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The STRATEGY project: decision tools to aid sustainable restoration and long-term management of contaminated agricultural ecosystems

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Abstract

The STRATEGY project (Sustainable Restoration and Long-Term Management of Contaminated Rural, Urban and Industrial Ecosystems) aimed to provide a holistic decision framework for the selection of optimal restoration strategies for the long-term sustainable

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management of contaminated areas in Western Europe. A critical evaluation was carried out of countermeasures and waste disposal options, from which compendia of state-of-the-art restoration methods were compiled. A decision support system capable of optimising spatially varying restoration strategies, that considered the level of averted dose, costs (including those of waste disposal) and environmental side effects was developed. Appropriate methods of estimating indirect costs associated with side effects and of communicating with stakeholders were identified. The importance of stakeholder consultation at a local level and of ensuring that any response is site and scenario specific were emphasised. A value matrix approach was suggested as a method of addressing social and ethical issues within the decision-making process, and was designed to be compatible with both the countermeasure compendia and the decision support system. The applicability and usefulness of STRATEGY outputs for food production systems in the medium to long term is assessed.

Keywords: Countermeasures; Restoration strategy; Stakeholders; Decision support system

1. Introduction

Following a large-scale accidental release of radioactivity into the environment, food production systems and inhabited areas may be contaminated for many years. However, accident response planning throughout Europe had previously tended to focus primarily on the early (emergency) phase, neglecting consideration of the longer-term management of contaminated areas.

An assessment of potential countermeasures should consider not only technical issues but also social and ethical aspects. To sustain acceptable living and working conditions in contaminated areas practicable restoration strategies are needed that address the different types of environment, land use and ways of life. In optimising restoration strategies, a wide range of objectives need to be considered (Howard et al., 2004). These include:

- Reducing individual and/or collective dose while minimising other health risk factors
- Meeting legal obligations regarding environmental protection, dose limits and intervention limits
- Optimising cost-effectiveness
- Maintaining and/or creating economic activity
- Providing public reassurance and maintaining a sense of well being
- Minimising social and cultural disruption
- Minimising environmental damage
- Maximising institutional, public and scientific learning
- Enhancing participatory dialogue

In practice, some of the objectives may conflict. For example, the goals of public reassurance and economic activity might only be achieved at the cost of social disruption. Therefore, decision-making criteria need to be established that are capable of addressing the ways of balancing cost-effectiveness with social, ethical and environmental considerations (Oughton et al., 2004).

The STRATEGY project (Sustainable Restoration and Long-Term Management of Contaminated Rural, Urban and Industrial Ecosystems; http://www.strategy-ec.org.uk) has established a framework for the selection of optimal restoration strategies for the long-term sustainable management of contaminated areas. The project comprised: (i) a critical evaluation of countermeasures, including waste disposal options; (ii) the development of a decision support system (DSS) capable of optimising spatially varying restoration strategies; (iii) an assessment of the most appropriate methods of estimating indirect costs associated with side effects and of communicating with stakeholders; and (iv) the development of a methodology to address social and ethical issues within the decision-making process. This paper provides a summary of the outputs of each of these activities (Howard and Beresford, 2003) and discusses their usefulness and applicability. The paper focuses on restoration in areas used for food production. More information about methods to reduce external exposure in inhabited areas is available in Andersson et al. (2003).

2. Datasheets on countermeasures for mid- to long-term restoration

Many different countermeasures have been developed or improved since the accident at Chernobyl in 1986, many of which have been applied on a large scale in Belarus, Ukraine and Russia, as well as in contaminated regions of Western Europe. Much of the published information on these countermeasures concerns their effectiveness in terms of dose reduction and, occasionally, cost. Costs of various countermeasures may be not only monetary but also social and environmental. Furthermore, there may be other detrimental or beneficial, direct or indirect effects of countermeasures. It is therefore important that countermeasures are evaluated in detail by considering a wide range of factors relevant to their implementation.

The aim was to develop compendia giving a critical and comprehensive evaluation of individual countermeasures relevant for the mid- to long-term for food production systems (Nisbet et al., 2004) and inhabited areas (see Andersson et al., 2003; Eged et al., 2003 for urban and industrial information. respectively). Initially, a large number of potential countermeasures were identified and critically evaluated with regard to a range of different criteria specifically related to their potential applicability in Europe. The final list of selected countermeasures is given in Table 1. It comprises 29 agricultural countermeasures, 12 agricultural waste disposal options, 10 countermeasures for use in aquatic and forest ecosystems and 36 options for inhabited areas. In addition, 15 ‘social’ options were identified that could help society or individuals deal with the contamination at a more local level in the mid- to long-term. Some countermeasures described in the literature were not selected because of their ineffectiveness (e.g. bioremediation, administration of clay minerals to soil, leaching of soil), inappropriateness for application in the medium to long term (e.g. administration of stable iodine to livestock) or a lack of relevant

Table 1
Countermeasures, and waste disposal options contained within the compendium

Agricultural countermeasures	Administration of AFCF boli to ruminants
	Administration of clay minerals to feed
	Application of K fertilisers to arable soils/grassland
	Application of lime to arable soils/grassland
	Clean feeding
	Change of hunting season
	Dilution
	Decontamination techniques for milk
	Distribution of saltlicks containing AFCF
	Distribution of concentrates with AFCF
	Distribution of concentrates with added calcium
	Deep ploughing
	Early removal of crops
	Feeding animals with crops/milk in excess of intervention levels
	Food bans
	Live monitoring
	Manipulation of slaughter time
	Ploughing, fertilising and reseeding of unimproved pastures
	Processing of milk for human consumption
	Processing of crops for consumption
	Salting of meat for consumption
	Selective grazing regime
	Select edible crop that can be processed
	Select alternative land use
	Slaughtering dairy cows
	Shallow ploughing
	Skim and burial ploughing
	Suppression of lactation before slaughter
	Topsoil removal
Agricultural waste disposal options	Biological treatment (digestion) of crops
	Biological treatment (digestion) of milk
	Burning of carcasses
	Burial of carcasses
	Composting
	Disposal of contaminated milk to sea
	Incineration
	Landfill
	Landspreading of milk and slurry
	Ploughing in of standing crops
	Processing and storage of milk for disposal
	Rendering
Aquatic and forest countermeasures	Addition of lime to lakes or catchments
	Addition of potassium to lakes
	Bans on drinking water consumption
	Construction of dykes or barriers
	Purification of drinking water at water treatment plants
	Regulation of contaminated water flow through reservoirs
	Switching or blending of drinking water supplies
	Forest soil treatment with fertilisers
	Modification in tree felling time
	Restriction on the use of wood

Table 1 (*continued*)

Industrial countermeasures	Application of detachable polymer paste on metal surfaces
	Chemical cleaning of contaminated metal surfaces
	Cleaning of contaminated ventilation systems
	Cleaning of contaminated plastic and coating surfaces
	Electrochemical cleaning of metal surfaces
	Filter removal from industrial areas
	Physical cleaning of metal surfaces
	Ultrasound treatment + chemical decontamination
Urban Countermeasures	Ammonium treatment of walls
	Application of clean sand or soil around dwellings
	Change of roof
	Deep ploughing (park areas)
	Fire hosing of roads and walkways
	Garden digging
	High pressure washing of dwellings
	High pressure washing of roofs
	Intensive indoor surface cleaning
	Lawn mowing
	Mechanical abrasion of wooden walls
	Pruning or removal of trees and shrubs
	Re-surfacing frequently occupied areas
	Road planing
	Roof cleaning by cleaning device
	Roof cleaning with pressurised hot water trolley
	Sandblasting of walls
	Shallow ploughing (park areas)
	Skim and burial ploughing (park areas)
	Snow removal
	Topsoil removal and applying lignin coating
	Topsoil removal by machines
	Topsoil removal manually
	Triple digging
	Turf harvesting
	Turning flagstones
	Vacuum sweeping roads and walkways
Social countermeasures	Advice on use of fire ash
	Compensation scheme
	Dialogue and consultation: citizen's jury
	Dietary advice
	Do nothing
	Education programme in schools
	Evacuation/sheltering
	Food labelling
	Information/advice bureau
	Medical check-up
	Provision of counting/monitoring equipment
	Raising intervention limits
	Relocation
	Restrictions on gathering of free food
	Restrictions on the use of recreational areas

information (e.g. administration of alginates to animal feed, selection of a different variety of the same crop).

A datasheet template was designed incorporating all criteria that decision-makers might consider when evaluating different countermeasures (Table 2). These included a short description of the countermeasure, its key attributes, constraints, effectiveness, feasibility, waste generated, doses incurred through implementation, costs, side effects, stakeholder opinion and practical experience. Datasheets containing information on these criteria were produced for all countermeasures and these were internally and externally peer reviewed by a group of 16 international experts and end-users.

The datasheets were intended to be comprehensive but concise, and generally applicable across Western Europe. Nevertheless, for some criteria (e.g. legal, social and communication constraints, ethical considerations, cost-effectiveness, wastes, additional doses and stakeholder opinion) more detailed guidance was thought to be useful. Therefore, additional documents were produced and this 'second layer' information was hyperlinked to particular criteria in the electronic versions of the datasheets (http://www.strategy-ec.org.uk; STRATEGY, 2003). Further, more detailed information, can be found in Nisbet et al. (2003).

3. Decision support system for mid- to long-term restoration strategies

The extent and time scale of radionuclide transport through ecosystems is dependent upon numerous factors, which vary both spatially and temporally. Consequently, when designing restoration strategies for land contaminated with radionuclides, decision-makers must not only decide *which* countermeasures should be implemented, but also *when* and *where*. Furthermore, draft ICRP recommendations (International Commission on Radiological Protection, 2004), currently available for consultation, state that within the optimisation of protection the "procedure (for protecting individuals) continues to include the requirement that all doses from a source are as low as reasonably achievable, social and economic factors being taken into account", and specify that the "basic role of the optimisation of protection is to foster a safety culture". Thus, decision-makers should be considering "Have I done all that I reasonably can to reduce these doses" in selecting the most appropriate restoration strategy. The aim of the DSS is to assist the temporal and spatial identification of mid- to long-term restoration strategies, by specifically incorporating features such as wastes, environmental constraints and countermeasure side effects.

3.1. DSS overview

The area under study is represented as a two-dimensional array of cells, whose scale is determined by the resolution of the input data. Each cell is associated with an input dataset within a raster-based GIS database, derived from Gillett et al. (2001), which allows the spatial variation in model inputs and outputs to be represented. Cell-level

Table 2
Criteria used to describe countermeasures

Criteria	Issues
Key attributes	Objective
	Other benefits
	Countermeasure description
	Target
	Target radionuclides
	Scale of application
	Contamination pathway
	Exposure pathway pre intervention
	Time of application
Constraints	Legal
	Social
	Environmental
	Communication
Effectiveness	Countermeasure effectiveness
	Factors influencing effectiveness of procedure (technical)
	Factors influencing effectiveness of procedure (social)
Feasibility	Required specific equipment
	Required ancillary equipment
	Required utilities and infrastructure
	Required consumables
	Required skills
	Required safety precautions
	Other limitations
Waste	Amount and type
	Possible transport, treatment and storage routes
	Factors influencing waste issues
Doses	Averted dose
	Factors influencing averted dose
	Additional dose
Intervention costs	Equipment
	Consumables
	Operator time
	Factors influencing costs
	Communication costs
	Compensation costs
	Waste costs
	Assumptions
Cost effectiveness	
Side effect evaluation	Ethical considerations
	Environmental impact
	Agricultural impact
	Social impact
	Other side effects
Stakeholder opinion	
Practical experience	
Key references	
Comments	

datasets contain information about radionuclide deposition, soil characteristics, topography, land use, the number of livestock and humans inhabiting the cell. Cells are aggregated into regions that are also associated with input datasets not available or not practical to use at cell-level resolution, such as food production rates and crop and livestock management regimes. Regional data are assumed to apply to all cells within a region and the contaminated area can have any number of defined regions.

The DSS comprises a series of models that are described in the remainder of this section. Outputs from the DSS include: the predicted levels and distributions of the individual and collective doses; the total contributions to ingestion doses by each food product; the overall level of expenditure on a restoration strategy; the expenditure on individual countermeasures and the amount of any associated waste.

3.2. Food-chain modelling

The food-chain model is based upon the SAVE system (Gillett et al., 2001), utilising available plant uptake models (Absalom et al., 2001; Müller and Pröhl, 1993), to predict the activity concentrations of Cs, Sr, Pu and Am in ten crop types in each cell; processing factors are used to estimate the activity concentrations in food products derived from the ten crops. The predicted activity concentrations of radionuclides in crops used for animal fodder within a cell (i.e. pasture grass, maize or grass silage and cereals) are then combined with the regionally defined feeding regimes of six livestock animal types to estimate the activity concentrations of radionuclides in the food products derived from livestock. A total of 27 food products are considered.

3.3. Population and dose modelling

The human population is assumed to be comprised of numerous sub-populations whose characteristics can be defined manually or generated by Monte-Carlo sampling. This approach allows the different radiological consequences experienced by each sub-population to be assessed and incorporated in the decision-making process.

In addition to the consumption rates of the food products considered, the geographical origins of food products are defined for each sub-population. Food product groups may be designated as home-grown, locally produced, regionally produced or externally produced (i.e. sourced from outside of the study area). This approach is used to give a more realistic representation of an individual's diets, as most individuals in Europe source large proportions of their diet from outside of their immediate locality. Assuming that all individuals' diets are sourced locally may lead to overestimation of ingestion dose in heavily contaminated areas, and underestimation in areas with low deposition levels.

To estimate the total inventories of radionuclides in foodstuffs produced in the region predicted activity concentrations of radionuclides in food products are combined with regional production rates. The predicted inventory of radionuclides which is exported outside of the region is then estimated as the difference between the total inventory and that part consumed in the region.

The time that individuals spend at various locations in the urban and industrial environments is also defined for each sub-population, and these data are combined with models to estimate the effective external doses received (Meckbach et al., 1988; Meckbach and Jacob, 1988; Kis et al., 2004).

Side effect costs, as estimated by approaches described in Section 5, can also be incorporated into the system.

3.4. Countermeasure implementation

Most of the countermeasures for food production systems and inhabited areas assessed within the project could be implemented in the DSS. However, to ensure that the development of the DSS was manageable within the constraints of this project, the number of countermeasures included within the system was restricted to those considered most likely to be implemented and took account of feedback from the FARMING network (Nisbet et al., 2005a).

The implementation of each countermeasure may be simulated independently within each cell in the study area, subject to certain constraints (e.g. ploughing countermeasures are not permitted in cells with an average slope greater than 16°). The extent of a countermeasures implementation is controlled by its implementation threshold. This can be manually defined as a constant value (to allow for the simulation of statutory regulations, such as Council Food Intervention Limits (CEC, 1989), or user defined strategies) or varied automatically by the system to identify optimal restoration strategies.

3.5. Optimisation of restoration strategies

The system evaluates potential restoration strategies using extended cost-benefit analyses. A cost function, C (€), is defined, which balances the benefits obtained through dose reduction with the direct costs of countermeasure implementation, and can also include the indirect social costs of countermeasures' side effects:

$$C = I - A$$

where I (€) is the cost of countermeasure implementation which can include not only the direct costs associated with implementation and waste disposal, but also the 'cost', in monetary units, of countermeasure side effects, and A (€) is the monetary value of the averted dose.

To accomplish this, the collective dose is transformed into a monetary value using a reference value (α; € man-Sv^{-1}) to estimate the monetary value of the averted dose. The α-value can either be defined as a constant value, or, if the user prefers, as a function of the levels of individual dose, as described by Lochard et al. (1996), to account for the preference for averting high individual doses.

Optimal restoration strategies are then identified by minimisation of the cost function using a modified version of Powell's direction-set method (Press et al., 1989), via adjustment of the implementation thresholds of the selected countermeasures. The outputs from the optimisation process are the optimum implementation thresholds for each of the countermeasures being considered.

Model outputs identify specific geographic areas, food products and time periods for the implementation of countermeasures and their associated costs. More detailed information can be found in Álverez-Farizo and Gil (2003), Cox and Crout (2003), Cox et al. (2003, 2005, this issue) and Howard and Beresford (2003).

Quantitative methods such as those utilised in the STRATEGY DSS provide a valuable input into decision-making. However, as stated in the current ICRP recommendations, "quantitative methods may provide an input, but given the many qualitative factors they should never be the sole input" (International Commission on Radiological Protection, 2004). Consistent with this view, various methods by which these qualitative societal factors can be incorporated into a decision framework have been considered and are discussed below.

4. Social, ethical and communication issues and approaches

4.1. Advice on social dimensions and communication issues associated with restoration

Potential countermeasures contain assumptions about the ways in which people will behave (in relation to radionuclide contamination and/or countermeasures), and what is meaningful, valuable, credible and possible for affected populations. If such assumptions are inaccurate, countermeasures will not be applied effectively. For example, restrictions on gathering and consuming local foodstuffs such as mushrooms and berries, as implemented in the former Soviet Union after the Chernobyl accident, will only be effective in the mid- and long-term if the relevant population accepts the rationale behind the ban, and if alternative food sources are available. In areas contaminated by the Chernobyl accident, restrictions on consumption of mushrooms were widely ignored (Beresford et al., 2001).

Societal groups are likely to respond differently to the implementation of countermeasures. However, the existing literature does not enable more than the identification of a broad range of factors that influence responses, such as the extent of credibility of involved institutions (itself highly dependent on the historical experience of those institutions by the lay public), the approach taken by the media and the economic, social and cultural reality of affected populations. This variability was reflected in a situation in Norway when intervention limits in reindeer meat were raised to protect the Saami culture (Gould, 1990). Thus, selection of the appropriate suite of countermeasures involves knowledge of the social and cultural dimensions of affected groups. Otherwise, countermeasure strategies are likely to be, at least in part, impractical or unacceptable.

What existing research does demonstrate is that relevant knowledge exists at the local level, but is often overlooked at the regional or national levels (e.g. Wynne, 1989). Knowledge gathering at the more detailed level of affected communities is therefore a necessary precondition of effective restoration strategies. If local knowledge is not recognised in the existing decision-making structures, it is necessary to incorporate it.

In combination with this local variability, radioactive contamination carries substantial stigma, at least for some groups (Flynn et al., 2001). The implementation of countermeasures is an indication that contamination exists, and this can have negative consequences, such as falls in property prices and destruction of locally produced food industries, as well as increasing anxiety.

A further significant social dimension of any countermeasure strategy is the extent of compliance among affected populations. Some issues to consider here are: (i) the potential for the development of a black market of contaminated foodstuffs; (ii) the scope for countermeasures to be inappropriately applied and the amount of supervision required; and (iii) the acceptance (or otherwise) of restrictions on behaviour. Compliance can be enhanced by greater understanding and agreement on the rationale underlying the choice of countermeasures, and by the parallel enhancement of a cultural commitment to compliance, which in turn promotes a degree of self and community ‘policing’ of appropriate behaviours. However, the issues raised—for example, the potential for a black market to develop—themselves illustrate the need for knowledge about the social and cultural conditions in any particular arena.

The social feasibility of countermeasures can be considered under three headings:

- *Material feasibility*: are the appropriate resources (e.g. equipment, finance, information) available? What disruption to existing activity will ensue? Are there viable and acceptable substitutes available for e.g. activities, foodstuffs which may be restricted?
- *Communicative feasibility*: is the relevant information accessible (both physically and in terms of whether it is understandable) to both decision-makers and to affected communities? Is information appropriate for the intended audiences? Is information credible? Have the necessary discussions and negotiations taken place with relevant parties?
- *Cultural feasibility*: is the way in which the risk is understood by affected communities acknowledged? What are the impacts of countermeasures on everyday life? Do the countermeasures affect local cultures and values?

In addition to the social impacts of countermeasures, the project has also considered ethical implications of both individual countermeasures and the selection of the overall restoration strategy. Overarching considerations reflect the degree to which (i) the distribution of cost and benefits is equitable; (ii) the risks are imposed or voluntary; (iii) stakeholders[1] have been involved in the decision-making process; and

[1] Although increasingly referred to in risk management, the use of the term “stakeholder” can raise problems since there are various definitions and interpretations of the word, including (in English) something akin to a legal claim. In this paper, we use the term very generally to indicate affected or interested parties.

(iv) the action carries a risk of serious environmental damage (Oughton, 1996; Oughton et al., 2004). Specific examples related to countermeasures are listed below. More information, including specific examples and the links to ethical values can be found in the 'second layer' information to datasheets in the STRATEGY compendium (see Section 2) and in Oughton et al. (2003, 2004).

- *Self-help/disruptive*: to what extent can affected people themselves implement the countermeasure; will the countermeasure increase or decrease their degree of personal control or choice over the situation?
- *Free informed consent*: is there an opportunity for workers, consumers or other affected parties to give consent, either to the countermeasure itself or to the negative side effects of countermeasure implementation? Have parties been compensated for any increase in risk? Who has the obligation to obtain consent?
- *Distribution of dose, costs and benefits*: how will the countermeasure change the distribution of costs, risks and benefits, over space and time, and between different members of a community? Who is paying and who is benefiting? Does the countermeasure have implications for vulnerable or already disadvantaged members of society (children, ethnic or cultural minorities)? Does any group stand to make an economic gain from the countermeasure (e.g., contractors)?
- *Liability and/or compensation*: who bears liability for any unforeseen health or property damages arising from the countermeasure? Do contractors risk being taken to court if the countermeasure causes unforeseen damage? Will workers/property owners be compensated if the countermeasure results in damage?
- *Environmental consequences and animal welfare*: will the countermeasure impact on animal welfare (e.g., farm animals, wild animals, pets, zoo exhibits ...)? Will there be potential consequences for future generations?
- *Change in public perception or use of an amenity*: how will the countermeasure influence on public use of an amenity (e.g. a park or forest)? Will it be perceived as changing from being "natural" to "unnatural" or "clean" to "damaged"?
- *Uncertainty*: what are the main uncertainties associated with the countermeasure? What action might be taken to avoid or reduce these uncertainties, and are some inevitably indeterminate? What are the consequences of being wrong?

4.2. Dialogue and decision-making

The importance of social and ethical values were recognised at the start of the STRATEGY project, and, as such, there was a decision to integrate relevant issues at various stages of the project, not just as an "add on" in the final decision-making process. Awareness of the importance of information on the distribution of doses and costs in communities, and the way in which countermeasures might change this distribution, led to these data being included as a specific model output. It is also clear that social and ethical issues need to be properly addressed in the actual selection of a countermeasure strategy, so that other, potentially competing, values and activities are not disproportionately affected, and that compliance is generated. However, the judgement of what is, and what is not, proportionate itself incorporates fundamental values, and can vary across and between communities. Some form of interactive, and iterative, dialogue between affected communities and decision-makers is therefore necessary to agree 'what is important'. This approach is consistent with the subsequent ICRP draft recommendations which emphasise the importance of the involvement of stakeholders as an important input into optimisation (International Commission on Radiological Protection, 2004).

Dialogue is used here as a generic term to cover a range of methods such as ongoing discussions ('stakeholder dialogue'), citizens' panels, internet fora, etc. (see Petts and Leach (2000) for a comprehensive review of methods). Methods need to be selected in relation to the available expertise and experience in conducting dialogue, and the needs of the various participants and particular context. Such dialogue has multiple social benefits. It enables information gathering on local conditions and values, provides a means of discussing potential restoration strategies and gaining feedback on these, and can generate greater consensus and acceptance. Information can be gathered across a wide range of domains. For example, people's behaviours and food consumption, the extent to which different institutions are trusted and credible, lay peoples' information needs, the social and cultural impacts of countermeasures, and the ethical judgements and preferences of communities.

The communication strategy proposed is generic, and does not specify particular methods as these are best determined in particular local contexts. It involves a chronological sequence as follows:

- map out the existing consultation and communication network related to the affected area, to utilise this in the development of an efficient process
- provide initial public information
- consult and discuss with the public and other stakeholders to ascertain the impacts of countermeasures, social preferences, ethical judgments, local knowledge and differentiation, information needs
- review outputs of consultation and discussion to identify any further inputs needed
- review public information provision and amend content and delivery as appropriate
- input consultation and discussion outputs to decision support model as appropriate
- convene representative and inclusive panels to consider the restoration strategy
- invite comment from wider community
- review strategy in light of comments
- implement strategy alongside inclusive review/feedback process
- gather comments on implementation of strategy, and revise as appropriate.

Such a process is necessarily time consuming, though it can be tailored to be more or less extensive in relation to the time and other constraints. Given that STRATEGY was concerned with management in the medium- and long-term, such an investment of time is warranted to identify effective and acceptable options which reflects the preferences and values of affected communities. Further, more detailed information can be found in Howard and Beresford (2003), Hunt and Wynne (2002) and Hunt (2003).

4.3. Value matrix

Many countermeasures have both positive and negative social and ethical consequences and complex impacts on different stakeholders. Thus, the actual selection of a strategy will require trade-offs and value judgements, and almost certainly some lack of agreement within society on what is practical or acceptable. If such a selection is going to be ethically defendable, decision-makers require advice on what criteria are important to consider and why, and also a methodology to ensure a transparent and publicly justifiable procedure for balancing these criteria. As a procedure for ensuring a systematic consideration of ethical issues, and as guidance for stakeholder participation processes, the project has focused on the development and application of a value or ethical matrix (Forsberg and Kaiser, 2002; Oughton et al., 2003, 2004).

A value matrix is a tool to ensure that all relevant concerns are being taken into consideration and to clarify the ethical basis upon which eventual decisions are made. As a decision support tool, the method has been employed in other contexts such as agriculture and biotechnology evaluation (Mepham, 2000; Kaiser and Forsberg, 2001). The matrix approach proposed takes its starting point in three fundamental principles, namely:

- To promote *well-being* and minimise health risks, welfare burdens and other detriments to affected stakeholders
- To respect the *integrity* or *dignity* of affected stakeholders
- To recognise the norm of *justice* and aim to treat everybody fairly and ensure an equitable distribution of goods among affected stakeholders.

In practice, a matrix can aid a decision-making group by giving an overall picture of the issue at stake, thereby making the ethical dimension of decision-making more transparent. Different countermeasures can affect different groups in different ways, and the matrix can be used to help identify the relevant information required for decision-making (i.e., the facts, values and stakeholders affected) (see example in Table 3). In this way, a bias towards certain kinds of values may be avoided, and the matrix can be used to address conflicts between values in a systematic way without, necessarily, having to invoke full-fledged theories. It is important to stress that the matrix is not a substitute for public and/or stakeholder participation, it is a tool that might be used in connection with other possible communication and consultation procedures (Hunt, 2003). However, a further advantage of the matrix is that it is well suited to use within a participatory process with appropriate stakeholder representatives of affected parties.

The value matrix has been tested with an end user group as part of a case study exercise, specifically designed to test the matrix in conjunction with the model and

Table 3
Excerpt of a template value matrix developed for countermeasure evaluation

Stakeholder	Example	Well-being	Dignity	Justice
Owners/ employers	Farmer; house dweller; hotel owner; business proprietor	Doses to humans; change in income; property damage	Self-help; consent; property rights	Possibility for conflict between different industries or projects
Users/ community	Tourists; public amenity user; local community	Access; aesthetics; empathy; community values; tourism	Respect for public heritage; community sense	Potential conflict of age/gender/cultural minorities
Animals/ environment	Farm animals; other biota	Animal welfare	Endangered species; habits loss	Potential conflict between farm and wild animals

countermeasure datasheets (Cox et al., 2003; Oughton et al., unpublished data). Thus, the exercise provided a limited opportunity to explore the practical benefits of the interaction between these two outputs and the value matrix in decision-making. The exercise demonstrated that the matrix was useful in mapping the concerns of various stakeholders and helpful in weighting the importance of those values. In general, the group evaluated the exercise positively, thought it would be worthwhile as decision-makers to be trained in this kind of method, and expressed a wish for further demonstration of the matrix approach.

Further, more detailed information can be found in Howard and Beresford (2003) and Oughton et al. (2003, 2004).

5. Side effect evaluation

Unintentional outcomes will arise from the implementation of countermeasures which could impact on the environment, agriculture and society. These impacts, characterised in economic terms as external effects, are referred to here as side effects. Some side effects have direct costs, which can be quantified (in monetary terms) via market prices (for example loss in land value). Other, indirect costs can be quantified using non-market approaches which assign a monetary value to those impacts which have no directly attributable value.

Indirect costs associated with countermeasure implementation could arise from side effects such as loss of scenic landscape, loss of biodiversity, effects on animal welfare, effects on recreational use of water resources and cultural impacts. The extent of the impact will vary in each situation, depending on deposition, location, season and traditional uses and perceptions of the local environment by the general public. Thus, impacts are site and time specific and depend on people's perceptions. Because of this complexity, there is no universal recipe to assign a monetary value to units of impact. Equally, the side effects of any countermeasure strategy have to be clearly described as objectively as possible as a basis for evaluation of the indirect costs. This will guide the analyst to choose the most appropriate available method for each case.

Similar side effects can arise from different countermeasures, and a restoration strategy may result in a number of simultaneous side effects. This reduces the number of methods of valuation which can be applied, since the majority of them can only consider one impact and one aspect of that impact. However, conjoint analysis techniques allow several impacts to be evaluated simultaneously. Of these, we have identified *choice experiments* as the most appropriate for the conditions described (Álverez-Farizo and Gil, 2003).

Choice experiments estimate non-market values, quantifying a person's intentional *willingness to pay* to potentially achieve some environmental improvement or to potentially avoid some environmental harm (impact) from the implementation of the countermeasures. This model contains elements from microeconomic theories of both consumer behaviour and value, namely rational choice, and several assumptions from the theory of preferences. Individuals allocate their limited budget among a variety of goods and services in a way that maximises utility.

From the theory of value, individuals get utility (satisfaction) from the characteristics of things (goods, services or ideas), rather than from the good as a whole. In other words, to be able to value the non-market costs derived from the implementation of a countermeasure, we need to consider all relevant component impacts (e.g. the deep ploughing of natural pasture may reduce biodiversity, impact on landscape and result in soil erosion and runoff). Thus, the relevant characteristics should be defined not in terms of an individual's reaction to the good (countermeasure in our case) but rather in terms of these objective component impacts.

In general, the interest is in how people will react to changes in identifiable features affected by the application of the countermeasure being considered. Choice experiments will produce estimates of the value of such changes individually as well as the aggregate value of the side effects of the countermeasures.

Choice experiments have been implemented in two different locations, in the UK and Spain. Five main impacts or aspects of impacts were identified under a hypothetical scenario and citizen's groups in each place were convened to appraise the situation. As the valuation of impacts is case specific, it is not possible to transfer results from one study to the other as demonstrated from the results shown in Table 4. For both the Cumbria and Zaragoza groups, the most highly valued attribute was scenic landscape and biodiversity, but the Zaragoza group did not show any desire to guarantee animal welfare or heritage. Instead, water recreation activities were the second most important side effect to avoid in Zaragoza. This may be due to the collective conscience in Spain to protect and preserve all water

Table 4
Valuation of side effects for two case studies

	Cumbria, UK (€)	Zaragoza, Spain (€)
Scenic landscape	50.0	47.5
Animal welfare	37.8	No value can be inferred
Water	19.3	23.7
Disruption	22.8	21.0
Heritage	No value can be inferred	No value can be inferred

assets, no matter what the water is used for, as a consequence of very strong cyclic droughts.

Further, more detailed information can be found in Howard and Beresford (2003) and Álverez-Farizo and Gil (2003).

6. Discussion

There are outputs from the STRATEGY project that can be used independently and relatively easily by people who were not involved in the project. The most obvious example is the countermeasure compendia which have been well received by national and international bodies. The interaction with the FARMING network has been valuable in making sure that the practicality and realism of the countermeasures has been rigorously evaluated (Nisbet et al., 2005b). It has also emphasised the importance of not prioritising on which countermeasure is ‘‘best’’ since there is considerable variation in the evaluations by the national stakeholder groups (e.g. compare the evaluations by the French (Reales et al., 2005; Métivier et al., 2005) and Finnish groups (Rantavaara et al., 2005, this issue). The compendium for agricultural countermeasures and rural waste disposal options is being taken forward by the FAO/IAEA for adaptation to other climate types. It is also being extended to the pre-release and early phase (including consideration of short lived radionuclides) and adapted for Mediterranean or Arctic conditions and scenarios such as deliberate releases of radionuclides (see EURANOS web site: http://www.euranos.fzk.de/index.php).

The STRATEGY DSS, in common with the countermeasure compendia, could be used by other groups with some training. A more user-friendly version of the DSS is being developed for operational use in Norway. To demonstrate the implementation of the DSS, two case study scenarios based on hypothetical accidents in the UK and Spain were conducted (Cox et al., 2003, 2005, this issue). In both scenarios, the model ‘successfully’ identified strategies that were much more cost effective than simply restricting the entry of food into the food chain; reductions in dose were similar. The implementation of countermeasures to reduce external exposure in and around dwellings and workplaces was not cost effective in either scenario even though in the UK study external radiation contributed more to doses in the contaminated region than ingestion doses. Whilst fruit was the predominant contributor to dose in the Spanish case study the countermeasure compendium does not adequately consider such production systems, although the update under the EURANOS project (http://www.euranos.fzk.de/) will address this problem; the DSS also models the temporal behaviour of radionuclides in tree-borne fruits rather simplistically. Inclusion of countermeasure side effect costs (as calculated in Table 4) had little impact on the optimisation output in either case study although only a limited number of side effects were considered. The model does not currently include doses to people implementing the countermeasures; these are described in second layer information of the countermeasure compendium (STRATEGY, 2003).

The latest recommendations of the ICRP specify that protection of individuals is broader than just considering the doses, and incorporates a range of qualitative and quantitative approaches (International Commission on Radiological Protection, 2004). The importance given to individual doses by the ICRP is supported in the DSS by its ability to calculate both individual and collective doses. The DSS is designed to form an integral part of the decision-making process and not to provide definitive answers to the problems of off-site restoration. Used in an iterative way, it allows decision-makers to investigate the effects of various options, and to provide information about the likely consequences of countermeasure strategies. In an exercise involving potential end-users, based on the case study scenarios, it proved a valuable tool for designing restoration strategies, and worked well with both the countermeasure templates and the value matrix. A particular strength was its ability to respond to stakeholder requests for specific information.

The DSS is currently not designed for use in the short term, and therefore does not specifically consider short-lived radioiodine isotopes, however many relevant countermeasures are included already. The DSS and countermeasure compendium were used as part of a recovery exercise in the UK which considered a hypothetical off-site accident at the Sellafield reprocessing plant in Cumbria. The DSS output of spatial variation in food contamination, agricultural production and countermeasure application was felt to be generally useful by relevant local and national agencies (Cumbria County Council, 2003). Application of the DSS within the exercise was constrained by its lack of consideration of short-lived radionuclides and the comparatively small scale of spatial implementation currently used (1×1 km).

The outputs of the project which considered social aspects of restoration strategies all emphasised the importance of stakeholder consultation at a local level and of ensuring that any response is site and scenario specific. Objectives to meet social needs must be given due weight and not subsumed by issues connected to dose reduction. Whilst early involvement of the local and wider community of stakeholders within participatory decision-making would be beneficial, the mechanism for doing so needs to be considered. The best mechanism for using the STRATEGY datasheets and DSS needs careful consideration and the value matrix approach developed is one means of doing this, although the matrix is not a substitute for ethical judgement. At the suggestion of the STRATEGY project, the recovery exercise discussed above included, for the first time, participation by local stakeholders (e.g. local and district authorities and local representatives of tourism industry, business, conservation area and farming). The STRATEGY DSS, countermeasure compendia and matrix are also to be included in an exercise by the Norwegian Emergency Planning Group.

The project set itself a considerable challenge in trying to provide methods for a holistic, integrated approach to decision-making regarding off-site restoration after accidents. The importance of considering a wide range of issues, and integrating technical information and approaches with social issues has been clearly demonstrated. The outputs and approaches within STRATEGY are generally consistent with the current draft recommendations of the International Commission on Radiological Protection (2004).

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