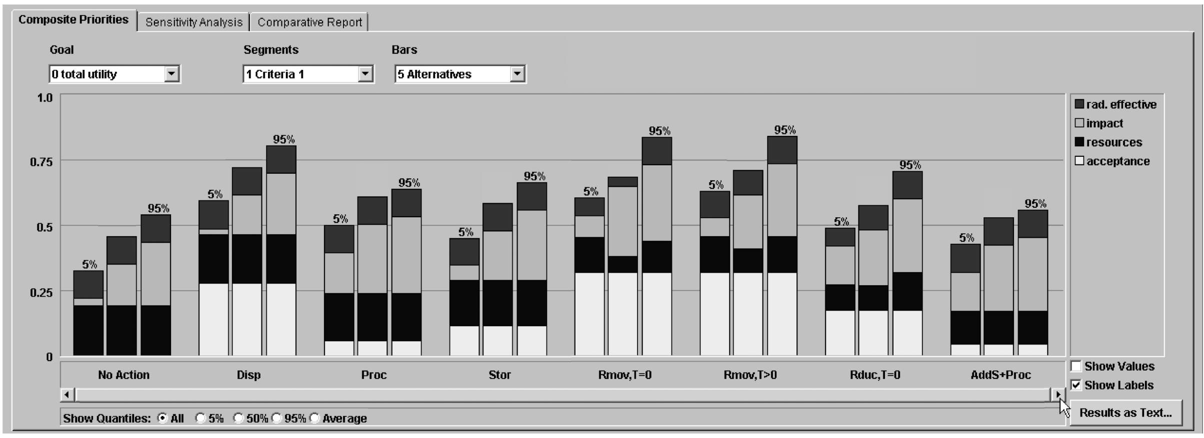

Figure 8: Visualisation of uncertainties associated with the results of the decision analysis in Web-HIPRE

Using that bar chart is the first attempt to visualise the impact of uncertainties in Web-HIPRE.

CONCLUSIONS AND NEXT STEPS

Decision support systems so far do not consider the uncertainty of the input data appropriately nor the potential range of preferences in the decision making process. The uncertainties which are partly propagated through the chain of simulation models in RODOS are so far not visualised in the operational releases of the system. Since the areas, in which the early phase countermeasures need to be initiated, constitute for the fast response to the emergency, first attempts are made with the visualisation of the potential area of sheltering as result of the uncertainties of the atmospheric transport and dispersion processes. The size of the area resulting from ‘worst’ or ‘best’ case calculations will provide a first guess of the variability of the input data and parameters and thus direct the decision making team towards the consideration of the potential of the problem. Allowing the user to select a particular percentile value allows to visualise that percentile which might best represent that level of uncertainty which the decision maker defines for her/him as most sensible to prepare for. It is not the intention to focus on the two extremes ’best‘ and ’worst‘ but percentiles at the lower end of the probability distribution (10% to 25%) might be the best selection for judging of the potential variability in each case.

Visualisation of uncertainties in the ESY module Web-HIPRE is based on the assumption that an easily understandable visualisation and communication of the uncertainties that arise in the decision making process is needed. In order to achieve this goal, it is proposed to illustrate simply the uncertainty ranges (i.e. the ranges in which the results of the alternatives can vary due to the uncertainties) to the decision makers. For this purpose, worst case and best case scenarios are defined as scenarios corresponding to the 5%- and 95%-quantiles of the overall performance score.

As next step, the visualisation of uncertainty of the areas for evacuation and sheltering will be realised in the CSY sub-system of RODOS and issued in its next release in 2009. Distributing this version to the RODOS Users

Group, feedback is expected for the application of these new features in exercises and internal demonstrations with decision makers. The realisation of the uncertainty handling inside Web-HIPRE requires further discussion in the RODOS Users Group as one pre-condition, the uncertainty handling in the later phase CSY models is still pending. However, the explicit handling and visualisation of early phase related uncertainties is a considerable step forward in communicating uncertainties to the decision makers.

ACKNOWLEDGMENT

This work has received partial financial support from the European Commission Sixth Framework Programme (Nuclear Fission/Radiation Protection) under the EURANOS integrated project: European approach to nuclear and radiological emergency management and rehabilitation strategies (Contract No: FI6R-CT-2004-508843).

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