Remediation Options for Agricultural Land: Evaluation and Strategy Development

Rafferty, B., Synnott, H. and Dawson, D.

Radiological Protection Institute of Ireland
3 Clonskeagh Square, Dublin 14, Ireland.

INTRODUCTION

Since the Chernobyl accident considerable research effort throughout Europe has focused on understanding the behaviour of radionuclides in agricultural systems. The ultimate aim of this work has been to identify strategies by which the radiological impact of large-scale accidents like Chernobyl can be minimized. Over the last 2 years the focus of research has shifted to one of evaluation of past research findings and compilation of the information into practical, user-friendly decision support systems for remediation of radioactively contaminated land. A number of international projects are presently under way all with this basic objective. These projects test different approaches to aspects of decision making such as (a) the different end-users of the system - whether it be a farm adviser or a local authority; (b) the use of computer models to predict effectiveness and impact; and (c) the geographical scale over which intervention is assessed.

This paper is based on a review of the available literature describing the current state of European research into remediation strategies for agricultural land. Also presented are preliminary observations on the difficulties of compiling this research into a meaningful and practical tool for use in real-life, post-nuclear accident situations.

Table 1 lists the agricultural countermeasure options which are discussed in the literature. This table is drawn from a 1994 IAEA publication[1] in which guidelines for agricultural countermeasures are reviewed. In the few years since its publication, the list of available options has not changed significantly but a few of the options have been found to be impractical due to poor availability of equipment and raw materials.

Table 1. Agricultural countermeasures as reviewed by IAEA[1]

Counter-measure type	Specific Application	Effectiveness[a]	Availability[b]
Soil Based - mechanical	Normal ploughing	High with mouldboard ploughs	A/B
	Deep ploughing	RF[c] of up to 10	C
	Skim and burial ploughing	RF of at least 10	C
	Remove 5-10cm top-soil	Removes up to 95% of radioactivity	C
	Soil stabilisation	Variable with material used	C
Soil based - additives	Lime addition	High on acid soils, RF up to 10 for ^{90}Sr, up to 3 for ^{137}Cs	A
	Potassium addition	High when soil soln K conc <20μM. RF up to 5 for ^{137}Cs	B
	Apply Sapropell	High, RF up to 6 for ^{137}Cs, up to 5 for ^{90}Sr	B
	Apply Aluminosilicates	Limited, RF up to 2 for ^{137}Cs	-B/D
	Apply organic fertilisers/manure	High, RF up to 5 for ^{90}Sr	A
	Apply soluble phosphate	High, RF up to 10 for ^{90}Sr	A
Production management	Select lower- uptake varieties	Variable but can achieve RF up to 5	A/B
	Select similar but lower-uptake crops	Variable but can achieve RF up to 3	A/B
	Select different, lower-uptake crops	Variable but can achieve RF up to 8	A/B
	Select crops from which processing removes contamination	Variable but can achieve RF of up to 10 in final product	A/B
	Select non-food crops	Not applicable	A/B
	Harvest crops for disposal	High, up to 80% removal	A/B
	Replace sheep/goats with cattle	Variable, RF up to 5	B
	Change from arable crops to cattle	Variable, RF of up to 100	B
	Change to forestry production	Not applicable	A/B
Animal based	Provide uncontaminated feed	High, up to 100%	A/B
	Grow forage with lower uptake rate	Switch from grasses to cereals, tubers and root-crops. RF 5-10	A/B
	Use land for non-dairy animals or those not yet for slaughter	Variable	B
	Raise cutting height of fodder grasses	Variable – reported RF of 3 for ^{137}Cs and 9 for ^{131}I. [2]	A
	Delay slaughter time to period of reduced uptake	Variable	A/B
	Provide prussian blue (AFCF)	Variable – 2 to 5 fold reduction in ^{137}Cs content of milk and meat	A/B/C
	Add clays to diet	Variable – 5 fold reduction in in ^{137}Cs content of milk and meat is possible	B
	Increase Ca in diet	Increase of 2-4 times Ca in diet reduces ^{90}Sr in milk by factor of 1.5-3 0	A

[a]Effectiveness as described in IAEA (1994)

[b] IAEA (1994) rating : A, Widely applicable; B, Effective but resources might not be available; C, Technically effective but requiring specialised equipment that is not widely available; D, Not recommended (either inadequately tested or proven to be of little or no value)

[c] Reduction Factor = Radioactivity or dose before treatment/ Radioactivity or dose after treatment

DISCUSSION

Strategy development

In developing a strategy for managing radioactively contaminated agricultural land, the intervention must be justified , in the sense that the action taken should achieve more good than harm. The levels at which the intervention is introduced and at which it is later withdrawn should be optimized, so that the protective measures will produce maximum net benefit[1]. The conventional approach[3,4] has been to compare the different actions in terms of reduction of dose to man and the associated cost factors according to the following relationship

Collective Averted Dose versus Costs (manpower + consumables + equipment costs)

But in practical terms what does this really mean to the farmer? The aim of dose reduction dictates that if the radiation dose to man from the contaminated agricultural situation is unacceptably high then some restriction must be applied to the use of the land or produce. However, to minimize the cost of this intervention a parallel aim of the remediation strategy must be the restoration of the economic use of the land. Except in the case of low-level contamination it is probably unrealistic to hope that the remediation will achieve complete restoration of the land to what it was prior to contamination. It is more reasonable to aim to restore economic viability to the agricultural situation or to shorten the time interval over which the land use is restricted. In this approach, the effectiveness of the action is compared only with limited economic factors. Other authors[1,5] have suggested that social and environmental factors also warrant consideration. Recent experience in evaluating remediation strategies confirms this suggestion and indicates several other, less obvious but equally important, factors as outlined in Table 2.

Each of the factors listed in Table 2 will be considered at some stage in every countermeasure evaluation process, but depending on the option being considered each will take on greater or lesser importance. Lost production and lost product value refer to situations in which production is restricted or where the crop attains a lower market value due to its contamination. In this case the farmer may expect compensation for lost earnings and so this factor becomes a real cost of the remediation option. Applicability involves factors such as the slope of the land and the stoniness of the soil, as well as the availability of equipment or raw materials In the final analysis these factors may exclude even the most effective or most economical remediation option.

Benefit		Costs	
Collective Averted Dose	vs	Direct monetary Costs	Application costs (Manpower, Consumables, Equipment, Waste disposal) Lost production or lost product value
		Applicability	Suitability to for example, topography, soil, production system etc.
		Acceptability	to farmer, consumer, local residents
		Secondary impacts	Environmental, Ecological, Social, Economic

Table 2. Cost-benefit analysis parameters for agricultural remediation options

Acceptability to the farmer is related to applicability and production losses and may ultimately depend on compensation arrangements. Acceptability to the consumer is a much more complex factor; it would be unwise to assume that a food product that is grown on decontaminated land, or produced using some method of dose reduction, will be acceptable to the consumer. This factor greatly influences costs in an agricultural context and represents the greatest challenge to the restoration of economic viability of agriculture after a nuclear accident.

Acceptability to local residents and secondary impacts refer to the fact that agricultural land is not only a food production system but has many functions in the wider natural, social and economic environment. For example, agricultural land is a feature of the landscape, a habitat for wildlife and a source of raw materials for industry. The integrity of the natural landscape has implications for the sense of well-being of the population.

These wider scale secondary impacts raise a very important question in the development of any remediation strategy: on what geographical scale should the evaluation be made? It is clear that there will be economic consequences for those whose livelihood comes from farming contaminated land. In addition to these costs however, there will be knock-on effects in for example, the local sales of seed and fertilizer. Evaluation on a regional level may require consideration of the impact on food processing industries, transport companies and export trade.

It is essential therefore, that prior to developing a strategy for management of radioactively contaminated land, a decision is taken about the geographical level to which the assessment of the remediation options will be made

Scenario analysis

A comparative analysis of the remediation options for a given agricultural scenario requires that the effectiveness and the value of each of the above cost factors is known and that the change in these cost values due to the remediation can be predicted. The experience attained in Europe is that this is where the greatest difficulties in restoration strategy development lie.

Evaluation of remediation effectiveness and costs as applied to real situations requires detailed knowledge of the environmental, economic and social parameters which influence these factors. Consider for example the site information needed to evaluate the application of potassium to agricultural soil as a countermeasure against radiocaesium transfer to vegetation. This countermeasure works by providing excess K ions which compete with and effectively dilute the available Cs ions. The effectiveness of K as a countermeasure is strongly dependent on the level of exchangeable K in the soil.[6] In order to evaluate the benefit of this countermeasure the decision maker requires knowledge of the K status of the soils to be treated. The K status of soil is a commonly measured parameter in normal agricultural practice but even so, our experience is that these data are not sufficiently available to facilitate a reliable evaluation of the effectiveness of this countermeasure on a wide geographical scale.

In the case of liming as a countermeasure against strontium transfer to vegetation, the key effectiveness parameter is soil exchangeable calcium. Ca is not a soil parameter which is commonly recorded for agricultural soils in Europe, therefore compared to K, these data are very scarce. Other remediation options present similar difficulties of poor availability of data essential for prediction of effectiveness, applicability, acceptability, costs and secondary impacts.

Many of these effectiveness parameters are spatially variable such that within even a single field, different areas will require different levels of treatment to achieve a uniform effectiveness of the countermeasure. In many cases, much of the information required is available on a very local level. Most farmers have a detailed knowledge of the peculiarities of their own land and how any change will affect the crop. It is therefore a useful strategy to avail of this wealth of experience in the analysis of remediation options. It may seem impractical to gather such detailed information, but on the other hand, we must conclude that the larger the unit of land upon which the strategy is assessed the lower will be the reliability of the analysis.

A practical approach may be to combine the local and the regional data and identify which stages in the decision-making process are best achieved at a local level and which can best be solved regionally. In this way the process maximizes the use of available information at each stage. An example of this combined approach is presented in Figure 1. Here the general, broad-scale applicability of countermeasure options can be assessed based on regional crop data, soil maps, topographical, demographic and climatic data etc. This step will eliminate all countermeasure options which are not applicable. The resulting list of appropriate remediation options can be evaluated regionally with respect to application costs but local assessment is required to evaluate these options in terms of effectiveness, small scale applicability and production losses. The resulting short-list of remediation options will require further local-level assessment with respect to acceptability and secondary impacts before a final decision on the best remediation strategy can be reached. If secondary environmental, economic and social impacts are to be evaluated on a wider scale then an additional step may be required prior to reaching a final decision.

CONCLUSION

A wide range of potentially useful agricultural countermeasures are reported in the scientific literature. The following points are indicated as being important to the development of a strategy for remediation of agricultural land following a nuclear accident:

- Cost-benefit analysis of remediation strategies should include consideration of production losses, applicability, acceptability and social and environmental costs
- The geographical scale of strategy evaluation should be established
- Consumer acceptability of products is a significant challenge to the restoration of economic viability to contaminated land

Extensive data are required to properly assess the costs and benefits of remediation. Experience in Europe is that these data are not always available in central databases but may be obtained directly from local farm personnel.

It is suggested that an approach to strategy evaluation which incorporates local assessment stages will maximise the use of the available data.

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