Integrated Long-term Management of Radioactively Contaminated Land: the Ceser Project

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INTRODUCTION

Accidents at nuclear installations can cause widespread long-term contamination of soils. On land used for agriculture this may necessitate countermeasures to reduce the transfer of radionuclides into the human food chain. A wide range of countermeasures have been evaluated in European countries in the aftermath of the Chernobyl accident.[1] The main aim of this evaluation has been to identify the most effective and practical techniques for reducing the radiation dose to humans. In comparison, little attention has been paid to the potential long-term impacts of these measures on the functioning of agro-ecosystems and their economic value. It is conceivable that environmental and economic costs due to these impacts may equal or even outweigh the benefits of dose reduction. Thus any changes in the economic and ecological values of resources should be considered as part of a comprehensive remediation strategy. It is the objective of the work presented here to develop and test an impact assessment methodology which permits decision makers to choose an ecologically and economically balanced long-term remediation strategy for severely contaminated areas. This research is part of an EU funded project under the Nuclear Fissioh Safety Programme entitled: Countermeasures: Environmental and Socio-Economic Responses (CESER) and involves partners in Austria, Finland, Germany, Norway and the UK

The approach shown in Fig. 1 is being adopted to assess ecological and economic impacts of countermeasures. The various steps included in Fig. 1 are characterized in the following.

DISCUSSION

Identification

Initially a comprehensive list of potential countermeasures intended to reduce radiation doses from radioactive cesium and strontium was compiled. Countermeasures reviewed include interventions both at the soil-plant level and at the animal level. Criteria adopted for countermeasure selection included radiological effectiveness, applicability, cost and acceptability to farmers. Based on these criteria, deep ploughing to bury contamination, soil application of fertilisers that compete with radionuclides in the soil solution, use of binding agents in soils or livestock, changes in livestock management or in land use (e.g. afforestation) were included in the study. For these countermeasures, a literature review identified potential impacts on the quality of soil, water and air; the health of plants, animals and humans; the quality and quantity of the products; and the diversity of landscapes and organisms. Examples are:

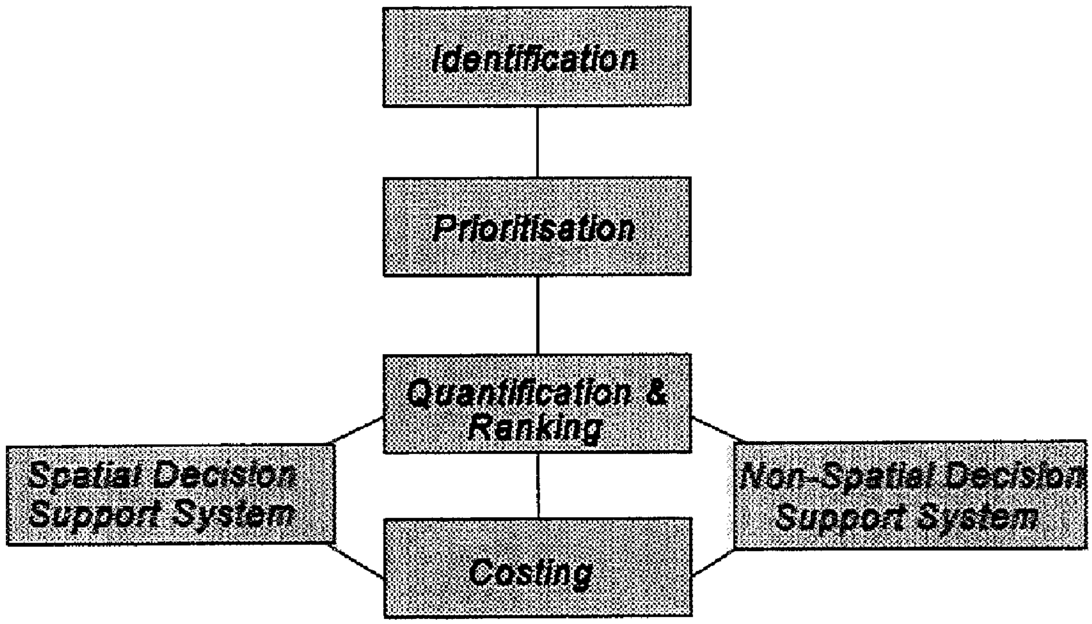

Fig. 1: Approach adopted for the integrated impact assessment of countermeasures.

At the soil-plant level, ploughing may enhance mineralisation of organic soils and increase erosion. At the animal level, movement of animals to less contaminated areas result in a shift of grazing pressure and may increase manure application which consequently may affect water quality and increase the potential for eutrophication. Both positive effects (e.g. growth stimulation of plants due to fertilizer application, higher milk yield) and negative effects (e.g. lower food quality, reduced animal health) were included.

Emphasis was given to identifying the basic physical and chemical mechanisms of the selected countermeasures and their potential non-radiological impacts, since their understanding is essential for quantification of site-specific effects by modelling.

For some potentially important non-radiological impacts of selected countermeasures, however, the information available in the literature was found to be inadequate for quantifying these effects. Thus laboratory experiments were initiated: Soil column experiments have been set up to study the environmental fate and identify potential degradation products of ammonium-ferric(III)-hexacyanoferrate(II) (AFCF) which is used as a cesium binding agent in livestock feeding Diffusion experiments[2] have been designed to investigate the potential of mobile organic matter degradation products (fulvic acids) for transport of trace nutrients and toxic trace substances.

Prioritisation

The potential countermeasures identified were then prioritised for case study areas in Finland and Scotland on the basis of four radioactive deposition scenarios and existing agricultural production systems taking into account crop and animal production. The four radiological scenarios included contamination levels ranging from depositions characteristic for greater distances from a damaged nuclear plant to levels to be expected near to the accident location.

Quantification and Ranking

The impacts selected are either quantified through calculations and simulation modelling or qualitatively assessed on the basis of expert knowledge. The models ICECREAM [3], OPUS [4] and PHREEQC [5] were chosen to simulate environmental changes due to countermeasures. ICECREAM and OPUS are used to simulate soil erosion and transport of water and solutes via surface runoff and percolation in the soil column in a watershed taking into account a variety of agricultural management practices (e.g. ploughing, fertilisation, manure application). Since both study areas include soils rich in organic matter, the OPUS code was modified to include a recently proposed hydrological model based on the Vereecken [6,7] pedo-transfer function which is applicable for both mineral and organic soils. PHREEQC is applied to simulate effects of changes of fertiliser addition on soil chemistry and availability of major and trace nutrients and of toxic trace substances taking into account a variety of chemical reactions (e.g. exchange reactions, precipitation).

For the selected countermeasures, the simulations will provide matrices of erosion, nutrient losses, changes in the availability of toxic trace substances and chemical changes in soil solution for the most common soil types, climates, slopes, land use categories and land management practices within the selected geographic areas. Within a geographical information system (GIS), the model output matrices are linked to spatial data sets covering topography, soil types and land uses. This enables the mapping of impacts for different countermeasures.

Costing

Environmental cost-benefit analysis is used to estimate off-site costs such as loss of fisheries or amenity value and benefits such as reduced radiation risk arising from the application of countermeasures. Costs will be derived by combining the environmental modelling results with valuations from the literature. Selected impacts such as landscape changes are being valued through an original 'willingness to pay' survey. The direct monetary costs of countermeasures will be included in the final analysis.

Decision Support Systems

Multicriteria Decision Making (MCDM) [8] has been chosen as the methodology for integrating the assessments of impacts and costs resulting from countermeasures. This methodology will provide the decision-maker with a set of countermeasure suitability rankings or suitability maps based on the quantitative and qualitative impacts.

The MCDM approach will be embedded into two types of decision support system. The first will be a non-spatial assessment for a single area, built as a piece of stand alone software using Visual Basic. "Wizards" will take the user down a series of decision trees regarding the type of agriculture and the deposition scenario. Based on this information the user is presented with a selectable list of countermeasures. Once the user has made the selection, he/she is asked to provide additional information on site properties which might limit the application of the countermeasures. The impacts, costs and benefits of the countermeasures are then assessed qualitatively and quantitatively using the MCDM methodology.

The second system will be a more generic suitability assessment of a larger, heterogeneous area using a GIS. A suitability assessment will be performed using spatial data within the GIS. Thematic maps depicting site suitability for a single countermeasure or showing the overall "most suitable" countermeasure can be created. By being custom built for this project, both Decision Support Systems should prove to provide greater flexibility, specificity and user-friendliness compared to commercially available software packages.

CONCLUSION

As final product, this methodology will provide decision-makers with a set of countermeasure suitability rankings or suitability maps based on an integrated assessment of their quantitative and qualitative radiological, ecological and economic impacts.

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