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GUIDELINES FOR AGRICULTURAL COUNTERMEASURES FOLLOWING AN ACCIDENTAL RELEASE OF RADIONUCLIDES

A JOINT UNDERTAKING BY THE IAEA AND FAO

INTERNATIONAL ATOMIC ENERGY AGENCY
VIENNA, 1994

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FOREWORD

The Chernobyl accident in 1986 caused significant radioactive contamination of the environment over widely separated areas, some relatively remote from the site. Considerable scientific research was stimulated directly and indirectly and a good deal of practical experience was obtained in dealing with the aftermath. Many effective measures were devised to counteract the agricultural consequences of such an accident, but some proved to be of doubtful value and in some cases there seemed to be harmful effects that outweighed the benefits. Often more factors required consideration than were immediately obvious and appropriate countermeasures not only varied regionally but sometimes from farm to farm.

The collation of the relevant information and experience concerning the transfer of radionuclides through food chains and ways of reducing this transfer is a prudent insurance for the management of agriculture should a major nuclear accident occur again. Work to this end was begun in 1990 by a consultants group convened in a co-ordinated research programme of the IAEA and the CEC on the Validation of Models for the Transfer of Radionuclides in Terrestrial, Urban and Aquatic Environments (VAMP). The work was further developed by a joint programme of the IAEA Division of Nuclear Safety and the Agrochemicals and Residues Section of the Joint FAO/IAEA Division of Nuclear Techniques in Food and Agriculture entitled "Alleviating the Adverse Effects of Excessive Radionuclide Contamination of the Agricultural Environment". The present Guidelines are an output of this programme and are intended to assist those charged with administrative, scientific and advisory responsibilities to prepare more detailed plans specific to the local conditions.

The IAEA and FAO wish to record their gratitude and appreciation for the work of the members of the consultants and advisory groups and others whose help made this publication possible They included: V.Y. Ageets (Belarus), R. Aleksakhin (Russian Federation), M. Antonovsky (Austria), N.P. Arkhipov (Ukraine), G. Bickerton (USA), N. Choudhury (Bangladesh), S.K. Firsakova (Belarus), M. Grauby (France), V. Gurkov (Belarus), O. Harbitz (Norway), S. Haywood (United Kingdom), E. Henrich (Austria), K. Hove (Norway), B.J. Howard (United Kingdom), K.J. Johansson (Sweden), A. Jouve (France), Y. Juncheng (China), Ki-Hak Han (Republic of Korea), R. Leitgeb (Austria), C. Myttenaere (Belgium), H. Oberländer (Austria), A. Povalyaev (Russian Federation), O. Premstaller (Austria), B. Prister (Ukraine), G. Pröhl (Germany), J.M. Quereshi (Pakistan), K. Raghu (India), A.N. Ratnikov (Russian Federation), I. Sachett (Brazil), F.J. Sandalls (United Kingdom), M.G. Segal (United Kingdom), J.A. Shirokov (Russian Federation), P. Strand (Norway), M. Suomela (Finland), V. Vetrov (Russian Federation), E. Wirth (Germany) and S.M.A.D. Zayed (Egypt).

EDITORIAL NOTE

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Part I

INTRODUCTION

1. INTRODUCTION

1.1. RADIATION ACCIDENTS AND AGRICULTURAL COUNTERMEASURES

The possibility exists of an accident that can result in a release of radioactive material into the environment. As nuclear facilities are not normally sited in densely populated areas, the adjacent land is likely to be agricultural or at least rural. Furthermore, the accident at Chernobyl in 1986 showed that agricultural practices can be affected hundreds and even thousands of kilometres from the accident site. Therefore contingency plans are needed to initiate countermeasures that can be used to reduce contamination of agricultural produce, even in countries with no nuclear power of their own.

As in any case of severe accidental contamination of the environment, all levels of government, from central down to local, will be involved.

The main considerations in preparing an agricultural countermeasures strategy are to:

— protect human health by reducing radioactive contamination of agricultural products
— return the land to normal usage as far as possible.

In practice, the decision to impose countermeasures must balance health protection measures, cost and the disruption to daily life.

In the immediate aftermath of a nuclear accident, short term restrictions may be imposed to reduce exposure to short lived radionuclides even though the contamination is likely also to contain other radionuclides. For example, a ban on the consumption of milk could be imposed for a period of a few weeks to allow ^{131}I to decay. If the nature of the contamination demands them, longer term aims will be to ensure 'safe' living conditions for inhabitants of contaminated areas and to restore contaminated land to some sort of agricultural production.

The intake of radionuclides by humans can be minimized by various techniques such as reducing uptake by crops through the addition of chemicals to the soil, or food processing. There are special animal feeding regimes designed to produce meat of acceptable quality even though some contaminated feedstuffs are used, and chemical binders can be added to animal feed to reduce the absorption of certain radionuclides.

The various actions taken to avoid and reduce radioactive contamination of agricultural products are described collectively as 'agricultural countermeasures'. Much information has been obtained from past experience of nuclear accidents, fallout from weapons testing and experimental investigations but some issues need further study. For example, some problems created by the accident at Chernobyl in 1986 have yet to be overcome, especially in Belarus, the Russian Federation and Ukraine. On the other hand, the results of the research carried out following the Chernobyl accident can be included in contingency plans to deal with any future accident.

1.2. PURPOSE AND SCOPE OF THE GUIDELINES

This document is intended to meet a need for general advice on the development of emergency response plans relating to food and agriculture in the event of a severe nuclear accident. The document addresses three main issues:

(i) establishing a general strategy for the introduction of agricultural countermeasures following an accidental release;
(ii) compiling data on a range of available countermeasures as an input to the decision making process;
(iii) providing assistance for Member States in the preparation of their own more detailed guidelines for agricultural countermeasures.

In attempting to satisfy these three objectives, the document necessarily discusses aspects of emergency response planning and radiological protection as well as the information on agricultural countermeasures themselves.

Part I outlines the problems of radioactive contamination of food and agriculture, radiological protection and the problems involved in developing a strategy for introducing countermeasures; it also summarizes the techniques available and aspects of their implementation. This overview is intended for decision makers and agricultural scientists and provides the context for the more detailed information given later. Part II contains technical information on the range of countermeasures available, their effectiveness and problems in their implementation. This part is of particular interest to those developing emergency plans and to agricultural scientists. Part III considers questions relating to the administration and organization of a response to potential or actual contamination of agriculture and food; it is particularly directed to administrators and planners. Part IV reviews the responses to past nuclear accidents. The Glossary contains definitions of various technical terms employed in the report. The report is complementary to others produced by the Food and Agriculture Organization of the United Nations (FAO) [1], the IAEA [2] and the World Health Organization (WHO) [3] concerned with responses to a nuclear accident.

2. GENERAL CONSIDERATIONS

2.1. THE NATURAL RADIATION ENVIRONMENT

Radiation has always been present throughout the biosphere in which life has evolved. Natural sources deliver the highest radiation dose that people normally receive. The average annual dose from natural sources is some 2.4 mSv [4], but typical individual doses range from 1 to 5 mSv a year and in extreme cases can exceed 100 mSv.

The two major natural radiation sources, cosmic radiation and radionuclides in the biosphere, have been present for thousands of millions of years. Cosmic radiation provides about 15% of background radiation and the gas radon, which stems from naturally occurring uranium and thorium, accounts for nearly 50%. The remainder is largely produced by radionuclides in the soil, principally ^{40}K. Internal irradiation of people is due mainly to the intake of ^{40}K, ^{210}Pb and ^{210}Po in food. The last two are decay products of ^{238}U. As the intake of ^{40}K is homeostatically controlled in the body, its contribution is essentially constant. However, dietary patterns can influence internal exposures to ^{210}Pb and ^{210}Po. For example, because they are present in relatively high concentrations in seafood, annual intakes in Japan, where seafood consumption is high, have been reported to be some five times greater than those in Germany [4].

Significant amounts of radioactive material were released into the environment during the late 1950s and early 1960s, when some 400 test nuclear weapons were detonated in the atmosphere. The fallout from this testing contained several hundred different radionuclides, but only four are of concern to humans: ^{14}C (half-life 5730 years), ^{137}Cs (30 years), ^{90}Sr (30 years) and ^{3}H (12 years). Traces of these nuclides can be found in soil and food the world over and are responsible for about 1% of the total annual exposure.

It follows from these considerations that 'radioactive contamination' of the agricultural environment, or a component of it, should be envisaged as an increase in radioactivity compared with the levels that occur naturally and that the definition of levels of radioactivity in agricultural products that can be used to separate 'contaminated' and 'uncontaminated' produce must take this into account. It is also possible to classify contaminated areas arbitrarily, for example on the basis of deposition levels of a particular radionuclide, to assist decisions concerning countermeasures as well as other judgements. This is only a first step because contamination of agricultural produce is not necessarily closely related to crude deposition levels.

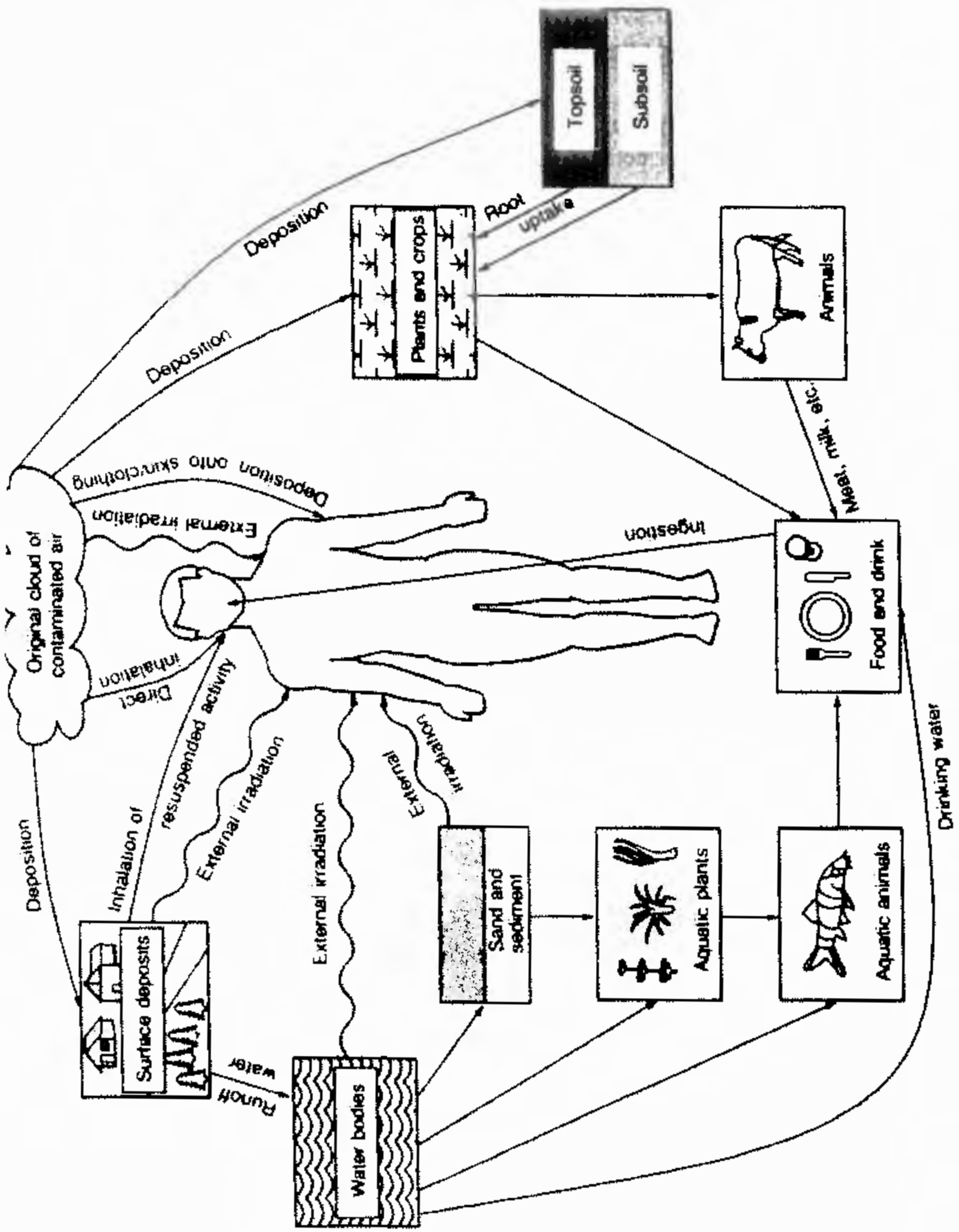

FIG. 1. Main environmental pathways of human radiation exposure.

2.2. RADIOLOGICAL PROTECTION

The term 'radiological protection' is used to describe the measures taken to protect humans against the effects of ionizing radiations. The complex interaction of ionizing radiations with living tissue has been studied for almost a century. Existing knowledge comes from extensive in vitro and in vivo animal experiments together with well documented epidemiological studies of the survivors of the atomic bombing of Hiroshima and Nagasaki in 1945 and of other groups exposed to relatively high doses of radiation. Whilst there are some uncertainties involved in extrapolating these effects to low doses, the approach recommended by the International Commission on Radiological Protection (ICRP) is generally well accepted internationally.

Accidental releases of radioactive material could occur to air, to water, or onto land, but those involving major releases to the atmosphere are the most likely to require urgent decisions for protective actions. Following such a release, people may be exposed to external radiation directly from the cloud of contamination and through inhalation of radioactive material from the cloud. As the cloud disperses, material will be either deposited onto the Earth's surface under dry conditions or washed out by rain or other forms of precipitation. Subsequently, people may be exposed to radiation directly from these radioactive deposits, by eating contaminated foodstuffs, by drinking contaminated water, or by inhaling dust resuspended from the ground (Fig. 1).

Two main classes of health effect can be caused by radiation exposure: 'deterministic' and 'stochastic' effects. Both classes have been quantitatively characterized extensively elsewhere. A useful and comprehensive summary is contained in IAEA Safety Series No. 109 [5]. Deterministic effects usually occur soon after exposure, and their severity increases with the radiation dose received, but there is an effective threshold of acute dose below which they do not occur at all (generally below about 0.5 Sv in two days). Thus, every possible effort should be made to prevent anyone receiving doses above the thresholds for these effects. Examples are bone marrow depression and skin burns. The doses received through contamination of food are usually much lower than those that give rise to deterministic effects; countermeasures are, in any case, invoked at lower levels.

Stochastic effects include the development of cancers and hereditary effects which usually occur many years after the initial exposure. In contrast to the deterministic effects, there is no threshold of dose below which they cannot occur. However, they do not occur in every exposed individual; the probability of an individual or their progeny developing an effect increases with the dose received. For instance, the additional risk of death from a radiation induced cancer is of the order of 5×10^{-5} per millisievert of dose received. Thus, even if the dose is very small there is still a finite chance of incurring one of these effects. For a large population, all receiving small radiation doses, it is possible to estimate the expected num-

... that would occur[1]. However, since other non-radiation-related causes also give rise to these effects[2], it is very difficult to be certain that a particular individual suffered an effect as a direct result of radiation exposure.

Following an accident where radioactive material is released to the atmosphere, it is likely that the total population dose will be made up of components ranging from a few people receiving high doses to large numbers receiving very small doses. Most of the expected cancers or other effects will occur in the large population receiving small doses, and these cannot be totally eliminated by any protective action. Thus, when considering intervention, the best that can be done will be to reduce the numbers of health effects by as many as possible. This will mean concentrating effort on those individuals who receive the higher doses since this will result in the maximum effect for the smallest number of people inconvenienced by any protective action.

Psychological stress and anxiety will always accompany a nuclear accident whether or not there has been significant radiation exposure. This is more properly attributable to the perception of the risk to health, and whether there is confidence that the authorities are competent and trustworthy and have taken prompt and effective action to control radiation dose. Clear, simple advice that has been internationally endorsed will do much to increase public confidence in the national authority, and thereby help to alleviate the inevitable psychological stresses and anxieties.

2.3. INTERVENTION LEVELS

Under normal operating conditions, the discharges from a nuclear facility are kept under strict control such that the additional doses to the nearby population are as low as can reasonably be achieved and within internationally agreed limits and constraints. These constraints are set at levels much lower than those that would prompt actions to protect the population or the environment. They also incorporate a margin to allow for possible future unknown sources of exposure. Typically, the values of these dose constraints are smaller than local geographical variations in the dose from natural radiation.

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[1] If 10^5 people receive 1 mSv each, then the collective dose is $10^5 \times 1 \times 10^{-3} = 100$ man·Sv. This could equally be made up from 10^4 people each receiving 10 mSv, or 1000 people receiving 100 mSv each. The expected number of additional deaths from cancer in each population would be the same, $5 \times 10^{-2} \times 100$, or approximately five.

[2] In developed countries, between about a fifth and a third of all deaths are due to cancer.

In the event of an accident, however, the amount of radioactive material released is no longer under control and, irrespective of liability for the accident, doses to individuals in the population can only be reduced by intervention — that is, through the imposition of protective measures, which will normally have considerable impacts on people and their environment. These measures may include sheltering, the taking of stable iodine tablets, banning of certain food, modification of agricultural and industrial processes, decontamination measures, temporary evacuation or permanent resettlement of the population. These actions have their own harmful features, sometimes involving direct effects on health and well-being. They all restrict freedom of action or choice and resources may have to be diverted from other socially beneficial purposes to pay for them. Therefore, when considering the adoption of a given protective measure, both the benefits of the measure in terms of reducing the risk to health from radiation and the harm from the measure itself must be assessed.

Hence, it is essential to distinguish clearly the roles of dose limits and constraints for normal operations, and intervention levels for use following an accident. Although similar principles hold (justification and optimization), they are applied to different quantities. In the case of control of planned releases, the benefit given by the source itself is compared with the additional radiation exposure it produces. In the case of intervention, the benefit of the intervention is compared with the reduction in radiation exposure, including any changes in exposure from natural radiation. For these reasons, intervention levels, and dose limits and constraints for normal conditions have entirely different bases and their numerical values will normally be very different. If their numerical values happen to be the same, this is entirely a result of coincidence.

The general principles that form the basis for these recommendations on intervention are derived from those contained in Safety Series No. 109 [5], and proceed naturally from the health grounds for protective action (Section 2.2). The three general principles that form the basis for making decisions on intervention are:

(a) **All possible efforts should be made to prevent serious deterministic health effects.**
As already stated, this principle has no practical relevance for agricultural countermeasures.

(b) **The intervention should be *justified*, in the sense that introduction of the protective measure should achieve more good than harm.**
Intervention is justified when there is a net benefit in taking action. In some circumstances, the disadvantages of intervention may outweigh the advantages of avoiding the exposure so it is important to consider this possibility carefully. A detailed discussion of the factors that should be considered is provided in Ref. [5].

(c) **The levels at which the intervention is introduced and at which it is later withdrawn should be *optimized*, so that the protective measure will produce a maximum net benefit.**

Intervention is optimized when the net benefit from a protective measure is at its maximum. It is possible to choose an intervention level for each protective action, above which the action is normally taken and below which the action is not normally taken. The values of the intervention levels for all the protective actions should be chosen so as to produce the maximum net benefit.

Intervention levels for use in abnormal situations should be specified in advance by the competent management authority. If the value of the quantity of interest exceeds or is predicted to exceed a particular intervention level, the appropriate remedial action should be taken. As already stated, intervention levels are not to be confused with dose limits; in principle, they should be derived from principles (b) and (c) above.

No two accidents will ever be alike — the proportions of the various radioisotopes released, the meteorological conditions, the transfer rates to different food products, and factors such as the season of the year will affect the doses that could be received by members of the public through the food chain. Theoretically, the intervention levels for different nuclides and different foodstuffs will depend on the particular accident and prevailing conditions. However, intervention levels must be specified in advance of an accident to avoid confusion within food control authorities, and must be consistent with existing food legislation. There is considerable advantage in using internationally recognized values for the intervention levels; this will help in maintaining credibility, confidence and trust in the authorities. The use of such values will also help to prevent the anomalies that otherwise might exist along the borders of neighbouring countries. Finally, strong arguments can be brought that any values adopted for intervention levels for international trade should not be different from values used nationally to control food. Since the difference between a theoretically more specific set of levels and a simple generic set is relatively small, the added complexity of more sophisticated schemes of intervention levels is not warranted.

The Codex Alimentarius Commission of the FAO and WHO has addressed the situation of international standards in order to maintain widespread international trading in food. Guideline levels for radionuclides in international trade following accidental nuclear contamination have been agreed [6]. It should be recognized that these levels are a compromise between what is appropriate on radiological protection grounds (which would give rise to higher values) and the natural wish of countries unaffected by an accident to avoid importing produce with any contamination at all, no matter how small, even compared with natural radiation. On the basis of the arguments described above, they are appropriate on a generic basis as intervention levels. They are reproduced in Table I.

TABLE I. RECOMMENDED GENERIC [illegible] WITHDRAWAL OF FOODSTUFFS WHERE ALTERNATIVE SUPPLIES ARE READILY AVAILABLE

Dose per unit intake (Sv/Bq)	Representative radionuclides	Level (Bq/kg)
	Foods destined for general consumption	
10^{-6}	Am-241, Pu-239	10
10^{-7}	Sr-90	100
10^{-8}	I-131, Cs-134, Cs-137	1000
	Milk and infant foods	
10^{-6}	Am-241, Pu-239	1
10^{-7}	Sr-90, I-131	100
10^{-8}	Cs-134, Cs-137	1000

Notes:

These levels apply to national control where alternative food supplies are available; if this is not the case, higher levels may apply. They coincide with the Codex Alimentarius Guideline Levels for Radionuclides for Use in International Trade Following Accidental Nuclear Contamination. They do not apply to naturally occurring radionuclides which are normally present in the diet.

The Codex Alimentarius Guideline Levels remain applicable for one year following a nuclear accident. By an accident is meant a situation where the uncontrolled release of radionuclides to the environment results in the contamination of food offered in international trade.

As the proposed levels were derived using extensive conservative assumptions, there is no need to add contributions from each of the three groups; each group should be treated independently. However, if more than one radionuclide is present, the activities of the different accidentally contaminating radionuclides within a group should be added together. For example, following a reactor accident, ^{134}Cs and ^{137}Cs could be contaminants of food and the 1000 Bq/kg refers to the summed activity of both these radionuclides.

These levels are intended to be applied to food prepared for consumption, and would be unnecessarily restrictive if applied to dried or concentrated food prior to dilution or reconstitution.

Both FAO and WHO have called attention to the special considerations that might apply to certain classes of food which are consumed in small quantities, such as spices. Some of the foods grown in the areas affected by the Chernobyl accident fallout contained very high levels of radionuclides following the accident. Because they represent a very small percentage of total diets and hence would make very small additions to the total dose, application of the Guideline Levels to products of this type may be unnecessarily restrictive. FAO and WHO are aware that policies vary at present in different countries regarding such classes of food.

The intervention levels are specified as activity concentrations of a particular radionuclide (or group of radionuclides) in the foodstuff (e.g. Bq/kg, Bq/L), and countermeasures must be taken to achieve values lower than these, otherwise the food must be withdrawn from consumption. There will also be a need for authorities to develop secondary reference levels (so-called 'operational intervention levels') for other quantities such as animal feeds and levels of contamination on pasture at which animals should be withdrawn. These working quantities will be specified in their own appropriate units (e.g. Bq/m^2).

It is clear that in exceptional circumstances the simple set of generic intervention levels recommended here may be inappropriate. The national authority may choose then to relax the standards for the specific and limited situation. Guidance on the levels to which the standards could be reasonably relaxed without compromising public health are given in IAEA-TECDOC-698 [7] and the WHO Derived Intervention Levels [3]. For example, following the Chernobyl accident, because of a set of peculiar conditions, reindeer meat in the north of Norway became contaminated to values exceeding the levels in Table I by a factor of 20 or so. However, because people do not consume large quantities of reindeer meat, the national authorities deemed that provided the meat was strictly monitored and controlled, appropriate intervention levels could be relaxed in order to protect the Lapp culture, without jeopardizing public health.

3. DEVELOPING A STRATEGY FOR AGRICULTURAL COUNTERMEASURES

3.1. TIMING

The timing and nature of countermeasures depend on the quantity and composition of the radionuclides in the release, the season of the year and site specific factors. The post-accident period can be conveniently divided into three phases, but these overlap so that distinct divisions cannot be made.

3.1.1. Early phase

This may begin before the fallout arrives since warning may be obtained several hours and sometimes days beforehand. The period should be used to estimate the severity and consequences of the expected deposition. Naturally, protection of the population will be the first priority, but then consideration should be given to protection of food and water supplies. Decisions concerning short term countermeasures

should be made, such as recommendations to house cattle. The organizations responsible for distribution of food must be given prompt information. The early phase ends when the 'cloud' has passed and the acute deposition has finished. It is self-evident that countermeasures taken during this phase must be applied promptly if they are to be effective. However, they will be based on forecasts derived from incomplete data so there is a high degree of uncertainty. Therefore they should be inexpensive.

3.1.2. Intermediate phase

Following the passage of the cloud and acute deposition, there is a period which may last several weeks or months, until contamination from short lived radionuclides is no longer of concern or the first crop is harvested. Distribution of the most important foodstuffs must be kept under supervision. The radiation doses to people with diets containing high radionuclide concentrations should be estimated. Foodstuffs must also be monitored and if the preplanned intervention levels are exceeded, countermeasures should be applied. Data on the type and distribution of contamination should be collected. If there is serious and widespread contamination, pilot studies should begin to determine the feasibility of countermeasures that are under consideration for later large scale application. Consideration should also be given to the possibility of obtaining uncontaminated food through domestic or international trade.

3.1.3. Late phase

In the late phase the radioactive contamination is mainly due to long lived radionuclides and contamination of foodstuffs occurs primarily through root uptake of radionuclides by plants. The need for long term agricultural countermeasures can be assessed and suitable countermeasures applied consistent with the availability of uncontaminated foods through trade.

3.2. PLANNING

A general strategy for the introduction of agricultural countermeasures should be established in the planning for emergency response. Experience of past accidents and of weapons testing is valuable in the preparation of such plans.

The first step is to determine the most probable scenarios for radionuclide deposition and contamination of foodstuffs. The most important radionuclides and pathways for contamination of foodstuffs should be considered and methods for the assessment of radionuclide concentrations due to direct contamination and root uptake should be available. Local, empirically determined transfer factors would be necessary to make reliable predictions. Internal dose estimates for an average diet will also be needed. Computer programs exist for making such assessments.

It is also desirable to have data available on soil types, production of foodstuffs and other factors for estimation of the effects and efficiency of countermeasures. A list of feasible agricultural countermeasures and some estimate of their costs should also be available.

Plans should also provide practical details of agricultural countermeasures in a form useful to agricultural scientists, veterinarians, farmers, the food industry and members of the public.

To survey the contamination, networks of stations for assessing radionuclide composition, geographical distribution and the radionuclide contents of foodstuffs have to be established. These networks may be based on the laboratories whose normal task is to monitor food quality, if they are equipped with appropriate instrumentation, but universities and other institutions can also be involved. It is necessary to have a continuous quality assurance programme for these laboratories as well as training of the personnel. Records should be kept in accordance with the principles of good laboratory practice (see, for example, Ref. [8]).

The emergency plans will also include a programme of regular exercises to test the organizational arrangements in different situations. It is important to realize that the situation following an actual release will not necessarily follow any of the anticipated scenarios. Therefore, all concerned must be able to respond to unforeseen situations and the test exercises should develop flexibility in the organizations.

3.3. DECISION MAKING

For the early phase of an accident, authorities will rely in the main on their own emergency plans. These plans will have been drawn up prior to an accident, taking into account the discussions of Section 3.2 above; the need for elaborate decision making in real time on the introduction of countermeasures will to a large extent be obviated by the existance of plans and there will anyway be a lack of time in which to react. After the emergency phase is over and as more detailed information becomes available and the potential for large expenditures becomes more apparent, more considered decisions will need to be made about the need for specific longer term countermeasures and/or the relaxation of countermeasures. These may well involve the use of decision aiding tools.

There can be no generic strategy for the introduction of agricultural countermeasures because environmental conditions vary from place to place, and the nature and size of accidental releases, the size of the affected population and the social, economic and agricultural conditions will all differ. Thus, although strategies should take into account the same basic considerations, local factors and hence the most appropriate countermeasures will also vary.

TABLE II. PRINCIPAL ELEMENTS OF INFORMATION NEEDED FOR REACHING DECISIONS

Topic	Information
Environment	Maps showing topography, soil characteristics, land utilization, hydrology, deposition of radionuclides, climate data
Agriculture	Production systems, yields, quantities and prices of products sold, materials inputs, economic importance
Infrastructure	Availability and costs of transport, communications, fuel, water, medical services
Social factors	Population size and distribution, employment patterns, health profiles, recreational uses of rural areas
Catalogue of suitable countermeasures	Effectiveness, resource requirements, costs, compatibility with others, possible side effects
Radioecology	Relevant transfer factors, accumulation and biological half-lives in livestock, retention factors by main local vegetation canopies, factors for reduction of radionuclide contamination by processing operations

As discussed earlier, the main objective of a countermeasure should be to reduce radiation doses to the population and hence diminish health risks. In practice, this translates into selecting a countermeasure strategy that will allow production of food with activity levels below the intervention levels in as cost effective a manner as possible, with minimum side effects. On this basis the simplest way to compare the cost effectiveness of countermeasure options is to calculate the monetary cost per unit collective dose saved. It should be noted, however, that it is possible to bring activity levels below intervention levels, by dilution with uncontaminated produce, without saving collective dose.

However, the side effects of some countermeasures, which can include ecological, economic and social factors, can be substantial. For example, agriculture could become unsustainable, farmers and their dependent communities could be made redundant, and the psychosocial consequences could be large, even leading to clinical health problems. It is therefore important that weight be given to measures that will allow contaminated land to be used in some way, preferably in agriculture. There may be cultural reasons why a particular strategy, although cost effective in financial terms, is unacceptable. There may be practical reasons why countermeasures must be adopted in a particular area in order to limit the spread of contaminated

... area. The markets could be severely distorted in the short to medium term by the introduction of a particular strategy. Subsidies and compensation to farmers may introduce their own market distortions. These additional factors will have to be taken into account in the drawing up of recommendations to farmers, and political decisions will be required in the consideration of financial compensations and subsidies. Some sophisticated techniques exist that can be used to aid decisions between different alternatives [9]. Nevertheless, these methods can only be used if the problem is relatively simple and well structured, and persons with specialist knowledge are available. Such techniques will generally require large quantities of data, some of which are listed in Table II. Such methods have not yet been used in practice for deciding on agricultural countermeasures; decisions have been based on the cost effectiveness of the particular countermeasure and a subjective weighing of other factors.

Part II

AGRICULTURAL COUNTERMEASURES: SCIENTIFIC BASIS AND PRACTICE

4. INTRODUCTION

This part of the present publication is primarily intended to provide an initial source of information on countermeasures which may be used in the event of a nuclear accident. The information is in a summarized format but the literature references give guidance to sources of more detail if required.

A wide variety of different countermeasures are available which can reduce or prevent the transfer of radionuclides through the food chain. Inevitably, in condensing the available information, many generalizations have been made. It must be borne in mind that countermeasures vary, both in their effectiveness and their economic, ecological and social impact [10]. Some countermeasures are widely applicable, others are not. The emphasis here is on countermeasures which aim to prevent contaminated food products reaching the consumer. This is a standard response in emergency planning [11]. There are a large number of radionuclides that can potentially be released in a nuclear accident. Those for which countermeasures are most likely to be needed have:

— a relatively high likelihood of release in an accident;
— comparatively long physical half-life;
— high radiological toxicity;
— a potentially high mobility in the environment;
— an essential role in the biosphere, or are closely related to such an element (e.g. strontium and calcium).

Over 30 radionuclides have been considered important as potential contaminants of the environment by Edley [12] and Arnold [13] and have physical half-lives exceeding 5 days. They include some, such as the actinides, which are not readily transferred along food chains but can provide significant doses to people working in affected areas.

Most information is available for radionuclides which have been released in previous accidents and which are readily transferred into food products, in particular for radioiodine (^{131}I), radiocaesium (^{134}Cs and ^{137}Cs) and radiostrontium (^{90}Sr). For other radionuclides, which are unlikely to be of similar importance, the range of available countermeasures is limited by lack of information, although some countermeasures listed below would be effective for many different radionuclides.

Many of the countermeasures listed in this part of the publication are based on papers published in the journal Science of the Total Environment (1993) from a CEC DGXII workshop on the relative effectiveness of agricultural countermeasure techniques (REACT). These papers can be consulted for more detailed discussion of some of the countermeasures listed. Useful sources of information which summarize studies on countermeasures are listed in the Bibliography.

... and usefulness of countermeasures depend on the time-scale. Radionuclides with short physical half-lives will cause problems only if the contamination rapidly passes through the food chain to an edible product or significant direct deposition occurs onto leafy plants just before harvest. The impact of long lived radionuclides must be considered for a much wider range of different circumstances, including agriculturally improved areas, semi-natural ecosystems, fisheries and forests.

For each countermeasure, the methodology (where helpful) and effectiveness (where possible) are given, followed by comments on the technique.

Reviewers of the draft text were invited to rate each countermeasure as:

A: Widely applicable

B: Effective but resources may not be available

C: Technically effective but requiring specialized equipment that is not widely available

D: Not recommended (either inadequately tested or proven to be of little or no value).

Not all reviewers responded to the invitation and a view was expressed that a classification could be misleading. The letters, sometimes with qualifying comments, in the following text, indicate how most respondents classified each countermeasure. They are certainly not intended as definitive assessments, not least because economic and social considerations as well as resource availability vary so widely. In addition, alternative classifications using different criteria can be devised. Several reviewers commented that many estimates of effectiveness quoted are probably optimistic.

5. PREVENTIVE MEASURES TO BE APPLIED BEFORE AND DURING THE ARRIVAL OF RADIOACTIVE FALLOUT

5.1. INTRODUCTION

Possible action in the short term is limited and depends on the availability of information on the nature and scale of the accident. In the early pre-deposition phase after an accidental release, there is likely to be little information on the extent and composition of the fallout or on the likely rate of deposition. Nevertheless, countermeasures applied at this stage may be effective in preventing or reducing longer term problems and merit consideration. The primary aim of responding prior to deposition

is to avoid contamination by direct deposition. Therefore, crops ready for harvest, particularly those which would be expected to intercept a comparatively large proportion of the fallout (such as leafy vegetables and grain crops), are of particular concern.

The countermeasures listed below are generally easy to apply, and in some cases, inexpensive. Such considerations are particularly important at this stage when it is not possible to be sure where, and to what extent, the fallout will be deposited. Rapid decisions, based on all available information, have to be taken as to whether or not they should be used.

It is important to balance the advantages in carrying out the countermeasures listed below against the potential disadvantages, including possible radiation doses to people working outside. The cost effectiveness of the operation must also be considered, including the potentially harmful social effects that might result from over-reaction, which is particularly likely when little information is available.

A more detailed discussion of these types of countermeasures and of their relative merits can be found in Willdrot [14]. Comparatively few of these procedures have ever actually been carried out after an accident and therefore it is not always possible to give examples of their use.

5.2. AVAILABLE COUNTERMEASURES

5.2.1. General countermeasures

5.2.2.1. Prevent the ingestion of contaminated herbage by grazing animals

Effectiveness: High, up to 100%.

Comments: Housing animals which are grazing outdoors (or preventing the return of stalled animals to pasture) and providing uncontaminated forage prevents the contamination of milk, meat and offal. Buildings are needed, but if they are not available it might be possible to restrict animals to small, fenced areas to limit their access to pasture while providing them with uncontaminated feed. If possible, animals should not be given rainwater or surface water. The availability of stored, uncontaminated fodder will vary with season, and may be limited just before the normal time for harvesting fodder. If animals need to be removed from pasture, consideration should be given to the resulting dose to people removing the livestock from the contaminated area. As a short term countermeasure it is particularly applicable if high levels of ^{131}I are likely to cause high radiation doses to animal thyroids, as occurred after the Chernobyl accident [15, 16]. It can, of course be applied as a medium to long term countermeasure (see Section 7).

Rating: A.

5.2.2.2. Avoid direct contamination of agricultural products

Method 1: Cover uncovered feed/food stores and open sources of water with water impermeable sheeting.
Effectiveness: 100%.
Comments: Covering haystacks, heaps of beetroots, potatoes, etc., with plastic sheeting or tarpaulins is effective and comparatively easy to arrange in areas where suitable covering is commonly available. Covering is probably most effective for wet deposition which can infiltrate beyond the surface material.
Rating: A.

Method 2: Harvest ripe crops before contamination occurs.
Effectiveness: 100%.
Comments: Radioactive contamination of crops can be avoided by harvesting all above-ground ripe crops. It must be done rapidly and at short notice so labour, harvesting equipment and storage space may be limiting. Ideally, the response should be based on considerations of averted dose but in practice growers are likely to give priority to high value crops.
Rating: A/B.

Method 3: Cover cultivated areas with water impermeable sheeting.
Effectiveness: 100%.
Comments: Covering large areas with plastic or other such sheeting is expensive and should only be considered for high value crops, such as vegetables, fruit and herbs. Availability of suitable sheeting material may be limited and there may be detrimental effects on the crops, particularly in hot climates, where scorching may occur. Subsequent decontamination and disposal of the sheeting will need to be arranged.
Rating: B.

6. COUNTERMEASURES TO BE APPLIED IN THE FIRST FEW WEEKS AFTER DEPOSITION

6.1. INTRODUCTION

Radionuclides with short physical half-lives will cause only transient problems. The most important example is the rapid transfer of ^{131}I to milk. The proportion of radioactivity which is intercepted by vegetation and the rate at which it is lost from

the surfaces determines the effectiveness of countermeasures [illegible] nuclides and plants, much of the radioactivity retained on plant surfaces will be lost through weathering processes within the first month after deposition. In addition, concentrations will be reduced by growth dilution.

Despite the short time scale, cost effective countermeasures are possible in many circumstances. It must also be remembered that there will usually be more than one radionuclide in the fallout and some of them will have long half-lives. Countermeasures used at this stage should therefore be effective for a wide range of different radionuclides. Such countermeasures have to be simple and easy to carry out so that they can be applied by large numbers of farmers with little instruction, using resources which are readily available.

6.2. AVAILABLE COUNTERMEASURES

6.2.1. General countermeasures

6.2.1.1. House animals which would normally be grazing outdoors and provide uncontaminated forage

Effectiveness: High, up to 100%.
Comments: The same as short term measure 5.2.1.1. The availability of stored, uncontaminated fodder may be more of a restriction over a period of several weeks. The ban on grazing should only be lifted when detailed knowledge of the nature and extent of the deposition is sufficient to show that radionuclide levels in pasture will lead to the production of milk with radionuclide concentrations below intervention limits.
Rating: A/B.

6.2.1.2. Harvest crops and grass for disposal or storage

Methods: Crops and pasture grass harvested as soon as possible after deposition may be either destroyed, or stored to allow short lived radionuclides (e.g. ^{131}I) to decay. Depending on contamination levels, the harvested feedstuff may be fed to livestock with added chemical binders to prevent absorption, or used to feed appropriate types of animals (see Section 7.5). Crops may also be decontaminated by appropriate food processing (see Section 8). Also grain may be used for alcohol production, or, in some cases, may be saved for seed.
Effectiveness: The main factor determining efficiency will be the interval between deposition and harvest. Furthermore, the efficiency of removal of radioactivity from the environment depends on the proportion which has been intercepted by the vegetation and the rate at which it is lost (by weathering). Initial interception depends on

factors such as the biomass per unit area, the overall cover provided by the vegetation and physical characteristics of the foliage. For agricultural crops about 25–50% of deposited contamination can often be removed by harvesting vegetation, but removal can reach about 80% for a dense ground cover [17]. The cost effectiveness depends on the use which can be made of the material.

Comments: Direct removal of vegetation avoids further ground contamination due to weathering losses from plant surfaces, and prevents the translocation of radionuclides from leaves to roots. Further information on the interception and retention of aerosols is given by Chamberlain [18]. Harvesting and disposal of pasture vegetation also reduces the radionuclide intake of grazing animals. However, removal of pasture vegetation can be contemplated only if alternative feed is available. Availability of labour may be the limiting factor.

If vegetation is harvested before intercepted fallout has been removed from the surface of the plants, a significant, but highly variable, proportion of the total deposition may be prevented from reaching the soil surface. The efficiency and benefit of this technique varies with the time and extent of deposition, the growth stage of the crop and the subsequent use of the harvested material. For instance, deposition just before a planned harvest may result in levels in forage which are so high that the vegetation has to be discarded. Disposal of such material is commonly by burial, although this can only be recommended for fallout which is short lived or of low solubility, or in soils which have a high immobilization potential and where there is no risk of subsequent uptake by roots. For instance, clay soils are particularly effective for immobilizing caesium but peaty soils are not and should therefore be avoided. The availability of suitable sites may thus be a restriction.

Further discussion of burial countermeasure methodology is given in Section 7.1. Resuspension of deposited radioactivity and external radiation dose is a potential problem for personnel carrying out crop removal [19] and appropriate precautions are needed.

Rating: A/B.

6.2.1.3. Delay the harvesting of forage/crops

Comments: If deposition occurs just before normal harvest time it would be advisable to delay harvest to allow reductions in radionuclide contamination by weathering and growth dilution [20]. Losses of surface deposited radionuclides could even be enhanced by using simulated rainfall or overhead irrigation to wash off the contamination. However, this contaminates the soil and so may produce a worse problem in the long term. The time of harvest should be determined on the basis of residual radioactivity. It is the converse of the countermeasure in Section 6.2.1.2. This apparent contradiction emphasises the importance of information about the amount and nature of deposition.

Rating: A (sometimes B).

6.2.1.4. Prohibit hunting, fishing, mushroom collection, and consumption of vegetables and water derived from surface water or precipitation

Comments: Game, fish, mushrooms and vegetables can contain particularly high levels of some radionuclides, and in the absence of information about contamination levels, prohibition may be an effective short term measure. This would be a socially disruptive and expensive countermeasure where such produce is an important component of the diet. There may also be problems in providing alternative food and water.

Rating: A.

6.2.2. Specific countermeasures against ^{131}I contamination in milk

Iodine-131 is one of the most mobile radionuclides. Regardless of whether it is in elemental, inorganic or organic form, iodine is thought to be rapidly and completely absorbed in the gut, and it accumulates in the thyroid gland, where it is incorporated into hormones. A constant adequate supply of stable iodine is essential for normal thyroid function and will minimize accumulation of radioiodine in the thyroid. This is particularly important in areas where there are endemic deficiencies of stable iodine [21].

Iodine-131 also accumulates in the mammary gland and is secreted in milk as well as being excreted in urine and, to a lesser extent, in faeces. Because both the physical half-life (8 days) and biological half-life in the thyroid and milk are short, ^{131}I contamination of milk is a short term problem. After a pulse of fallout onto pasture, ^{131}I levels in cow's milk reach a maximum in about 2 days. Net transfer of radioiodine from plasma to milk is much lower in cows than in goats and sheep; in the latter it can exceed 50% of the daily intake. Transfer of ^{131}I into milk can be affected by many factors, including the nutritional status of the animal, milk yield, stable iodine intake, temperature and goitrogenic substances in feedstuffs [22] but the interrelationships have yet to be established in a predictable way.

After the Chernobyl accident, ^{131}I was detected in milk for up to 45 days [15]. Because of the high rate of transfer of ^{131}I to milk it is well worth considering suitable countermeasures.

6.2.2.1. Process contaminated milk to storable products

Method: Use milk to produce butter, skimmed milk powder, cheese and other products which can be stored to allow ^{131}I to decay before consumption.

Comments: This method is not applicable when milk is also significantly contaminated with radiocaesium, radiostrontium or other long lived radionuclides. Food processing industries may refuse to accept contaminated milk. For further details see Section 8.

Rating: A/B.

6.2.2.2. *Add stable iodine to feed*

Method: Feed stable iodine at a rate in excess of normal daily requirements.
Comments: The amount of stable iodine, as either sodium or potassium iodide, in the diet affects the amount of radioiodine which is secreted into milk and taken up by the thyroid. The dynamic relationships between radioiodine uptake by the thyroid and transfer to milk are not clear and in some circumstances provision of stable iodine may increase ^{131}I levels in milk [23, 24]. Stable iodine should be given as soon as possible to have maximum effect so it is important that supplies are available.

If stable iodine levels in the diet are increased, concentrations of stable iodine in milk also increase. This will have an added benefit for human consumers of milk in that it will reduce radioiodine uptake, thereby protecting the thyroid from irradiation [25].

There may be practical difficulties in arranging and enforcing the administration of stable iodine by large numbers of dairy farmers. Such a countermeasure would rely on the goodwill of farmers, efficient administration and the availability of the iodine additive.

These considerations, combined with the possibility that this measure could actually increase the ^{131}I content of milk, make it difficult to classify.
Rating: A/B/D.

7. COUNTERMEASURES TO BE APPLIED IN THE MEDIUM AND LONG TERM

7.1. INTRODUCTION

Once the contamination is distributed throughout the biosphere, the range of appropriate countermeasures increases as does the time-scale of their operation. Thus, removal and disposal of a contaminated soil layer is (in principle) simple and does not take long but has a long lasting effect, while changing land use is technically, economically and socially complicated and takes a long time to establish.

7.2. DECONTAMINATION OF LAND THROUGH MECHANICAL TREATMENT OF SOIL

7.2.1. Introduction

Many radionuclides deposited on the soil surface remain in the top few centimetres of soil and movement down the soil profile is slow. More than 30 years

after the cessation of most above-ground nuclear weapons tests the released radioactivity is largely in the top 15 cm of most soil types. Strontium is somewhat more mobile than caesium but plutonium and americium are virtually immobile. The retention of radionuclides has both disadvantages and advantages. The major disadvantages are that radionuclides retained in the topsoil are: (i) potentially available for root uptake by shallow-rooted species such as grasses; (ii) a relatively unshielded source of external radiation dose; and (iii) liable to resuspension thereby providing an additional potential radiation dose to humans. However, a major advantage is that, because of their low mobility, the majority of deposited radionuclides can be removed effectively by skimming off a relatively shallow layer of topsoil (see, for example, Ref. [17]).

This section discusses mechanical methods of removing radionuclide contamination, including removal of soil, ploughing or preventing its redistribution. Further information on the techniques described can be found in the summary REACT paper by Maubert et al. [26], in more detailed REACT papers by Vovk et al. [19] and Jouve et al. [27] and also from the reviews by Van Dorp et al. [20] and Arnold [28].

7.2.2. Available countermeasures

7.2.2.1. *Plough to dilute the radionuclides in the rooting layer*

Method 1: Normal mouldboard ploughing.
Effectiveness: The efficiency depends on the type and depth of soil and on the type of crops, especially the rooting depth.
Comments: Where mouldboard ploughing to a depth of 20–30 cm is a routine cultivation procedure, this is a valuable method since ploughs and tractors are readily available and no reduction in fertility would occur. Contamination would remain in the upper 20–30 cm but at reduced concentrations. Therefore, although it would be taken up by most crops, the rate would be lower than that before ploughing. Subsequent ploughing could, of course, return the contamination to the surface. Ploughs, such as disk or chisel types, which do not invert a furrow slice will be less effective. Where ploughs are pulled by animals, exposure of the operator to contaminated dust must be considered.
Rating: A/B.

Method 2: Deep ploughing.
Effectiveness: Deep ploughing greatly reduces the uptake of radionuclides, especially for shallow-rooting plants. For such plants with a short growing period, the reduction can be by a factor of 10.
Comments: Large ploughs drawn by powerful tractors can work at depths of up to 1 m. The availability of machinery is a major limitation. Drawbacks of deep

... destruction of land drains; the loss of the upper fertile layer of soil, possibly permanently; the placement of a potentially infertile layer of soil on the surface; impracticality of the technique on sandy soils.
Rating: C.

Method 3: Skim and burial ploughing.
Effectiveness: Skim and burial ploughing minimizes the uptake of radionuclides, especially for shallow-rooting plants. Even for deep-rooting crops there can be an average reduction by a factor of at least 10.
Comments: A skim and burial plough has been developed which can be set to skim off the topmost 5–10 cm layer of soil and place it, as a discrete layer, at a depth of 50 cm beneath a non-inverted soil layer. Such a plough has the advantage that soil fertility would not usually be impaired. Of course, land drains could still be damaged, but this is seen as a secondary and not insurmountable problem. At present, only a small number of such ploughs exist, so the applicability of this measure is limited. Furthermore, tractors which are more powerful than those found on the majority of farms are needed.
Rating: C.

7.2.2.2. Remove a shallow surface layer of the contaminated soil

Method 1: Use of conventional road building equipment such as bulldozers, scrapers and so on.
Effectiveness: Removal of 5–10 cm of soil can remove up to 95% of deposited material. The technique may be less efficient a year or so after deposition for radionuclides that are mobile in the particular soil considered.
Comments: Removing a shallow layer of contaminated topsoil substantially decreases the resuspension hazard and also permits the production of less contaminated plants. Removal of a layer of contaminated soil is a possibility for both arable and pasture systems as long as the remaining topsoil is sufficiently fertile to sustain plant growth. Scraping off topsoil is not possible under all circumstances, for instance on shallow, stony soil. On wet peaty soil it will be difficult to use large machinery and on heavy clay soils decontamination may be limited to times of year when the soil is workable. Sandy, structureless soil cannot be removed effectively as a thin layer.

On land where the fertility and drainage would not be impaired by removing a shallow layer (5–10 cm) of soil, this is an effective, but expensive, countermeasure. For less fertile soils there may be a significant loss of nutrients so that additional fertilization is required in subsequent growing seasons.

The major disadvantages are the enormous logistic and disposal problems which were highlighted after the Chernobyl accident [19]. For instance, a 5 cm layer of soil over an area of 1 ha has a volume of 500 m^3 and a mass of about 700 t.

These disadvantages eliminated this countermeasure from consideration in many countries. It was, however, successfully applied after the Palomares incident (see Part IV).
Rating: C.

Method 2: Use of a turf harvester to remove a shallow layer of topsoil.
Effectiveness: Removal of 2–4 cm of topsoil can remove almost all of the radioactivity.
Comments: A turf harvester removes only the top few centimetres of soil. It can be used on meadows or on abandoned cultivated fields colonized by native species of plants.

The current designs of turf harvesting machines are not suitable for large areas and are not available in some countries. Investigations are currently proceeding to evaluate the possible manufacture of a multimodule machine in which a number of the turf harvesters would be linked together and driven by a single tractor [29].

Stabilization of the soil surface, to facilitate soil removal, has also been attempted using the decontaminating vegetal network (DVN) [29]. Grass seeds are sown together with a mixture of peat, polysaccharides and water. When the root network is sufficiently established, the top 1–2 cm of soil is removed with a turf harvester. The DVN has the added advantage that resuspension of contaminated soil is reduced by the cover of the growing medium. There is less radioactive waste than is the case with soil removal. Since this technique removes only about 15% of the topsoil of most arable soils, the soil structure is largely preserved. Natural regrowth of indigenous plants is possible, as shown by investigations carried out in the Chernobyl zone [30].
Rating: C.

The following two countermeasures are not strictly agricultural and, indeed, may result in land being taken out of production. They are included, however, because they could be applied to agricultural land.

7.2.2.3. Stabilize the soil surface to prevent resuspension

Method: Application of surface stabilizers, such as water, soil, asphalt-type materials, road oil, emulsions or chemical binders/synthetic polymers.
Effectiveness: Variable, depending on the covering used and its rate of deterioration.
Comments: After deposition, radionuclides associated with the surface soil are liable to resuspension. Stabilizing the surface reduces this risk and also maintains the deposit in a fixed location, either permanently, or until an appropriate decontamination technique can be applied. However, the original soil is buried, and therefore difficult to retrieve subsequently. Further details of the different stabilizers available

and their effectiveness are given by Smith and Lambert [31], Arnold [28], and Jouve et al. [29]. See also the section above on the DVN.
Rating: C.

7.2.2.4. Add a sorbent layer to prevent migration of buried radioactive waste

Comments: Groundwater can be contaminated by radionuclides from buried radioactive waste such as the topsoil removed from contaminated areas. Research is in progress with sorbent materials which could prevent migration, particularly of radionuclides buried after the Chernobyl accident [19, 26].

7.3. CHANGE IN LAND USE

7.3.1. Introduction

Changes in land use, including crop selection, can be effective medium or long term countermeasures to employ against radioactive contamination. The possibilities have been reviewed in the REACT summary paper by Alexakhin et al. [32].

Changes in land use range from comparatively minor changes, such as altering the variety of a crop or the species of grazing animal, to radical changes, for example conversion of arable or livestock systems to forestry. Severe changes will inevitably have long term, and potentially detrimental, economic and social consequences. Therefore, it is important that the more radical measures are implemented only when other, less stringent measures are shown to be inadequate. Such decisions are likely to be taken some years after deposition and will be particularly influenced by the extent of deposition of long lived radionuclides such as ^{137}Cs, ^{90}Sr and $^{238/239/240}Pu$. They must also take account of the composition of the contamination to ensure that the benefits of a measure against one radionuclide are not outweighed by the detrimental effects with another.

Changes in land use will be constrained by:

— Agricultural limitations of the contaminated land, which may not be able to support certain crops or land uses.
— Any requirements imposed by crop rotations.
— Economic, social and ecological limitations (including possible loss of employment, the need to purchase new machinery, or absence of markets for the produce).
— Radiological implications, such as changes in external irradiation of people living or working in the area, possible inhalation of resuspended material and reductions achieved in contamination levels in foodstuffs. The total radiation dose saved should therefore be considered, rather than just the reduction in activity concentrations in the food chain.

Given the discussion above, it is evident that the possible effect of using the countermeasures listed below will be highly variable and will depend on a large number of socioeconomic as well as radioecological factors. They are therefore likely to be highly site specific and country specific.

7.3.2. Available countermeasures

Those measures with comparatively minor social and economic consequences are listed first, followed by more radical measures.

7.3.2.1. Select suitable varieties of a crop that accumulate lower levels of the contaminating radionuclide than the variety normally grown in the area

Effectiveness: Variable, but can achieve reductions of up to fourfold to fivefold.
Comments: This approach has very few social and economic consequences, yet it can achieve significant reductions in contamination levels in crops [15, 33, 34]. Indeed, Prister et al. [15] stated that plant variety selection is one of the most effective, yet simple and cheap measures that can be used to reduce contamination of agricultural products. Currently, most data on variety specific differences are for radiocaesium and originate from the areas affected by the Chernobyl accident in the countries of the former Soviet Union, and there are few data for other radionuclides or for crops grown elsewhere.
Rating: A/B.

7.3.2.2. Select alternative, but comparable crops that accumulate lower levels of the contaminating radionuclide than the crops usually grown

Effectiveness: Variable, but can achieve reductions of up to threefold.
Comments: Selecting alternative yet comparable crops, the next step from changing varieties, has been used successfully in the countries of the former Soviet Union after the Chernobyl accident to reduce radiocaesium contamination of crops [34]. Such substitution of, for instance, one root crop for another, is a simple and comparatively cheap countermeasure which is easy to apply and causes little disruption to the farming community. Data for other radionuclides and crops are limited.
Rating: A/B.

7.3.2.3. Grow crops such as sugarbeet and oil seed rape where the edible product is processed and the contamination reduced

Effectiveness: Variable, up to a factor of 10 in the final product.
Comments: This is a potentially effective countermeasure, which retains the use of the land in food production. Often the industrial refining removes much of the

... the human food chain. However, data on this aspect are not always available. Care must be taken to ensure that highly contaminated waste products are safely utilized. For instance, feeding to ruminants might be inappropriate.
Rating: A/B.

7.3.2.4. Select crops which accumulate low levels of radionuclides

Effectiveness: Variable, but can achieve reductions of up to eightfold.
Comments: Plant species vary considerably in their rate of uptake of radionuclides rom the soil. Also, the distribution of radionuclides between edible and non-edible parts varies. Therefore, changing to crops which are botanically very different can lead to substantial reductions in contamination levels. For instance, growing cereals instead of leafy vegetables would give reductions of up to fivefold, since uptake of radionuclides into grain is low. Hence, cereals can be grown on land where green vegetables would be too highly contaminated. However, converting to cereal growing is a major change in land use and would have considerable social and economic consequences. Although considerable variation would be expected for radiocaesium, a review by Segal [11] suggests that the average soil-to-plant transfer factors for different crops grown on the same soil would follow the order: cereals < roots < grass < tubers < leguminous seeds < green vegetables. An equivalent series for radiostrontium quoted by Arnold [13] is: cereals < tubers < roots < leguminous seeds < grass < green vegetables.
Rating: A/B.

7.3.2.5. Cease food production on the land and grow crops for non-edible products such as flax, cotton, ornamental plants or seed crops for industrial oil

Effectiveness: Not applicable.
Comments: Under this approach the land can continue to be cultivated, but not for food products. Ornamental crops can be grown only on a relatively small scale. When large areas are contaminated, the growing of plants such as flax, cotton or oilseed rape is preferable. Before recommendation of this countermeasure it is necessary to ensure that these non-food products would not give unacceptable radiation exposure and that there is a market demand for them. Also, processing facilities must be available and it must be possible to dispose safely of the waste materials, which may be radioactive.
Rating: A/B.

7.3.2.6. Use contaminated land for non-dairy animals or for animals not intended for immediate slaughter

Effectiveness: Variable.
Comments: Where pasture land is contaminated and supplies of non-contaminated forage are limited, the 'clean' forage will be used to best effect if fed continuously to dairy cows so that acceptable milk can be produced, and for meat cattle in the final stages of fattening. Following the Chernobyl accident, the concentration of radio-caesium in the flesh of beef cattle was controlled by a phased feeding programme to maximize the use of available forage while producing meat of an acceptably low level of contamination [16]. The more highly contaminated feed was given early in the animals' life, the radiocaesium level in the feed was then gradually reduced, causing a concomitant reduction in the level of radiocaesium in the animal (Tables III and IV). The least contaminated feed was retained for the later stages so as to reduce radiocaesium levels in meat to below intervention levels.
Rating: B.

TABLE III. ^{137}Cs CONCENTRATION IN THE DIET AND MUSCLE OF CATTLE AT VARIOUS STAGES OF FATTENING [16]

Stage of fattening	Diet (kBq/d) (Mean ± SD)	^{137}Cs in muscle (Bq/kg·wt)	
		At the beginning of each stage	At the end of each stage
Initial	74 ± 3	No limitation	2960 ± 73
Intermediate	33 ± 2	2960 ± 73	1300 ± 65
Final	15 ± 1	1300 ± 59	600 ± 48

TABLE IV. DURATION OF EACH STAGE OF FATTENING [16]

	Age of animals at time of slaughter (years)		
Stage of fattening	1.5	2.5	2.5-9
	Time needed before transfer to next stage (d)		
Initial	Depends on initial activity		
Intermediate	15	15	30
Final	50	60	60-120

7.3.2.7. Alter animal species

Method: Replace sheep or goats with cattle.
Effectiveness: Variable, up to fivefold reduction.
Comments: Small ruminants such as sheep and goats generally accumulate higher radionuclide levels than cattle when grazing the same pasture. For instance, radiocaesium levels in milk and meat may be two to five times higher. However, output may be reduced when the species is changed because the infrastructure and knowledge of husbandry practices will probably have some deficiencies. Also, small ruminants utilize low grade grassland better than cattle. Furthermore, the most efficient products, judged from the viewpoint of reducing radionuclide transfer, may not give the best economic returns and in many regions cattle will not be available in adequate numbers.
Rating: B

7.3.2.8. Change from arable crops to cattle

Effectiveness: Variable, from a factor of less than 10 to 100, depending on the criteria used.
Comments: Highly contaminated land can be used for meat animals as long as the biological half-life of the radionuclide in the animal is short enough to ensure that a period of clean feeding before slaughter will remove most of the contamination. However, this is a substantial change in land use and will have a significant impact on those farming the land and the associated communities.

All measures requiring introduction of animals or changes in type of animal are constrained by the availability of the alternative animals, appropriate husbandry skills and the market for the produce.
Rating: B.

7.3.2.9. Change land use to forestry

Effectiveness: Not applicable.
Comments: Contamination of wood products is generally about two orders of magnitude lower than that of many food products and for some applications higher contamination is tolerable than is the case for edible crops. The potential social and economic costs of converting from an arable or animal husbandry system to forestry are high. Therefore, this change should be considered only when the land is highly contaminated so that further agricultural use, even with appropriate countermeasures, is no longer possible. For long lived radionuclides such as ^{90}Sr and ^{137}Cs the long time delay between planting of trees and harvest may have the advantage of allowing significant radioactive decay. However, the substantial delay of many years before any economic return is derived from the land is a disadvantage. Access and usage of the forest may need to be carefully controlled depending on the level of contamination.
Rating: A/B.

7.4. APPLICATION OF AMELIORANTS AND FERTILIZERS TO REDUCE SOIL-TO-PLANT TRANSFER OF RADIONUCLIDES

7.4.1. Introduction

Radionuclides in the topsoil are potentially available for uptake by plant roots, although plant uptake of many radionuclides is controlled by a variety of factors. The rate of uptake differs substantially for different radionuclides and soil types and depends on the physicochemical processes in the soil that govern their availability [35] and on the physiological requirements of the plants.

The amount of information for various radionuclides concerning both behaviour in soil and effectiveness of countermeasures varies greatly. Radiocaesium and radiostrontium have been identified as potentially the most important contributors to ingestion dose because they generally behave like potassium and calcium respectively in biological systems [10]. Since both were released by above-ground nuclear weapons tests and during a number of different nuclear accidents, much is known of their behaviour. There is also information available on the behaviour of plutonium, which is a potential source of radiation exposure, in particular via resuspension [10]. Uptake of ^{131}I from soil is not important owing to its short physical half-life. The long lived ^{129}I (half-life of 1.6×10^7 years), could be significant but is unlikely to be released during most nuclear accidents so countermeasures to reduce soil-to-plant transfer have not been developed.

Soil amendment is a simple, inexpensive and often effective means of reducing soil-to-plant transfer of radionuclides and causes little damage to the environment. Such countermeasures have been used extensively since the Chernobyl accident [16, 34]. Many involve the application of materials commonly used in agriculture and are therefore readily available and can be applied with normal farm machinery. It must be emphasized that the response to each treatment varies with different soil types and crops. Soil amendment can be used in isolation, or combined with other measures such as ploughing. However, the freedom to plough may be limited by the need to retain land for grazing, which emphasizes the importance of chemical amendments.

Because of the importance of radiocaesium and radiostrontium, and the likelihood that the need for countermeasures for other radionuclides will not arise, the following information is restricted to these two radionuclides. The information and countermeasure guidelines given below are largely derived from the REACT summary paper by Nisbet et al. [36], which itself summarizes more detailed information papers, particularly those of Lembrechts [37], Prister et al. [16], Alexakhin [34], Nisbet [38] and Konoplev et al. [39].

The success of the countermeasures described below greatly depends on the soil properties: caesium salts are very soluble and therefore $^{137}Cs^{+}$ might be expected to be readily available to plants. However, in most soils the caesium ion is strongly sorbed by certain clay minerals and is effectively immobilized. Radiocaesium uptake by plants depends on the quantity and type of clay present, the soil pH and the concentration of competing cations (in particular K^{+} and NH_4^{+}, but also Cs^{+} and Rb^{+}). Uptake of ^{137}Cs is favoured in soils which have relatively low clay mineral contents and relatively high organic matter contents, are acidic (low pH), and have a low available potassium status. Anaerobic conditions, including those in paddy soils, also increase ^{137}Cs uptake.

In contrast, $^{90}Sr^{2+}$ is available to roots in a much wider variety of soils, as it is not adsorbed by clay in the same way as Cs^{+} [36]. Strontium is reversibly sorbed by soil colloids (both inorganic and organic) by cation exchange so the extent is governed by the cation exchange capacity of the soil and the concentration of other cations, particularly Ca^{2+}. Alterations in soil conditions, such as pH, and addition of fertilizer can have substantial effects on plant uptake rates.

Soil treatment countermeasures can reduce plant uptake of $^{137+134}Cs$ or ^{90}Sr by:

(a) increasing the concentration in the soil solution of the nutrient cations (K^{+} or Ca^{2+}), thus decreasing the $^{137}Cs/K$ or $^{90}Sr/Ca$ ratios;

(b) immobilizing the radionuclide by adsorption onto added clay minerals or zeolites, or by co-precipitation with insoluble salts (e.g. phosphates).

In the countries of the former Soviet Union countermeasures based on fertilizers, in combination with pasture improvement (ploughing and reseeding with liming and fertilizer application), have been more effective than immobilization for radiocaesium [34]. Their effectiveness is partly due to the enhanced soil fertility and plant productivity and so such treatments may be less useful in more productive soils [10]. It should be noted that increases in crop yield resulting from these measures may partly, sometimes wholely, cover the costs.

Decisions on which countermeasure to apply must be based on the extent and spatial distribution of ground deposition, the inventory of radionuclides present, land use and the dominant soil type. It must be stressed that an effective countermeasure for one radionuclide may not necessarily be effective for others present in the same soil and may even enhance their uptake. For instance, treatment of organic soils with potassium to reduce radiocaesium availability may increase the availability of radiostrontium. The effects of different treatments on ion ratios in the soil solution can be assessed with batch equilibrium studies [38]. This would be particularly useful for soils contaminated with a mixed deposit requiring medium and long term countermeasures.

The use of mineral fertilizers (phosphorus, potassium) at rates normally applied in the agriculture of advanced countries in the temperate zone has frequently proved to be sufficient to reduce root uptake of radionuclides in soils of low fertility. Thus, in intensive agriculture, a further increase of fertilizer rates might not result in reductions in radionuclide uptake, but might even have undesirable agronomic effects, such as reducing the availability of essential micronutrients.

By raising the pH, lime increases the cation exchange capacity of the soil. This is because the dissociation of some of the functional groups, particularly those of the organic matter, increases with increasing pH, thus providing more negatively charged sites for cation exchange. Conversely, acidic fertilizers decrease cation exchange capacity and so should not be used.

Ammonium fertilizers, both salts and liquid ammonia, should also be avoided [40, 41] since the NH_4^{+} ion is similar in size and charge to Cs^{+} and so can displace it from sorption sites into the soil solution. Therefore, fertilizers should be applied as neutral salts, and nitrogen should be applied in the form of nitrate [38].

7.4.2. General countermeasures

7.4.2.1. Lime acid soils

Effectiveness: High but varying with initial soil pH; reduction factor for ^{90}Sr up to 10 (with average of 2 to 3), for ^{137}Cs up to 3.
Comments: Liming reduces radiocaesium and radiostrontium uptake into plants by increasing the cation exchange capacity of the soil. It is usually inexpensive and easy to apply.

Because of the chemical similarity between Ca^{2+} and Sr^{2+}, the application of calcium also reduces Sr uptake by decreasing the Sr^{2+}/Ca^{2+} ratio in the soil solution. Thus the highest efficiency is achieved in soils with a low concentration of exchangeable calcium (< 10 meq Ca^{2+}/100 g soil) and with a low percentage base saturation, but is still effective in soils with exchangeable calcium levels up to 10 meq/100 g. This applies to mineral soils in which Sr^{2+} is preferentially adsorbed to Ca^{2+}. In soils with a high organic matter content, which preferentially adsorb Ca^{2+}, it is conceivable but unlikely that lime may displace radiostrontium from exchange sites and increase its availability.

Liming is most effective in suppressing root uptake of radiocaesium when applied in conjunction with potassium. It is most effective when applied to organic soils. No benefit has been observed when application exceeds 3 t/ha.
Rating: A.

7.4.2.2. Apply sapropell

Effectiveness: High, reduction factor up to 6 for caesium, and 5 for strontium.
Comments: Sapropell originates from deposits at the bottom of natural lakes and is composed of plant residues decomposed under anaerobic conditions [16]. Sapropell reduces the uptake of both caesium and strontium. It is inexpensive, where available, and easy to apply and it increases plant production by increasing the nutrient and microelement contents of treated soil. However, long distance transport of wet sapropell is not practicable. The effectiveness of sapropell has been found to be sustained for a number of years in land contaminated with radiocaesium from the Chernobyl accident in countries of the former Soviet Union. For radiocaesium, sapropell is particularly effective when applied to soil with low levels of exchangeable potassium. It is not harmful to plants, even when applied in large quantities (> 150 t/ha). Although it contains calcium, if the sapropell used has a pH of less than 5, lime should also be applied. Sapropell has been extensively used in countries of the former Soviet Union since the Chernobyl accident [16], but there is no information on its availability and effectiveness in other countries. Similar depositis elsewhere must be considered with care as they may contain unacceptable levels of heavy metals if the catchment includes industrial areas.
Rating: B.

7.4.3. Specific countermeasures against radiocaesium contamination

7.4.3.1. Apply potassium fertilizers

Effectiveness: High when applied to soil with low levels of exchangeable potassium and soil solution concentrations of potassium below about 20μM. Reduction factor up to 5.
Comments: Applying potassium fertilizers reduces the radiocaesium uptake by plants by decreasing the Cs/K ratio in the soil solution.

The application of potassium is inexpensive and comparatively easy to carry out. Potassium is a chemical analogue of caesium and competes with radiocaesium for absorption by roots. The highest effectiveness is achieved in soils with very low levels (< 10μM) of available potassium. Higher rates can displace radiocaesium from ion exchange sites and hence could increase root uptake. Applications of no more than 200 $kg \cdot ha^{-1} \cdot a^{-1}$ are recommended.
Rating: B.

7.4.3.2. Apply aluminosilicates

Effectiveness: Limited, reduction factor up to 2.
Comments: Aluminosilicates increase the cation exchange capacity of the soil, thereby increasing the sorption of radiocaesium. However, they are comparatively expensive, needing application rates of several tonnes per hectare, and are not available everywhere.
Rating: B/D.

7.4.4. Specific countermeasures against ^{90}Sr contamination

Most information on the effectiveness of soil treatment to reduce radiostrontium uptake arises from studies carried out after the Kyshtym accident in the Urals in 1957. Some of these studies were described by the Commission of the European Communities [42].

7.4.4.1. Apply organic fertilizers such as farmyard manure

Effectiveness: High, reduction factor up to 5.
Comments: Organic fertilizers are usually inexpensive and easy to apply, effectively substituting for inorganic fertilizers and increasing plant production by increasing the nutrient and microelement contents of treated soil. They can be effective in reducing ^{90}Sr uptake from mineral soils but it is important to note that the application of organic matter may increase the uptake of radiocaesium and therefore would not be recommended if the soil was contaminated with a mixed deposit. It is also important to ensure that materials such as locally dug peat are not contaminated by radionuclides from the same incident.
Rating: A.

7.4.4.2. Apply soluble phosphate fertilizers

Effectiveness: Reduction factor up to 10.
Comments: Because strontium phosphate is relatively insoluble, application of soluble phosphates might reduce its availability by precipitation. However, application of phosphates (or sulphates and silicates) may reduce the availability of essential micronutrients whose phosphates are also of low solubility.
Rating: A.

7.5.1. Introduction

Because of the importance of animal products as sources of radiation dose there is much information on the behaviour of radionuclides in animals, particularly for radiocaesium, radiostrontium and radioiodine. Much of the following section is based on the REACT papers, with additional reference to the International Union of Radioecologists (IUR) report to CEC DGXI [43].

The extent to which an animal product is contaminated by radionuclides depends on rates of absorption, metabolic fate in the animal and the rate of loss (principally in urine, faeces and milk) together with the behaviour of the nuclide in the plant–soil system.

Although absorption can occur through the skin and lungs, oral ingestion of radionuclides in feed, and subsequent absorption through the gut, is the major route of entry of most radionuclides. Absorption of most nutrients takes place in the rumen or the small intestine at rates which vary from almost negligible, in the case of actinides, to almost complete for radioiodine.

TABLE V. TRANSFER COEFFICIENTS FOR ^{131}I, ^{134}Cs, ^{137}Cs AND ^{90}Sr AND VARIOUS PRODUCTS FROM ANIMALS [45]

Product	Transfer coefficients (d/L or d/kg)		
	I-131	Cs-134,137	Sr-90
Cattle			
milk	1.0×10^{-2}	7.9×10^{-3}	2.8×10^{-3}
meat (beef)	3.8×10^{-2}	5.1×10^{-2}	8.0×10^{-3}
Sheep			
milk	4.9×10^{-1}	5.8×10^{-2}	5.6×10^{-2}
meat (lamb)	3.0×10^{-2}	4.9×10^{-1}	3.3×10^{-1}
Goat			
milk	4.3×10^{-1}	1.0×10^{-1}	2.8×10^{-2}
meat		2.3×10^{-1}	2.8×10^{-3}
Pig			
meat (pork)	3.3×10^{-3}	2.4×10^{-1}	4.0×10^{-2}
Poultry			
meat	1.10×10^{-2}	12.0	8.0×10^{-2}
eggs	1.0	4.5×10^{-1}	1.8×10^{-1}

TABLE VI. DRY MATTER AND WATER INTAKE OF DOMESTIC ANIMALS [45]

Animal species	Dry matter intake (kg/d)		Water intake (L/d)
	Expected	Range	
Dairy cows	16.1	10–25	50–100
Beef cattle (500 kg)	7.2	5–10	20–60
Calves (160 kg)	1.9	1.5–3.5	5–15
Dairy goats	1.3	1.0–3.5	5–10
Dairy sheep	1.3	1.0–2.5	5–8
Lamb (50 kg)	1.1	0.5–3.0	6–10
Pigs (110 kg)	2.4	2.0–3.0	6–10
Laying hens	0.1	0.07–0.15	0.1–0.3
Chickens	0.07	0.05–0.15	0.1–0.3

After absorption, radionuclides circulate in the blood. Some accumulate in specific organs, for instance metal ions such as ^{60}Co, ^{54}Mn, ^{65}Zn and ^{110}Ag accumulate in the liver and radioiodine accumulates in the thyroid. Actinides and radiostrontium tend to be deposited in the bone whereas radiocaesium is distributed throughout the soft tissues.

The extent of contamination is commonly quantified using the transfer coefficient, which is defined as the equilibrium concentration of the radionuclide in the meat or milk divided by the daily intake of the radionuclide [44].

Contamination of animal products can be calculated from contamination levels in feedstuffs, using transfer coefficient values (Table V), daily intake values (Table VI), which are given in the IAEA Handbook of Parameter Values for the Prediction of Radionuclide Transfer in Temperate Environments [45], together with biological half-lives. Biological half-life is usually calculated using two or three exponential equations depending on the radionuclide. A discussion of suitable parameters for caesium, strontium and iodine can be found in Coughtrey [46] and Bishop et al. [47]. Generally, products in which the radionuclide has a high transfer coefficient and a short biological half-life will initially become most highly contaminated. For example, soft tissues and eggs quickly become contaminated with caesium.

The only effective countermeasure for all radionuclides is the provision of clean feeds. Since the metabolic characteristics and physical and biological half-lives of radionuclides differ, the rate of response to this and other countermeasures also differs.

Transfer factors of all three radionuclides to milk, and radiocaesium to meat, are generally lower for large animals such as cattle than for smaller animals such as sheep and goats. Transfer factors to poultry meat and eggs are also relatively high.

In many intensively managed agricultural ecosystems high levels of contamination in animal food products will often occur only for a few weeks, or at most a few months, after a pulse of fallout. In these circumstances, the extent of interception and retention on plant surfaces largely determines both the duration and level of contamination. The exception is where very high deposition occurs or where plant uptake is high and sustained. Contamination levels of radiocaesium in animal food products from extensive ecosystems can be high and persist for longer, even though the original deposition may not have been very high. This is because: (i) the soils allow significant uptake of caesium; (ii) some of the plant species accumulated relatively high levels of caesium, e.g. ericaceous species and fungi; and (iii) these areas are often grazed by small ruminants which accumulate higher caesium levels than larger ruminants [48].

Countermeasures can be divided into four categories according to Hove et al. [49]:

— limiting the intake of radionuclides
— reducing the absorption of ingested radionuclides
— blocking the uptake into and transport through organs
— increasing the excretion of a previously accumulated body burden.

The most effective countermeasures tend to belong to the first two categories. A general discussion of the factors influencing the choice of appropriate countermeasure is given in Hove et al. [49] and the report by the IUR [43]. The countermeasures which are generally applicable for use against a wide range of radionuclides are considered separately from those specific for radiostrontium and radiocaesium. Those dealing with radioiodine in milk have been considered above (Section 6.2.2).

It is important to remember that levels of γ emitting radionuclides can be measured externally in some cases. This is valuable for assessing the contamination levels in live animals before the decision to slaughter is taken. For other radionuclides and products a sample of each batch of product can be measured destructively before consumption is allowed. This is particularly useful for eggs, which have comparatively high transfer coefficients, but which would not be highly contaminated if the chickens were fed with uncontaminated grain.

7.5.2. General countermeasures

7.5.2.1. *Remove animals from contaminated pastures or areas and/or provide uncontaminated feeds*

Methods: Provide uncontaminated feed for animals or move animals to uncontaminated areas. Prevent grazing by keeping animals indoors or in enclosed areas.
Comments: These are the same countermeasures as in Sections 5.2 and 6.2, applied for a longer period.

The substitution of contaminated feed is simple to carry out for most domestic animals, but is more difficult in semi-natural ecosystems, particularly for longer periods. A disadvantage is that feeds are used which are intended for use at other times of the year. In intensively farmed areas the availability of uncontaminated land for grazing may be limited, particularly if animals routinely graze outdoors. In systems where animals are normally housed stored feeds are usually available.
Rating: A/B.

7.5.2.2. *Grow forage crops with lower tendency for contamination*

Comments: Perennial grasses and leguminous plants tend to be more contaminated than cereals, tubers and root crops. Therefore growing the latter crops for forage can reduce overall transfer from soil to animal products (by fivefold to tenfold). A comprehensive summary of this and other methods used in countries of the former Soviet Union following the Chernobyl accident is given in Prister et al. [16]. General approaches to growing less contaminated plants are given in Section 7.3.
Rating: A/B.

7.5.2.3. *Use contaminated land for non-dairy animals or for animals that are not intended for immediate slaughter*

Comments: Already discussed in Section 7.3.2.

7.5.2.4. *Alter animal species*

Comments: Already discussed in Section 7.3.2.

7.5.2.5. *Divert animal products from human to animal consumption*

Comments: Contaminated meat may be incorporated into animal feedstuffs, in combination with chemical binders, for feeding to livestock that are not intended for slaughter in the near future.
Rating: B.

Comments: Not strictly a countermeasure but it is an action that might be considered. For example it was used immediately after the Windscale accident, when about 3 million litres of milk contaminated with ^{131}I were discarded into the Irish Sea [50] (not necessarily appropriately, see Section 6.2.2) and after the Chernobyl accident when meat contaminated with radiocaesium was destroyed. Suitable disposal of highly contaminated carcasses or milk may not be easy to arrange. Destruction is very wasteful and should be used only in exceptional circumstances.
Rating: A/D.

7.5.3. Specific countermeasures against radiocaesium contamination

Radiocaesium, like potassium, is readily absorbed in the gut and transfers to both meat and milk. Absorption of radiocaesium in the gut varies between different animal species. In monogastric animals such as pigs and suckling ruminants, absorption of radiocaesium is virtually complete, whereas in adult ruminants absorption of radiocaesium in plant material is about 70–85%. Absorption also depends on the nature of radiocaesium present in the environment, for example the absorption of particulate radiocaesium released from the Chernobyl accident was estimated to be about 65% in sheep [51]. Absorbed radiocaesium is distributed throughout the soft tissues, with similar levels in muscle, liver and kidney. Levels in bone are much lower. Radiocaesium activity concentrations in young animals are generally high compared with those in adults for the same daily intake of radiocaesium.

TABLE VII. TRANSFER COEFFICIENTS AND BIOLOGICAL HALF-LIVES FOR RADIOCAESIUM IN MEAT IN DIFFERENT ANIMAL SPECIES

Product	Transfer coefficient (d/kg)	Biological half-life[a] (d)
Cattle (beef)	5.1×10^{-2}	29
Lamb	4.9×10^{-1}	14
Goat	2.3×10^{-1}	18
Pig	2.4×10^{-1}	19
Poultry	12.0	28
Reference	[45]	[46]

[a] Long term component.

A comparison of the transfer coefficient and biological half-lives for radiocaesium is given in Table VII. Transfer to poultry is particularly high, and the biological half-life in cattle is longer than in sheep and goats.

The biological half-life of radiocaesium is comparatively short in milk and radiocaesium levels in milk respond rapidly to changes in the contamination level in the diet. After a single contamination event, ^{137}Cs levels in milk from cows grazing pasture will reach a maximum in 3–5 days. During continuous intake, levels of ^{137}Cs in cow's milk stabilize after about 3 weeks and about 5–12% of the ^{137}Cs ingested daily will be secreted into milk.

The comparatively long physical half-life of both ^{134}Cs (2.07 years) and ^{137}Cs (30 years) provides potential for a persistently high transfer of radiocaesium to animals in contaminated environments. High and prolonged transfer of radiocaesium has been found to occur in many ruminants inhabiting semi-natural ecosystems [48]. Since the Chernobyl accident, the methodology of measuring radiocaesium in live animals has been improved and these measurements are now relatively easy and rapid to perform, using hand-held sodium iodide monitors [52]. Management of countermeasures for radiocaesium should depend on the results of the monitoring of milk and animals. A wide range of suitable countermeasures are available for radiocaesium, some of which have been developed since the Chernobyl accident.

7.5.3.1. *Increase the height of the cut when harvesting forage, including grass, silage, hay and grains*

Comments: Raising the height of the cut avoids harvesting the lower parts of plants which may have highly contaminated, resuspended soil adhering to the surface. This countermeasure would be most useful in the first year after deposition. The efficiency will vary according to the crop and soil characteristics. Bertilsson et al. [53] observed reduction by threefold in ^{137}Cs and up to ninefold in ^{131}I concentrations in milk from cows fed forage harvested at different stubble heights. Lower reductions might be expected for grain. However, without monitoring contamination the effectiveness is not known for any particular situation.
Rating: A.

7.5.3.2. *Use live monitoring to avoid slaughter of highly contaminated animals*

Comments: Live monitoring can be used both in slaughterhouses and at the farm to identify animals that must be fed uncontaminated feed for a period before slaughter. It is effective but requires semi-skilled labour. Adequate shielding of monitors is required in highly contaminated areas. The live monitoring technique has been widely used to good effect after the Chernobyl accident, both in the three original republics affected (see, for example, Ref. [54]) and in some western European countries [52].
Rating: A.

7.5.3.3. *Change slaughter time to reduce contamination levels in animals*

Method 1: Immediate slaughter before and/or close to the time of deposition.
Comments: Immediate slaughter may be advisable because meat radiocaesium levels rise in animals for several weeks after deposition. Measurements of radiocaesium levels must be made in order to avoid killing highly contaminated animals. A major problem is that there is likely to be public resistance to the acceptance of such meat, despite acceptable radiocaesium concentrations. The economic value of the meat may be reduced by premature slaughter. Other limitations could be slaughterhouse capacity and storage facilities.

Method 2: Delay slaughter after deposition.
Comments: Delaying slaughter allows reduction in radiocaesium intake through natural weathering and binding processes. Dilution of activity by crop growth will reduce radiocaesium concentrations considerably when deposition occurs during periods of active plant growth. Other countermeasures may be applied as well to accelerate the rate of radionuclide loss.

Method 3: Change slaughter time to a season of the year when the levels in meat are low or when peak activity levels can be avoided.
Comments: This measure is applicable to game animals with seasonal feeding habits. For example, in autumn, some animals eat large quantities of mushrooms or lichens which can be highly contaminated. Following the Chernobyl accident, roe deer taken in the autumn had carcass radiocaesium levels up to fivefold higher than those taken in the spring [55]. This countermeasure requires a thorough knowledge of the seasonal variation in eating habits and contamination levels for each animal species. Killing at unusual times may reduce the palatability of the meat and carcass weight, thereby reducing the economic return.
Rating: A/B.

7.5.3.4. *Prevent animals eating highly contaminated feedstuffs*

Method 1: Grow less contaminated forage crops.
Comments: See general countermeasures (Section 5.2.2).

Method 2: Do not feed highly contaminated whey to pigs.
Comments: Whey and whey products can be comparatively highly contaminated by radiocaesium and radiostrontium. It is therefore undesirable to feed these products to pigs, unless a chemical binder (see below) is added to prevent absorption of the radionuclide in the gut.
Rating: A/B.

7.5.3.5. *Administer chemical binders to reduce radiocaesium absorption in the gut*

Method 1: Provide Prussian Blue by addition to concentrate.
Comments: Prussian Blue compounds (potassium and ammonium iron hexacyanoferrates) are very effective and practical binders of radiocaesium in the gut of farm animals [49]. They were used extensively in Norway after the Chernobyl accident and more recently in countries of the former Soviet Union. About a 50% reduction in caesium intake is obtained at a dose level of 1 mg/kg body weight per day, and reduction of more than 90% in the transfer to meat and milk can be achieved at doses of 5–10 mg/kg per day. Prussian Blue may be given to all farm animal species including ruminants, poultry and pigs (it was also used for humans following the Goiânia incident in Brazil) and no toxicity has been observed at these dose rates. For maximum effect, Prussian Blue should be given every day.
Rating: A.

Method 2: Insert Prussian Blue slow release boli into the animal.
Comments: Boli are particularly useful for grazing ruminants as they release Prussian Blue for extended periods (weeks to months) into the digestive tract. To ensure a long term effect the composition of the boli should be standardized, particularly with regard to maintaining their specific weight to ensure retention in the rumen. Boli should provide release rates of at least 1 mg/kg body weight per day in order to be effective. A twofold to fivefold reduction can be achieved for milk and meat of grazing ruminants. Further information is given by Hove [56].
Rating: A/B.

Method 3: Provide Prussian Blue in salt-licks (2.5% or more).
Comments: Prussian Blue can be incorporated into salt-licks to be left in areas accessible to domestic or free ranging animals that are not handled daily. Salt-licks are most efficient where the sodium content of vegetation is low. They were used in Scandinavia after the Chernobyl accident, but would also be expected to be particularly effective in tropical countries. The palatability of the salt-lick is generally good, but high concentrations of Prussian Blue reduce the durability of the stone. An average reduction of radiocaesium levels in sheep of about 50% has been obtained with salt-licks containing 2.5% Prussian Blue [56].
Rating: A/B/C.

Method 4: Supplement diet with clay minerals or zeolites.
Comments: Several clay minerals such as bentonite, vermiculite and mordenite, and zeolites such as clinoptilolite will bind radiocaesium in the gastrointestinal tract and reduce absorption. Humalyt, a commercially available feed additive which binds caesium, was found to be very effective in countries of the former Soviet Union when used following the Chernobyl accident. It is based on clinoptilolite with added

... faeces from worms, so that it also provides vitamins and trace elements to the animal.

Possible chemical binders for radiocaesium are reviewed by Voigt [23]. Reductions of about 50% can be achieved by a dose of about 0.5 g/kg body weight per day. A maximum reduction of about fivefold can be achieved at a dose level of 1–2 g/kg body weight per day. Clay minerals from different sources have different binding capacities and there are logistic problems if a large number of animals need to be treated. The method is most suitable for hand-fed animals. Application to grazing animals may be difficult or even impossible in semi-natural environments.
Rating: B.

7.5.3.6. Increase the fibre content of the diet to reduce radiocaesium absorption in the gut

Method: Feed more roughages such as hay and silage, especially for dairy cows receiving a high-concentrate diet.
Comments: Relatively few studies have been carried out on the effect of increasing fibre content of the diet. A study by Johnson et al. [57] suggested that radiocaesium levels in milk could be reduced twofold by increasing the fibre content of the diet. The feasibility of this approach is dependent on the availability of suitable roughages, the ability of the animal to adapt to a new diet [21] and the level of productivity.
Rating: A/D.

7.5.4. Specific countermeasures against radiostrontium contamination

The metabolism of radiostrontium is largely governed by the presence of its chemical analogue, calcium, which is invariably present in biological systems at a much higher concentration than that of strontium. Dietary calcium levels determine, to a large extent, the absorption of radiostrontium in the gut. The transfer of calcium across biological membranes is more efficient than that of strontium. In the gut, this factor is 5, and at the mammary gland it is about 2. Overall, therefore, radiostrontium is transferred to milk about tenfold less efficiently than calcium. As for calcium, comparatively high radiostrontium absorption rates will occur in growing and lactating animals. Absorption will also be enhanced when the calcium intake is low. The metabolism of radiostrontium is not under homeostatic control, but closely reflects the homeostatic adaptations of calcium.

Radiostrontium is deposited in bone, from which it is released very slowly. Elimination occurs primarily via faeces. Urinary excretion is low but milk is a significant vehicle for strontium loss from the body. After a pulse input onto pasture, $^{89/90}Sr$ concentrations in cow's milk reach a maximum in 3–4 days. For cows ingesting herbage with normal calcium levels, up to 20% of the daily intake of ^{90}Sr

will be secreted into milk. Radiostrontium levels in milk can be enhanced by the slow release of $^{89/90}Sr$ from bone if there are significant reservoirs present.

There are fewer specific countermeasures available for radiostrontium than for radiocaesium.

7.5.4.1. Provide high calcium diets to reduce concentration of $^{89/90}Sr$ in milk

Method: Feed calcium salts or natural feeds rich in calcium.
Comments: Increasing the calcium content of the diet by 2–4 times reduces radiostrontium levels in milk by a factor of between 1.5 and 3 depending on the initial level of calcium nutrition. Sources of calcium supplements are numerous and inexpensive. According to the IUR [43], additions of calcium compounds have a diminishing effect in the order: $Ca_3(PO)_4$ > CaO > $Ca(COO)_2$ > $CaCO_3$ > $Ca(C_3H_5O_3)_2$. Calcium in vegetables seems more effective than that in mineral form. Caution is necessary with this countermeasure as animal health problems can arise if the Ca/P ratio of the fodder becomes too high.
Rating: A.

7.5.4.2. Provide alginate with diet to reduce gut absorption

Comments: Alginates reduce radiostrontium absorption in both monogastric animals [58] and ruminants. For instance, Lengeman et al. [22] reported that sodium alginate added to the diet of dairy cows reduced ^{90}Sr absorption by a factor of 3–4. There are practical difficulties in incorporating alginates, which are commonly derived from seaweeds, such as Laminaria species, into commercial feeds because of the viscosity of the preparation. It is frequently difficult to persuade the animals to eat the feed if the alginates make up more than 7% of the diet [59]. Therefore, the use of alginates could not currently be recommended.
Rating: D.

7.6. COUNTERMEASURES FOR FRESHWATER FISHERIES AND FISH FARMING

7.6.1. Introduction

Contamination of fish can occur either directly from contaminated water or via the ingestion of contaminated food or sediments. For many radionuclides, contamination of freshwater produce is unlikely to be a problem because either the radionuclides rapidly become immobilized in bottom sediments of the catchment or contamination is limited to parts of the animals that are rarely eaten.

However, the ingestion of freshwater fish contaminated with radiocaesium can be a significant source of radiation dose. After the Chernobyl accident, freshwater fish were identified as one of the major sources of radiocaesium in the diet of certain population groups in Sweden [60] and Norway [61]. In these areas, persistently high levels of radiocaesium occur, primarily in lakes with peat catchments.

As with animal products, radiation exposure can be limited by the use of an efficient monitoring system to ensure that intervention levels are not exceeded. For gamma emitters, such as radiocaesium, this may include external monitoring of catches prior to sale although with large numbers this may be restricted to samples of each catch.

7.6.2. Available countermeasures

Countermeasures could, theoretically, be used at several stages in the production of freshwater fish products. However, very few studies of potential countermeasures in freshwater ecosystems have been reported, reflecting the practical difficulties. Therefore it is difficult to quantify the likely effect of many of the measures suggested below, which are largely based on studies of radiocaesium, although some of them would be effective for other radionuclides.

Overall, given the lack of information, there are no practicable and cost effective countermeasures, other than a ban on fishing, that could currently be recommended.

7.6.2.1. Prohibit fishing

Comments: Although often the only practical measure, this could be socially disruptive and expensive where such produce is an important component of the diet or is vital for the local economy. Replacement foodstuffs may be required.
Rating: A.

7.6.2.2. Limit the types and quantities of fish that can be used for human consumption

Comments: Restriction of the use of those types of fish likely to be more highly contaminated would reduce radionuclide intake and hence radiation dose. However, this would probably include all predatory fish and all bottom-feeding fish, which in some areas constitute all the fish stocks, in effect imposing a total ban.
Rating: A.

7.6.2.3. Process fish to remove organs with high radionuclide concentrations

Comments: Processing of fish prior to consumption is useful for radionuclides which are concentrated in specific organs; for example, cobalt and zinc concentrate in the liver and radiostrontium in the bone. It is not useful for radiocaesium, which is distributed in all the soft tissues, or for animals which are eaten whole. Skilled labour is needed together with some degree of monitoring [62]. For further information on food processing see Section 8.
Rating: A.

7.6.2.4. Provide uncontaminated pelleted feed as a substitute for the contaminated feed normally eaten by the fish

Method: Provide regular stocks of uncontaminated, pelleted feed.
Comments: Since the major source of radiocaesium for the contaminated fish is their food [63, 64], replacement of natural fish foods with uncontaminated food will significantly reduce the caesium content of the tissues. This is easily achieved in fish farms where the fish are normally fed in this way but in this situation the feed is unlikely to be contaminated anyway. It is unlikely to be practicable in natural lakes and rivers.
Rating: B/D.

7.6.2.5. Treat the water and/or sediment to reduce the level of radioactive contamination of the aquatic food chain

Method 1: Increase the potassium and/or calcium levels in the lake.
Comments: Reducing radionuclides in the food chain by measuring the concentration of the stable element is of limited value because the residence of radionuclides in the water column is typically of the order of only a few weeks [62]. (It might be considered where there is a chronic input of radionuclides into a water system.) Radionuclides in fish in temperate waters tend to have comparatively long biological half-lives (sometimes over 100 d [62]) so that application of this type of countermeasure must be carried out immediately after deposition to reduce the potential long term contamination of the fish.

Method 2: Drain lakes and remove the top contaminated layer of sediments.
Comments: Removal of sediments is an extremely expensive countermeasure. Sediments increase in depth naturally with time, as more material is deposited, so the radionuclides are gradually removed from contact with the food chain, generally within 5–10 years. Hence, the relative cost effectiveness of sediment removal versus compensation for other measures such as fishing restrictions for this period must be closely examined before such drastic measures are used.
Rating: D.

7.7.1. Introduction

Much of this section is based on the summary REACT paper by Guillitte et al. [66]; more detailed information is given in the REACT papers by Guillitte and Willdrot [67] and by Tikhomirov et al. [68] which summarize the approaches used in countries of the former Soviet Union after the Chernobyl accident. Additional recent information on the behaviour of radionuclides in forest ecosystems is available in papers arising from the CEC Stockholm seminar on the behaviour of radionuclides in forest ecosystems (September 1992), which will be published in Science of the Total Environment. Perhaps more than in any other section, the countermeasures described here have been developed exclusively with temperate forests in mind. Whether any of them are relevant to tropical natural forests is doubtful.

Forest canopies can intercept considerable proportions of the deposited fallout, particularly of dry deposition. Because rainfall is channelled through leaf and stem flow there is enhanced local wet deposition around stems [67, 68]. A variety of different mechanisms enhance radionuclide levels in forest components so that the effective biological half-lives are longer than those seen in agricultural systems. Soil-to-plant transfer is high in the highly organic surface horizons of many forest ecosystems and perennial plants tend to retain radionuclides in storage organs. Lichens, mosses and mushrooms, which can become highly contaminated by radiocaesium, are common in many forested areas.

As with many semi-natural ecosystems, forests are highly diverse and vary with soil type, climate, topography and composition of both trees and other flora and fauna so that the nature and extent of radionuclide contamination in forested areas also varies considerably. Equally, forests are used for a wide variety of activities, in addition to timber production, including recreational uses. Such diversity affects the selection of countermeasures for use in each individual forested area. The countermeasures given below encompass methods of reducing radiation doses to people using forested areas as well as measures intended to reduce contamination levels in forest products or general decontamination procedures.

As with other sections, consideration must be given not only to the reductions achieved in radiation dose, but also to the social and economic consequences of the measures, especially in the first year after deposition. This is particularly important as some of the countermeasures involve radical alterations in normal usage or expensive remediation procedures. Indeed, in all but the most severely contaminated forests the overall detrimental effect of radionuclide contamination is likely to be small. However, those who work in forests, particularly if they depend heavily on forest food products, can be at risk. For example it has been estimated that in 1990 Russian forestry workers received radiation doses up to three times higher than others living in the same areas. Therefore, the best course of action will be simply to exclude humans until the natural processes of decontamination (weathering from surfaces and gradual immobilization in the soil) have reduced the potential radiological hazard to an acceptable level [66].

A wide variety of possible countermeasures exist which can be used in forest ecosystems. From experience gained after the Kyshtym and Chernobyl accidents, it is clear that the most effective approach will often encompass a broad range of both agrotechnical (including chemical and biological approaches) and management procedures. Since complete decontamination is impossible in forest ecosytems, the implementation and enforcement of effective management practices is essential, particularly when long lived radionuclides have been deposited. Selection of the most appropriate countermeasure will depend on the main exposure pathway in a particular situation. Therefore it is difficult to 'prioritize' the measures listed below.

7.7.2. Restrictive countermeasures

7.7.2.1. Restrict access to forests

Effectiveness: Potentially high, but variable depending on how strictly the restrictions are enforced.
Comments: Restricting access to contaminated forests will reduce radiation doses to both forest workers and the general population. Such restrictions may have to be applied immediately after deposition and continue in the long term, particularly when long lived radionuclides have been deposited. If restrictions are imposed, radiation monitoring is necessary to determine when they can be relaxed. Ensuring compliance with the restrictions, particularly by those who habitually used the forest before contamination, may be difficult.
Rating: A.

7.7.2.2. Prevent forest fire by special restrictive and management measures

Comments: Forest fire prevention is a necessary long term measure to reduce the probability of secondary contamination via resuspension. It is particularly important in highly contaminated areas such as the Chernobyl 30 km exclusion zone. Relatively small investments are required for fire precautions.
Rating: A.

7.7.3. Decontamination procedures

7.7.3.1. Collect and remove contaminated fallen leaves/needles

Method: Collect leaves/needles by scraping by hand or with suitable mechanical equipment.

Effectiveness: Low to high depending on the time elapsed after fallout, extent of original interception by leaves/needles, season and weather conditions.
Comments: Collection and removal of contaminated fallen leaves/needles can effectively decontaminate the forest floor, thereby reducing external dose rates. This countermeasure will be most effective when fallout is deposited just before the autumn leaf fall of deciduous trees. Because of the difficulties in collecting fallen leaves/needles from large, established forest stands and their subsequent disposal, this method is only practicable for relatively small areas such as urban parks, gardens and orchards.
Rating: C/D.

7.7.3.2. Defoliate and remove contaminated fallen leaves

Effectiveness: Potentially low to high, depending on season.
Comments: A variety of different defoliants are currently being assessed for effectiveness [29]. This approach is similar to that above, except that the trees are defoliated artificially. Currently, this countermeasure is in the research stage and cannot yet be recommended. It is likely to be expensive, impractical in many forests and with possible toxic side-effects. The negative social impact of such an invasive technique may also be high. One potential advantage is that defoliation could prevent foliar absorption of deposited radionuclides.
Rating: D.

7.7.3.3. Clear-fell and remove timber

Method: Use normal clear-felling techniques but timber would have to be disposed of in suitable pits if contamination is high.
Effectiveness: Except in specific circumstances, this method is likely to be effective only when combined with removal of the surface soil layer.
Comments: Over the short term, clear-felling and removing timber reduces the primary contamination of the affected area and was used in countries of the former Soviet Union after the Chernobyl accident to remove the 'red forest' [19]. However, it is expensive and could result in a high radiation dose to the personnel carrying out the work. Other disadvantages include the considerable waste disposal problem and the potentially severe ecological damage, including soil erosion. This approach is only practicable for limited areas and does not seem to have been used except in the 'red forest'.
Rating: D.

7.7.3.4. Plough after clear-felling and prior to replanting

Effectiveness: May be high on soils with a high buffering capacity.
Comments: Ploughing, after clear-felling and prior to replanting, reduces radionuclide availability to plants by dilution and the effect of physicochemical fixation processes in the soil. Although this countermeasure is theoretically attractive it is usually impracticable owing to physical constraints such as topography and the probability of soil erosion. Ploughing may also increase the mineralization of the organic horizons in forest soils, which could lead to increases in radionuclide mobility in poorly buffered soils.
Rating: D.

7.7.3.5. Scrape and remove the surface soil layer to decontaminate the forest floor

Effectiveness: Very high — can be greater than 90%.
Comments: As for agricultural systems, it is theoretically possible to scrape off the highly contaminated top layer of soil in forests. However, this procedure would obviously be more difficult to undertake in forest stands where it will damage the roots of the trees and the removal of nutrients in the upper soil layers would be particularly damaging in forest soils. The procedure would be very expensive and could result in high doses to personnel carrying out the removal. The large volume of radioactive waste generated is a serious disadvantage. For these reasons this procedure can only be recommended for limited areas, such as urban parks and orchards.
Rating: C/D.

7.7.3.6. Spray contaminated canopies with detergents from aircraft

Effectiveness: Low, almost negligible.
Comments: Spraying contaminated canopies with detergents is a short term measure which could potentially reduce initial surface contamination and the likelihood of secondary contamination via resuspension. However, available data suggest that it is impracticable, ineffective and expensive. Not recommended.
Rating: D.

7.7.4. Use of chemicals

7.7.4.1. Perform chemical treatment of soil (liming, fertilizers, etc.) to reduce radionuclide transfer to forest plants

Effectiveness: Variable, depending on radionuclide and soil type.
Comments: A long term countermeasure which is relatively simple, though more

... to apply in forest ecosystems than on arable land. As with agricultural ecosystems, negative side-effects are possible — see Section 7.3 [38, 69].
Rating: A.

7.7.4.2. Provide mineral supplements with added caesium binders for game animals to reduce contamination of game meat

Method: Incorporate chemical binders of radionuclides (and stable analogues) in specially prepared salt-licks or supplementary forage.
Effectiveness: Highly variable, up to a twofold to threefold reduction of ^{137}Cs contamination in game meat might be possible.
Comments: Cheap, in the case of widely used caesium binders. The reduction in activity will depend on whether animals visit and lick the salt-lick. Difficult to monitor the effectiveness. For more information see Section 7.5.3.6.
Rating: B/D.

7.7.5. Processing of raw forest products

7.7.5.1. Convert raw wood materials into less contaminated processed products

Method: Process raw wood into bark-stripped wood, paper and cardboard, or chemical products such as alcohol, tar and turpentine.
Effectiveness: Varies according to the processing technology applied (see Table VIII). A more than 1000-fold reduction of ^{137}Cs can be achieved by conversion to chemical products, 50–100-fold by paper production.
Comments: Contaminated timber can be processed into relatively uncontaminated products. Some examples are given in Table VIII. A high initial investment may be needed if the manufacturing facilities are not already available, but this may be worthwhile given the high social and economic benefits. There are potential problems with marketing, disposal of radioactive waste from processing and the additional dose commitment to workers.
Rating: B.

7.7.5.2. Use wood as fuel

Effectiveness: Sufficient positive economic benefit to be worth considering.
Comments: Burning wood from poorly productive contaminated forest plots is one method of using such a forest. However, the resulting radioactive ash poses a disposal problem, particularly if the wood contains ^{137}Cs.
Rating: A/D.

TABLE VIII. REDUCTION FACTORS (RF) FOR ^{137}Cs WHEN PROCESSING RAW WOOD MATERIALS.
(RF = ^{137}Cs activity concentration in raw material/^{137}Cs activity concentration in final product) [70]

Raw material	Processing technology	Final commercial product	Reduction factor for Cs-137	Comment
Wood trunk	Bark stripping	Bark-stripped wood	>2	Estimated RF averaged for the mass of a whole trunk
Wood	Chemical treatment	Alcohol, tar, turpentine, etc.	>1000	Estimations based on indirect data
Softwood chips	Pulp/paper processing	Paper and cardboard	50–100	Experimental data from Swedish industry
Hardwood chips	Pulp/paper processing	Paper and cardboard	~50	

7.7.6. Change of forest management/use

7.7.6.1. Change collection and preparation of food products from forest areas

Method: Avoid the collection of highly contaminated foodstuffs such as certain species of mushroom, and use suitable food preparation to reduce contamination levels in foods.
Effectiveness: Potentially highly effective for those people who habitually consume products from forests.
Comments: This countermeasure would rely on providing the affected individuals with adequate information to differentiate between plant and mushroom species. It is likely to be highly effective in seasons when mushroom production is high. For information on food processing see Section 8.
Rating: A.

7.7.6.2. *Change hunting time schedule to reduce contamination of game meat*

Effectiveness: Twofold or threefold reduction of ^{137}Cs contamination in meat, depending on seasonal variation in animals' diet.
Comments: Usually involves changing the hunting season from autumn to spring. Likely to be highly effective in areas where there is high mushroom production in the autumn. Will not be acceptable (or even ethical) if hunting is moved to the breeding season. For further information see Section 7.4.
Rating: A.

7.7.6.3. *Change forest utilization*

Effectiveness: Potentially high positive ecological and economic effects.
Comments: Utilization of forest regions can be altered from timber production to nursery establishment so that young trees are subsequently transferred to less contaminated land. This is a medium to long term measure which is recommended for areas contaminated at only moderate or low levels (e.g. <0.6 TBq/km^2 ^{137}Cs). This change in land use allows the continued commercial/ecological utilization of contaminated land.
Rating: A/B.

7.7.6.4. *Carry out afforestation of marginal land and reforestation of low productivity forest areas*

Effectiveness: Variable, depends on specific scheme of land use changed.
Comments: Afforestation of marginal land and reforestation of low productivity forest areas enables commercially acceptable forest products to be grown on abandoned, formerly agricultural, land. A high initial investment is needed and the benefit may not be realized for several decades.
Rating: A/B.

8. LOSSES OF RADIONUCLIDES IN FOOD BY PROCESSING AND CULINARY PREPARATION

8.1. INTRODUCTION

The following information on reducing contamination of food is largely derived from the VAMP report by Noordijk and Quinault [71], and the subsequent summary given in the IAEA Handbook of Parameter Values for the Prediction of

Radionuclide Transfer in Temperate Environments [45]. These measures can be carried out at both domestic and industrial premises. Preservation of foodstuffs contaminated by short lived radionuclides by canning, freezing or dehydration allows the products to be stored to allow for the physical decay of the radioactivity.

Significant reductions in both short and long lived radionuclide contamination, and hence internal dose, can be achieved by many of the normal practices used in the preparation, cooking and processing of food. However, preparation of dehydrated products will cause an increase in activity concentrations, although these will be reversed if the food is adequately rehydrated [72].

Food processing to reduce radioactive contamination can be categorized into three types: (i) surface cleansing, such as washing, rinsing and brushing; (ii) selective removal of parts with the highest contamination, such as peeling, removal of outer leaves and deboning; and (iii) processes such as blanching, marination, cheese-making and oil extraction. However, it must be recognized that commercial retailers are unlikely to buy contaminated produce on the assumption that the contamination will be reduced to safe levels by processing in the home.

The effect of food processing is quantified here using two terms:

- The food processing retention factor, F_r, which is the fraction of radionuclides retained in the food after processing.
- The processing efficiency, P_e, defined as the weight of prepared product divided by that of the original raw material. Values of P_e are important for dairy products and take into account the yield of each product.

To avoid misinterpretation, these definitions can be illustrated with reference to radiocaesium and radiostrontium. The F_r value of 0.4 for radiocaesium in boiled meat indicates that only 40% of the radiocaesium present in raw meat is retained after boiling and 60% passes into the boiling liquid (Table IX). In the case of processed dairy products (Table X) P_e has to be taken into account. For example, an F_r value of 0.61 for goat's cheese indicates that 39% of the radiostrontium is removed by the conversion of goat's milk to cheese, but, owing to the 12% yield of cheese, the concentration of radiostrontium in goat's cheese is $0.61/0.12 = 5$ times the concentration of radiostrontium in goat's milk. Therefore, F_r values for each radionuclide have to be divided by the relevant P_e values to obtain the overall effect. The effect is reversed in foodstuffs such as pasta and rice which absorb water during cooking.

F_r values for animal food products are all based on internal contamination. All data on plants refer to total contamination, in general via root uptake followed by translocation, although F_r values based on 'external contamination' are also presented for vegetables. External contamination needs to be considered when the outer surfaces of the plant are directly contaminated by the fallout or resuspended soil and are not removed during the harvest operation.

It must be stressed that all F_r values referring to extraction procedures such as boiling, frying, etc., are valid only when the extraction liquid is removed and not

TABLE IX. FOOD PROCESSING RETENTION FACTOR F_r AND PROCESSING EFFICIENCY P_e FOR MEAT AND FISH

Raw material	Method of processing	Sr		Cs		I	Ru	P_e
Meat of mammals	Boiling meat	0.5	0.4–0.9	0.4	0.2–0.7	0.6	0.3	0.7
	Boiling bone		0.999		0.2–0.3	0.98	0.7	1.0
(cow, pig, sheep, deer, rabbit)	Frying, roasting or grilling meat		0.8		0.5–0.8			0.4–0.7
	Microwave baking				0.4–0.5			
	Pickling wet				0.1–0.7			0.4–0.7
	dry				0.8			0.9
	Marinating				0.1–0.6			
	Sausage production				0.4–1.0			
Birds	Boiling meat		0.5					
Fish	Boiling meat		0.9	0.7	0.2–0.9	0.5–0.9		
	Frying meat				0.8–0.9	0.7–0.8		

Note: underlined data denote best estimates.

used for other culinary purposes. Similarly, it should be remembered that radionuclides removed from foodstuffs by processing may subsequently be used for other products such as animal feeds. Therefore the effect of food processing should consider by-products and waste.

The effects of processing on contaminated food depend on the radionuclide, the foodstuff and the method of processing. Food processing is capable of at least halving levels of radioactivity in many foodstuffs and is therefore an important and simple countermeasure. The application of such countermeasures is easier to regulate in industrial processing. However, advice on the selection and cooking of foods can be useful. In Norway, after the Chernobyl accident, such advice led to effective and sustained changes in diet selection and culinary habits in some members of critical groups [61].

8.2. EFFECTS OF FOOD PROCESSING AND PREPARATION

Detailed data for the effects of food processing and preparation are given below for the major groups of foodstuffs.

8.2.1. Dairy products

Many data are available on the behaviour of radiocaesium, radiostrontium and radioiodine during milk processing (Table X), but not for other radionuclides. In this case, F_r represents the fraction of the radionuclide which remains in the processed food. However, under normal circumstances, nearly all by-products are now used for other food products so only a small amount of radioactivity will be removed from the total population diet by milk processing. Although milk processing, following an accident, may be deliberately modified to reduce consumption, it is important to ensure that the overall nutritional requirements of the population are not ignored. In particular, deliberate exclusion of radiostrontium from milk products may also lead to deficiencies of calcium.

The distribution of radionuclides over the various products is influenced by the yield of each product. For example, a higher yield of cream will lead to a proportionally higher F_r value for cream if the increase in the yield does not affect the concentration of the radionuclide in the cream.

As can be seen from Table X, all three radionuclides tend to remain in the aqueous fraction of milk. However, comparatively more radioiodine is found with the fat fractions and somewhat more strontium and iodine tends to be transferred to cheese.

Contaminated milk should not be used for powders unless the contaminants have relatively short half-lives and will decay during storage (e.g. ^{131}I). Otherwise the process of drying does not remove radionuclides.

	Sr		Cs		I		P_e	
Butter	0.006	0.0025–0.012	0.01	0.0003–0.16	0.035–0.01		0.04	0.03–0.05
Buttermilk	0.06	0.03–0.07	0.05	0.02–0.13	0.05–0.13		0.04	0.03–0.14
Butterfat		0.001–0.002	0.00	0.00–0.00	0.02		0.04	0.04–0.04
Milk powder	1.00		1.00		1.00		0.12	
Cheese[a]								
goat	0.61			0.07–0.15		0.08–0.14	0.12	0.08–0.17
cow rennet	0.025–0.80		0.07	0.05–0.23	0.20	0.11–0.53	0.12	0.08–0.18
cow acid	0.04–0.08			0.11–0.12		0.22–0.27	0.10	0.08–0.12
Cottage cheese rennet	0.07–0.17			0.01–0.05				
Cottage cheese acid	0.22							
Yoghurt			0.34					
Whey[a]	0.20–0.80		0.73–0.96		0.47–0.89		0.90	0.70–0.94
rennet	0.70–0.90		0.75–0.90		0.60–0.73			0.82

Product	Sr	Cs	I	P_e	
Casein[a]	0.10–0.85	0.01–0.08	0.02–0.12	0.03–0.06	
rennet	0.05–0.08	0.01–0.04	0.03–0.04	0.01–0.06	
Casein whey[a]	0.08–0.16	0.77–0.83	0.69–0.82	0.76	0.73–0.79
rennet	0.67–0.86	0.83–0.84	0.78–0.80	0.78	0.75–0.79
Milk[b] ion exchange	0.1	0.01	0.1		

Note: underlined data denote best estimates.

[a] Separate values are given for the rennet and acid coagulation procedures.

[b] Decontamination of milk by ion exchange on a commercial scale.

...ING RETENTION FACTOR F_r AND PROCESSING EFFICIENCY P_e FOR VEGETABLES AND FRUIT.
Data are based on total contamination of the plant [71]

Plant	Method of processing	Sr	Cs	Other nuclides	P_e
Spinach	Washing	0.4–1.0	0.6		1.0
	Washing and blanching	0.4–1.0	0.5–0.6		0.8
	Cooking and rinsing	0.9	1.0	Co: 0.9	0.7
	Canning	0.5	0.2		0.7
	Freezing	1.0			0.7
Lettuce	Removing inedible parts		0.5		0.7
	Blanching	0.3–0.9	0.1–0.6		0.5
Cabbage	Marinating		0.9	Ru: 0.5	0.9
	Washing	0.3	0.9		1.0
	Washing and blanching	0.4–1.0	0.1–1.0		0.7
	Cooking and rinsing	0.8			0.7
	Freezing	0.2–0.9	0.7		0.7
	Canning	0.4	0.2		0.7
Cauliflower	Peeling		0.5		0.7
Beans	Washing	0.1			1.0
	Blanching	0.3–1.0	0.6–0.9		0.9
	Canning	0.3–0.8	0.4–1.0		
	Froth flotation	0.4–0.6	1.0		
	Brine grading	0.6	1.0		
Tomatoes	Washing	0.7			1.0
	Peeling and slicing	0.7			0.9
	Canning	0.8			
	Frying	0.5			0.5
Onions	Peeling, washing and boiling	0.5			
Mushrooms	Boiling	0.7–0.9	0.2–0.5		0.6
	Boiling in 2% NaCl	0.2			
	Canning	0.5			
	Parboiling	0.1–0.4			
	Soaking of dried mushrooms	0.1–0.2			
	Parboiling, salting and soaking	0.00			

TABLE XI. (cont.)

Plant	Method of processing	Sr	Cs	Other nuclides	P_e
Cucumbers	Pickling		0.15		
	Canning	0.35	0.06		
Peaches	Peeling	0.5			0.9
	Canning	0.5			
	Lye peeling	0.09	0.03		
Strawberries	Rinsing	0.7	0.6		1.0
Berries	Making purée		0.6–0.8		0.6–0.8
	Rinsing		0.8		

Radiocaesium salts tend to remain in the aqueous phase so concentrations in butter, cream and cheese are comparatively low. The activity concentrations in cheese depend on the type of cheese. Diverting production to the types of cheese which are known to contain comparatively small amounts of radiocaesium is one of the most effective responses to milk contamination. One notable exception is goat's cheese, made from whey which has comparatively high levels of radiocaesium [73]. This could be avoided by using demineralized whey as the radiocaesium is removed during demineralization.

The coagulation process appears to have a considerable effect on the transfer of radiostrontium to cheese. F_r values for radiostrontium are quite unpredictable in the case of rennet coagulation, but often a high transfer to cheese occurs. Coagulation by an acidifying procedure appears to lead to a much lower transfer of radiostrontium to cheese. For all radionuclides, the variation in F_r values for cheese production by acid coagulation is smaller than by rennet coagulation.

8.2.2. Fruit, vegetables and cereals

The effects of food processing on fruit and vegetables are highly variable. The reductions in total contamination which can be achieved by various procedures are given for total contamination in Table XI and for external contamination only in Table XII. In considering them, it is important to differentiate between contamination by deposition and by root uptake.

TABLE XII. FOOD PROCESSING RETENTION FACTOR F_r AND THE PROCESSING EFFICIENCY P_e FOR VEGETABLES AND FRUIT.
Data are based on external contamination only [71]

Plant	Method of processing	Sr	Cs	I	Other nuclides	P_e
Spinach	Washing	0.2	0.2–0.9	0.07–0.8	Ru: 0.4–0.8	1.0
	Washing plus blanching	0.4–0.7	0.2–0.9	0.6–0.7	Ru: 0.5–0.8	0.8
	Cooking plus rinsing			0.4		
Lettuce	Washing		0.2–1.0	0.1–0.5	Ru: 0.2	1.0
	Removing inedible parts		0.1–0.4	0.1–0.4	Ru: 0.01–0.3	0.7
Cabbage	Removing inedible parts		0.9	0.5	Ru: 0.7–1.0	0.8
	Washing	0.07	0.09	0.4		1.0
	Washing plus blanching	0.3	0.2–0.7			0.7
	Cooking plus rinsing			0.2–0.5		0.7
Cauliflower	Peeling		0.05–0.2	0.03	Ru: 0.02	0.7
Beans	Washing					1.0
	Blanching	0.3	0.3	0.7		0.9
	Froth flotation	0.4	0.4	0.2		
	Brine grading	0.4	0.4			
Tomatoes	Washing			0.5		1.0
	Boiling			0.2		0.7
Onions	Removing inedible parts		0.2	0.2	Ru: 0.2	0.9
	Washing		0.3	0.2		1.0
Mushrooms	Boiling in 2% NaCl		0.3			
Berries	Rinsing		0.8–0.9		Ru: 0.8–1.0	
	Making purée				Ru: 0.7	0.6–0.8
	Boiling		0.3–0.5	0.2	Te: 0.3–0.7 Ba: 0.6–0.9	

For externally contaminated products washing, scrubbing, peeling or shelling fruit and vegetables (including roots and tubers) to remove surface contamination are simple, generally applicable and effective methods of reducing activity concentrations. In many instances, such procedures are a normal part of culinary preparation.

For root crops, the effects of food processing are generally small with the exception of beetroot (Table XIII). Peeling may be very efficient in removing radionuclides in soil particles attached to the peel.

Radiocaesium activity concentrations in certain species of mushrooms can be particularly high and persist for a long time after deposition. However, the majority of the radiocaesium can be removed by boiling, parboiling and soaking of dried mushrooms.

TABLE XIII. FOOD PROCESSING RETENTION FACTOR F_r AND PROCESSING EFFICIENCY P_e FOR POTATOES AND ROOT CROPS [71]

Raw material	Method of processing	Sr	Cs	Other nuclides	P_e
Potato	Boiling with peel	0.9–1.0	0.8–0.9	Po: 0.4–0.7	0.9
	Peeling	0.5–0.9	0.6–0.8	Po: 0.3–0.5 Pu, Am: 0.1–1.0	0.8
	Peeling and boiling	0.7–0.8	0.6		0.8
	Frying	0.6			0.6
	Microwave boiling unpeeled		0.8		0.8
	Microwave boiling peeled		1.0		0.6
	Canning	0.7	1.0		
	Decontamination	0.5	0.05–0.2	Ru: 0.5	
Carrot	Scraping, washing and boiling	0.8			0.8
	Peeling	0.7	0.5	Pu, Am: 0.4	0.8
	Cooking unpeeled		0.5–0.8		0.8–0.9
	Microwave cooking unpeeled		0.7		0.8
	Microwave cooking peeled		0.5		0.7
Beetroot	Peeling	0.8	0.4–0.7	Pu, Am: 0.45	0.8
	Cooking unpeeled		0.3–0.7		0.9
	Cooking and peeling		0.3		0.8
	Microwave cooking unpeeled		0.4		0.75
	Microwave cooking peeled		0.3		0.7
Parsnip	Peeling	0.7	0.6	Pu: 0.3	
Swede	Peeling	0.65	0.6	Pu: 0.7	

TABLE XIV. FOOD PROCESSING RETENTION FACTOR F_r AND PROCESSING EFFICIENCY P_e FOR CEREALS [71]

Raw material	Method of processing	Sr	Cs	Pu, Am	P_e
Wheat grain	Milling to white flour	0.09–0.5	0.2–0.6	0.1–0.2	0.7
	Milling to dark flour	0.1–0.2	0.05–0.1		0.05–0.1
	Milling to semolina		0.15–0.5		0.2–0.3
	Milling to bran	0.6–0.9	0.5–0.6		0.1–0.2
	Cooking wheat sprouts		0.9		1.8
	Shredding or puffing wheat		0.1–0.15		0.9–0.95
Durum wheat grain	Milling to flour		0.1–0.6		0.08–0.8
	Milling to groat and groatdust		0.3–0.4		0.6–0.7
	Milling to bran		0.4–0.5		0.2
Rye grain	Milling to white flour	0.6	0.3–0.6	0.2	0.6–0.8
	Milling to dark flour		0.2		0.1
	Milling to bran		0.35–0.7		0.15–0.4
	Cooking rye sprouts		0.8–0.9		1.9–2.4
Barley grain	Milling to white flour	0.5	0.2–0.6	0.1–0.2	0.6–0.8
	Milling to semolina		0.35		0.1
	Milling to bran		0.4		0.4
Oat grain	Milling to white flour	0.3	0.4	0.4	0.4
Pasta	Cooking		0.8–0.9		2.2

Values of F_r for milled cereals are generally lower than 0.5 (Table XIV). However, as for dairy products overall effects of processing depend on the yield of the product.

8.2.3. Meat and fish

Table XIII gives data on the effects of food processing on radionuclide levels in meat and fish. The effect of meat processing does not appear to be influenced by the type of animal. Radiocaesium levels in meat are little affected by frying, grilling and dry curing, but boiling, pickling and marination are effective at removing radiocaesium, as are sausage and rib production.

Mechanical removal of bone should be avoided for carcasses contaminated with radiostrontium [74] as it will increase the contamination of the meat.

Part III

ORGANIZING FOR RESPONSE

9. INTRODUCTION

Provisions for agricultural countermeasures are a component of national emergency plans for action in the event of a release of radionuclides. Administrative, scientific and food production arrangements vary but the following types of organization can be involved in devising and implementing countermeasures:

— central and local government
— public and private scientific institutions
— agricultural advisory institutions
— the food processing industry
— the agricultural community.

Because of the broad nature of the possible consequences of radioactive contamination of the environment, central government should be responsible for establishing the response structures, which are likely to include agricultural, food control, health, trade, financial and legal departments.

The particular tasks of local administrations will depend on the functions allocated nationally. It may just be noted that in many cases local authorities may play a key role by directly administering countermeasures. Because most local administrative staff will not have agricultural or scientific expertise, close co-operation with all other administrative groups and specialists must be established. It also follows that, as far as possible, the functions of local administration should be clearly and specifically defined.

It is important to recognize that staff to carry out the activities set out in Sections 10.1, 10.2, 10.3 and 11 below are a vital national resource that must be maintained in a constant state of preparedness.

The agricultural community itself is not addressed directly in the following discussion. Advisory institutions acting through individuals (veterinarians, agronomists, etc.) or corporately (boards, councils) should act as the links between administration and farmers. They should play an active role in developing instructions and advice concerning countermeasures, transmit these to farmers and provide the principal teachers for training and educational programmes.

The food industry should participate in any activities concerning the reduction of food contamination by processing. In particular, they could contribute significantly by providing a range of feasible options for the utilization of contaminated food products. They would also be valuable in the evaluation of transport facilities.

10. EMERGENCY PREPAREDNESS

10.1. DEVELOPMENT AND MAINTENANCE OF EMERGENCY STRUCTURES

As a rule, any administration has machinery for dealing with problems arising from the accidental contamination of the environment, which is usually established in the principal governmental departments (such as Ministries of Agriculture, Health, etc.). It is important that it includes provision to ensure co-operation between groups so that actions taken by individual departments are consistent with both general policy and the actions of other departments.

The system should be established permanently and rehearsed regularly, both in terms of individual units and as a national system so as to make preparation for the pre-accident and early-warning phases as well as those which follow the arrival of contamination.

The administrative function is to develop and deploy a programme of contingency actions. The main items to be considered are to:

- Prepare an emergency plan of actions/countermeasures;
- Ensure adequate liaison and co-ordination between the various organizations involved;
- Ensure that monitoring and assessment systems can be activated with the necessary speed;
- Ensure that relevant scientific and technological databases are developed;
- Educate and train administrative and professional staff in emergency actions;
- Provide a system for giving emergency information to farmers, the food industry and the general public;
- Establish communication links with neighbouring countries, international organizations/institutions, and the mass media.
- Establish a database of food suppliers;
- Develop, where feasible, databases with names and addresses of all farmers and details of their production.

10.2. EMERGENCY PLANS

There should be well established emergency plans that staff can turn to with confidence. The rules and responsibilities of each individual should be clearly defined so that he/she knows both what is expected and to whom to go for direction.

The following general points should be included:

- The executive units should be in close contact with the policy and planning bodies.
- Intervention levels and corresponding operational intervention levels (acceptable upper contamination levels in foodstuffs) should be established beforehand for initial and subsequent time periods following an accident. These levels provide the scientific basis for countermeasures.
- There should be data available on the costs, effectiveness and correct timing of different countermeasures. Together with the schedule of intervention levels and operational intervention levels, these provide a framework for national guidance on countermeasures.
- Mechanisms to introduce countermeasures to farmers must be established and made functional, perhaps through a specific agency but preferably by using existing structures such as advisory boards or councils.
- Plans and facilities for monitoring the effects of countermeasures, including live animal, soil and crop monitoring, and plans for controlling end products (foodstuffs) should be available.

Consideration should be given to establishing stocks of materials such as animal feed and/or additives, for example Prussian Blue, which can inhibit the uptake of radionuclides. It is, however, unlikely that individual farmers would do this and it is questionable whether national stores could be large enough to be very useful.

The scale of most preparatory efforts will basically depend on the estimated probability of accidental radioactive contamination of the region. Full-scale precautionary programmes are justified in areas close to potentially hazardous nuclear sites (such as nuclear power plants) but the costs will be less acceptable in remote regions with a low population density.

10.3. MONITORING AND ASSESSMENT

The scientific community should support the administration in education/training and in advisory capacities. Ideally, the main items would be to:

- Assist in developing emergency plans for responding to possible wide-scale radioactive contamination of the environment;
- Develop and implement educational and training programmes for scientists, administrative staff, the rural population and the general public;
- Establish radioanalytical laboratories with standard analytical methods and trained personnel, appropriate quality assurance validation and a communications network between laboratories and administrative centres (to facilitate

guidance on analytical methods and sampling protocols as well as to share results); however, it will be unlikely that it will be feasible or necessary to undertake all these activities in all regions (for example, developing models for specific local environments could not be done for all areas);

— Make arrangements to monitor the agricultural environment and food which can be used both routinely and in emergency situations;
— Prepare databases from monitoring results;
— Prepare and maintain a database of countermeasures;
— Develop countermeasure programmes for agricultural areas around existing and planned nuclear sites;
— Establish and update dose estimation models specially adapted for the region's environmental conditions; these models should also allow for the estimation of the effects of countermeasures;
— Collect, if feasible, a specimen bank of soil and plant samples for reference in the event of a nuclear accident;
— Prepare and maintain a database of relevant information on agricultural production, soil types and climates;
— Prepare and maintain a database of information on radioecological parameters such as transfer factors of radionuclides through food chains;
— Choose or develop models for the movement of radionuclides in the specific local environment.

10.4. LEGAL CONSIDERATIONS

A clear legal basis should be established for intervention in the event of an accident. Prevailing food law and consumer protection legislation should be sufficiently comprehensive so that it is not necessary to pass any new laws in the period immediately following an accident.

Specific numerical limits for radioactive contamination in food in an emergency should be laid down in advance as noted above. The internationally agreed FAO/WHO *Codex Alimentarius* Commission Guidelines [6] for foods moving in international trade will form the basis for these limits. Such limits may have to be reviewed in the light of the specific conditions of an accident within a predefined period of time (e.g. 1 or 3 months).

Legal aspects specifically related to agricultural countermeasures that should be considered include:

— any legal obstacles to the implementation of countermeasures;
— the need to license chemicals planned for soil treatment or feed additives (e.g. Prussian Blue);
— legal action that may be necessary to ensure the stockpiling of uncontaminated feed, chemical agents, etc.;
— the legal basis for compensation for losses in agriculture following accidental contamination of farmlands;
— the liability of an operator responsible for an accident.

10.5. EMERGENCY FUNDS AND RESOURCES

Almost any programme of countermeasures will require financial and material support. Therefore special contingency funds and reserves of materials (food, feed, chemical agents, special machinery) should be established.

Possible sources of financial support include:

— budget contingency;
— liability claims against the operator responsible for the accident;
— national and international donations.

Of these, only the first is likely to be a source of immediately available finance.

11. RESPONSE

11.1. EARLY WARNING PERIOD

In areas further than 500 km from a release, fallout can be expected from a few hours to a few days after the event. Sometimes information will be available about an incident while it is still developing and before the likely extent of off-site contamination can be estimated. In such cases there might be enough time to undertake actions in advance.

11.1.1. Administrative tasks

Contingency plans should be able to:

— Activate arrangements for managing the accident response;
— Activate and test emergency communication networks, including those with international links;
— Keep the general public, and farmers in particular, fully informed of the expected course of events, and of the steps that may be taken to protect the food chain;
— Begin to develop intermediate and late phase countermeasure plans appropriate to the expected contamination.

… administrative actions at this and all subsequent phases should be made known to neighbouring countries and international organizations to ensure adequate co-ordination.

11.1.2. Scientific tasks

The information available, for example, from the site, from analysis of the plume and meteorological data, should be used to predict the likely consequences for the country, and in particular for agriculture. Collaboration with other national and international scientific organizations, particularly by sharing data, is important.

If necessary, all emergency staff should be mobilized, monitoring teams prepared for action, laboratories cleared of other work, and administrative staff assembled in their emergency centres. The monitoring of radioactive contamination of food and the environment should begin or should be intensified.

11.2. SHORT TERM RESPONSE

Initial information regarding contamination of the agricultural environment and the consequent food chain will be based largely on model calculations. These predictions can be used to identify areas and products which should have the highest priority in the early monitoring programme. Calculated figures will progressively be supplemented by measured values. It is important that the responsible authorities receive the data rapidly and that the public is kept as fully informed as possible.

The duration of the short term response depends on the half-life of short lived radionuclides deposited (normally ^{131}I, half-life of 8 d). A period of a few weeks is sufficient for such radionuclides to decay to negligible amounts.

11.2.1. Administrative tasks

The first priority should be to prevent harvesting, movement and distribution of agricultural produce contaminated at unacceptable levels. Specific actions should include the application of predefined maximum contamination levels and the introduction of intensified monitoring programmes. Foods which exceed predefined maximum contamination levels should be prohibited from sale or distribution. Alternative sources of food available through domestic or international trade should be identified.

The second priority is to ensure adequate response from scientific institutions. The main tasks should be identified so that scientific support can be organized for assistance in decision making. Necessary pilot investigations should be initiated and provisional programmes of countermeasures should be organized and implemented.

11.2.2. Scientific tasks

The main activities will be in the areas of monitoring, dose assessment and countermeasures.

The principal items of information include adequately detailed and comprehensive maps of contamination of the agricultural environment (see Table II). These should be obtained from monitoring surveys beginning as early as possible, preferably including data from pre-fallout or pre-accident periods. The system should permit the replacement in decision models of calculated data with actual data as they become available. Contamination levels at harvest of currently growing crops should be one of the principal objectives of the forecast.

Agricultural countermeasures taken during the early-warning phase should be now reviewed and additional short term actions considered.

11.3. INTERMEDIATE RESPONSE

If it is judged that the problem in the affected areas will persist, long term countermeasures to reduce contamination of the food chain must be considered. It may also be appropriate to review intervention levels. Consideration should also be given to worker exposure, including that derived from nuclides such as ^{239}Pu that are not generally taken into food chains.

The main long term problems are caused by contamination with long lived radionuclides, especially ^{137}Cs and ^{90}Sr. The extent of this contamination would have been identified by the radiological surveys made during the short term phase. An adequate response to long term contamination needs a more extensive and systematic approach than is necessary for short term action. Hence, ongoing countermeasures will require revision.

However, the main task for both administrative and scientific groups will be to prepare for long term programmes. This involves:

- a review of intervention levels and operational intervention levels;
- continuation of monitoring to control foodstuffs;
- initiation of relevant scientific/technological studies;
- development of databases to facilitate future decisions;
- preparation of a long term radiological forecast (contamination of the environment and crops, dose commitment, etc.);
- maintenance of the most important and effective countermeasures and preparation of long term programmes;
- initiation of educational programmes for specialists and the general public.

11.4. LONG TERM RESPONSE

In many cases the benefit of long term measures will include the continuation of sustainable agriculture in an affected area, as well as the reduction in dose commitment to the public and/or saving the cost of bringing in food from outside the region. Because they may require significant changes in local practice, the implementation of such countermeasures may require more than giving advice. For instance, resources may be provided such as feed additives, chemicals for soil treatment or machinery. In some cases, legal compulsion may be imposed although such a step requires the strongest justification.

Continued monitoring of contamination levels in produce will be needed to check the effectiveness of countermeasures, and also to provide essential public reassurance. The agricultural advisory services have an important role to ensure that farmers are applying the countermeasures. The levels of radionuclides throughout the ecosystems of the affected areas should be monitored to determine the need for continuing interventions or countermeasures.

The use of model farms or demonstration projects might be an effective way to train farmers in countermeasure techniques, and to demonstrate both to them and to the public the effectiveness of the countermeasures. An ongoing research and development programme may be needed to improve the countermeasures.

12. PUBLIC INFORMATION AND INFORMATION FOR FARMERS

It is necessary that the information released be consistent, internally and between sources. Often, information will be released from several sources which may be separated geographically, so it is important to ensure that there is no conflict so as to maintain credibility and minimize rumours. Within this constraint the public should be kept as fully informed as resources permit and any hint of censorship should be avoided.

12.1. IN NORMAL TIMES (ACCIDENT-FREE)

In normal times the media should be kept fully informed on nuclear matters so that they are mentally prepared to understand what is happening following an accident. The public should be informed about the possible consequences of a future accident, and the responses available to ensure their protection. Farmers need more specific information on how they might be affected, and what they might be expected to do after an accident.

Preparations should be made to provide rapid and authoritative information to the public after an accident. For instance, the physical locations for media briefings must be established in advance. Staff must be trained both in the details of nuclear emergency response actions and in dealing with highly motivated, or even aggressive, media correspondents. They must be able to work not only with representatives who are supportive of nuclear energy but also those who oppose it. The staff should be sensitive to the deadlines that media representatives face and be as accommodating as the emergency permits. Some government statements can be drafted in advance, in such a way that only accident specific details need to be filled in at the time.

12.2. AFTER AN ACCIDENT

It is essential that spokespersons are fully aware of the actions and statements of all departments; rapid communication among all departments and the central government press team is therefore vital. This is another area where regular drill exercises are extremely important. In some cases authorities may wish to ensure that official statements appear unaltered in newspapers, perhaps by paying for advertisements.

In addition to general information released to the media, authoritative information should be issued directly to the farmers in a clear and concise form. The following topics may be relevant to them:

- The scale and distribution of contamination of farmland in an easily understandable form (maps);
- The main hazards and possible consequences;
- The identity of the central and local authorities to be contacted for information and advice;
- The actions being introduced or planned, including the observance of intervention levels and contamination limits;
- Financial aspects of the countermeasures.

Part IV

CONTAMINATION IN AGRICULTURE FROM PAST NUCLEAR ACCIDENTS

13. INTRODUCTION

During the past 35 years, three major accidents at nuclear power plants have given cause for concern and required the implementation of countermeasures in agriculture. These accidents occurred at Windscale (United Kingdom), Kyshtym (former Soviet Union) and Chernobyl (former Soviet Union).

Other serious nuclear accidents contaminating the land occurred in Palomares in Spain, when an aircraft carrying nuclear weapons crashed, and in Canada following burnup on re-entry of the nuclear powered satellite Cosmos 954.

These incidents caused in some cases only local short term consequences and in some cases also widespread long term consequences.

14. NUCLEAR ACCIDENTS REQUIRING COUNTERMEASURES ONLY IN THE SHORT TERM

14.1. WINDSCALE

On 10 October 1957, in the course of an exercise to release stored Wigner energy in the graphite moderator of an air cooled natural uranium reactor, uranium fuel overheated and volatile radioelements, in particular iodine, were accidentally discharged to the atmosphere. The principal fission products released were ^{131}I (740 TBq) and ^{137}Cs (22.2 TBq) plus very much smaller amounts of ^{89}Sr, ^{90}Sr, ^{103}Ru, ^{106}Ru, ^{95}Zr, ^{95}Nb, ^{144}Ce and ^{210}Po [75]. Within 12–24 hours after the release, ^{131}I was found in milk from local farms. On 12 October, two days later, a decision was taken to prevent human consumption of all milk containing at least 3700 Bq/L and the extent of the ban was defined on 14 October. Within the restricted area of 500 km^2, all milk was collected and dumped. The ban lasted for up to 25 days and is estimated to have saved 3.5×10^3 man·Sv to the thyroid glands of the local populace [76]. It was not deemed necessary to impose restrictions on any foodstuffs other than milk. The ^{131}I on or in the grass decayed with an effective half-life of five days and the levels in milk declined correspondingly [75]. An empirical correlation of the activity of milk and grass showed that about 370 kBq/m^2 of ^{131}I on grass was required to give 37 kBq/L in milk.

Action taken: Ban on the use of milk from the restricted area of 500 km^2 for 25 days after the accident. The derived intervention level for ^{131}I in milk was 3.7 kBq/L.

14.2. PALOMARES

In January 1966, in the course of in-flight refuelling over Palomares in southern Spain, an aircraft of the United States Air Force and its four thermonuclear bombs were lost. Two of the bombs fragmented on impact with the ground and uranium and plutonium were disseminated. Much of the land contaminated was agricultural and covered an area of about 226 hectares: contamination levels exceeded 1200 kBq/m^2 over 2.2 hectares, ranged from 120 to 1200 kBq/m^2 over 17 hectares and 12–120 kBq/m^2 over 87 hectares and was less than 12 kBq/m^2 over 120 hectares [77].

Action taken: Decontamination of agricultural land by removing the top layer of the soil.

14.3. COSMOS 954

In January 1987 the Soviet satellite Cosmos 954 went out of control and disintegrated on re-entering the Earth's atmosphere. The debris was distributed over a 600 km path in the Canadian Northwest Territories. In addition to large fragments of steel plate, beryllium rods, etc., which fell along a well defined track, a wide area was affected by scattered small particles (0.1–1 mm in diameter) from the enriched fuel in the reactor core. No agricultural countermeasures were necessary.

15. NUCLEAR ACCIDENTS REQUIRING COUNTERMEASURES IN BOTH THE SHORT AND LONG TERM

15.1. KYSHTYM [78]

The Kyshtym accident was caused by an explosion in a tank containing high level radioactive wastes of a plutonium reprocessing plant near Kyshtym, about 100 km south from Sverdlovsk, now Ekaterinburg (southern Urals, Russia). A breakdown in the cooling system led to drying-out, spontaneous radioactive heating and subsequent explosion of the mixture of nitrate–acetate salts stored in the tank. As a result, about 74 PBq of medium and long lived radionuclides were released into the atmosphere (Table XV) and deposited on the terrain. Contamination of ^{90}Sr up

TABLE XV. TOTAL ACTIVITY OF MAJOR RADIONUCLIDES IN THE KYSHTYM ACCIDENT [78]

Radiouclide	Half-life	Total activity (TBq)
Sr-90 + Y-90	28.6 a	4 × 10^3
Zr-95 + Nb-95	65 d	18 × 10^3
Ru-106	1 a	2.7 × 10^3
Cs-137	30 a	26
Ce-144 + Pr-144	284 d	48.8 × 10^3

to about 4 TBq/km^2 was observed and several γ emitting radionuclides were also released in large quantities (Table XV).

The contaminated areas were estimated to be 15 000 km^2 (300 × 50 km^2) with a ^{90}Sr content of 3.7 GBq/km^2. There were 23 villages (10 700 people) within the area of 1000 km^2 contaminated with more than 74 GBq/km^2 of ^{90}Sr.

During the first few months after the accident, external irradiation proved to be the main hazard from the deposited radioactivity. After medium lived γ emitting radionuclides (^{144}Ce, ^{95}Zr + ^{95}Nb, ^{106}Ru) had mostly decayed in the subsequent 4–5 years, ^{90}Sr became the principal source of radioactive hazard in the contaminated areas, mostly via food chains.

Actions taken: In the emergency phase of the post-accident period the evacuation of 1100 people from severely contaminated areas (above 3.7 TBq/km^2) was the main protective measure. A restricted zone was imposed where no access was allowed and all agricultural and other economic activities were banned. During the following year, evacuation of people continued until almost 90% of the affected population was evacuated from 19 villages in areas contaminated above 74–148 GBq/km^2 of ^{90}Sr. As a result, about 700 km^2 of farm and forest land was abandoned. Later, upper permitted levels of ^{90}Sr in food chains were defined and introduced in areas surrounding the restricted zone [78].

15.2. CHERNOBYL [79]

As a result of an accident on 26 April 1986 in Unit 4 of the Chernobyl nuclear power plant in Ukraine, about 2 EBq of radioactive substances were emitted. Several million hectares of agricultural land and forests were contaminated to levels requiring radiological control and countermeasures, and detectable fallout occurred thousands of kilometres distant within days. During the first few days after the accident, radioiodine was the major cause for concern and banning of milk consumption was the countermeasure employed. At distances of up to 70 km from Chernobyl, much of the land was contaminated by small fragments of irradiated fuel and so-called 'hot particles' were detected as long distance contamination in many European countries. In a later phase, the long lived radionuclides ^{134}Cs and ^{137}Cs were the main contaminants found in foodstuffs. The following short descriptions of the actions taken in some countries during and after the spread of released radionuclides are given to illustrate the complexity of such situations and the importance of preplanning and preparation.

15.2.1. The former Soviet Union (Belarus, the Russian Federation and Ukraine)

From 1986, the planning and implementation of agricultural countermeasures in the former Soviet Union was done generally within All-Union programmes which had been developed by central government in co-operation with local institutions in the republics. Therefore, a retrospective review of the application of agricultural countermeasures can be made on a common basis.

15.2.1.1. Contamination of the agricultural environment

About 52 000 km^2 of farmland in the former Soviet republics now known as Belarus, the Russian Federation and Ukraine were contaminated by fallout from the Chernobyl accident with deposition levels of ^{137}Cs exceeding 37 GBq/km^2 (Table XVI). The most severe contamination occurred in temperate latitudes.

In contaminated regions within 200–300 km of the Chernobyl nuclear power plant about 40% of the area is agricultural and a similar fraction is forested. About 5 million people live in this region, 50% of them in rural areas.

The early field observations showed that the deposited radioactivity contained practically the same range of radionuclides (except noble gases) present in the reactor core of the 4th unit of the Chernobyl plant at the time of the accident. ^{131}I was the

TABLE XVI. DISTRIBUTION OF CONTAMINATION LEVELS OF ^{137}Cs

Contamination (GBq/km^2)	37–185	185–555	555–1480	Above 1480	Total
Area (km^2)	38 000	9000	3500	1550	52 050

major contaminant of food in the first few weeks following the accident. To identify contaminated areas in Belarus and Ukraine, averaged data for milk contamination by ^{131}I were used; these had been obtained by monitoring milk produced on large collective farms that supplied milk to major dairy plants.

The first map of radioactive contamination was prepared by the middle of June 1986 and it showed only the spatial distribution of γ radiation dose rates measured at 1 m above the surface. Consequently this map allowed only rough estimates to be made of soil deposition levels for various radionuclides. Therefore, during the first few months following the accident, decisions concerning agricultural production had to be made with inadequate data on the contamination of the main foodstuffs. More detailed and more reliable information for intermediate and long lived radionuclides become available only in August–September 1986.

In May 1986, areas with abnormally high deposition levels of ^{137}Cs were discovered in regions remote from Chernobyl in Belarus (Gomel, Mogilev provinces), the Russian Federation (Bryansk province) and Ukraine (southern districts of Kiev province). The extremely heterogeneous pattern of contamination prompted the authorities to start a programme of aerial surveys over the whole of Belarus and Ukraine and large areas of the European part of the Russian Federation. These surveys were subsequently complemented by intensive soil sampling and eventually maps of levels of long lived radionuclides (^{137}Cs, ^{90}Sr and plutonium) were prepared.

By the end of 1986 the contaminated areas were classified according to the levels of ^{137}Cs in soil, and appropriate agricultural countermeasures were implemented. There were four classes of deposition level of ^{137}Cs:

(i) Levels less than 555 GBq/km^2: no agricultural countermeasures, unrestricted agricultural production;

(ii) Levels between 555 and 1480 GBq/km^2: a zone of strict control with restrictions on inhabitants (children and pregnant women were excluded); agricultural production was possible only if specific measures were applied to protect workers;

(iii) Levels higher than 1480 GBq/km^2 but lower than 3.7 TBq/km^2: evacuated zone with agricultural production under strict control to limit radioactive contamination of products;

(iv) Levels above 3.7 TBq/km^2: agricultural production stopped and arable land afforested.

15.2.1.2. Government, administrative and scientific support for agricultural countermeasures

Because of the delay before official information on the scale of the accident became available, the first group of government agricultural experts was not established until a week after the accident.

... administrative commission under the State Committee of the USSR for the Agro-Industrial Complex (Gosagroprom) was established to meet management problems caused by the wide-scale contamination of the agricultural environment. Similar regional groups were formed in Belarus and Ukraine. At the same time, corresponding commissions of experts in agricultural radiology and monitoring were formed. One of the main tasks of these commissions was to develop and prepare recommendations on agricultural countermeasures. However, most of the practical work in monitoring the agricultural environment and implementing countermeasures was done by local staff responsible for agricultural management at the provincial and district level. Up to 15 000 administrative officers and specialists were involved in co-operation with corresponding Union, republic and local departments of the Ministry of Health, the State Committee of the USSR on Hydrometeorology and Environmental Control, the Ministry of Defence and the State Committee of the USSR on Forestry.

The principal tasks were to:

- Prepare maps of ^{137}Cs and ^{90}Sr contamination of farmland and food;
- Develop derived intervention levels in terms of acceptable levels of contamination of soil and forage (feed) corresponding with previously adopted upper limits for contamination of food;
- Monitor and control radioactive contamination of raw and processed food products;
- Develop and apply short term and intermediate countermeasures to reduce contamination of agricultural products and to utilize contaminated raw products;
- Devise long term programmes of agricultural production on contaminated land.

During 1986–1992 those tasks were addressed in the following ways:

(i) Because of limited resources the mapping of vast contaminated territories was performed gradually, beginning with areas within 30–50 km of the Chernobyl nuclear power plant, which were mostly evacuated zones. Areas with ^{137}Cs deposition levels of less than 185 GBq/km^2 were included in the mapping programme from late 1986. Sampling intensity increased from one measurement point in each 10 km × 10 km in the first version of the map in 1986 to one measurement point in each 1 km × 1 km in 1991. The numbers of sampling points for ^{90}Sr and plutonium were respectively 10 and 100 times fewer than those for ^{137}Cs.

The experience gained from this programme showed that detailed maps of contamination for each field were needed rather than averaged data derived from such large scale maps. Such individual field surveys were initiated in 1987 and continued until at least 1993.

Unexpectedly high concentrations of ^{137}Cs in milk were found in 1987–1988 in some regions of the Byelorussian and Ukrainian Polesje with relatively low levels

of ^{137}Cs in the soil (37–110 GBq/km^2). This abnormally high transfer of ^{137}Cs from soil to plants was associated with specific properties of the peat and peat-bog soils in these particular provinces. Because of the possible occurrence of such soils elsewhere, mapping surveys were extended to areas with ^{137}Cs deposition levels down to 37 GBq/km^2. In addition, the preparation of maps of ^{137}Cs contamination of milk and meat was continued in 1987–1989 as an effective method to identify areas which should be included in detailed ground sampling surveys for producing soil contamination maps.

(ii) A radiation monitoring network for foodstuffs was established within a few weeks of the accident but for some time there were problems in co-ordination between the various organizations involved in the USSR Ministry of Health and Gosagroprom. It took some time for responsibilities to be clearly allocated among the local units of these departments. The first versions of instructions for the control of foodstuffs had been developed by June–August 1986. They were continually improved in 1987–1991 to take account of improvements in measurement techniques. In particular, a technique for in vivo measurements of ^{137}Cs in animals that effectively reduced the production of contaminated meat was developed and used from 1987 onwards.

In 1991–1992 about 12 000 people were employed in 73 local agrochemical units and 749 veterinary laboratories and control stations within the Ministries of Agriculture in Belarus, the Russian Federation and Ukraine.

(iii) The first version of the document "Temporary Recommendations on Agricultural Production in Affected Territories of Ukrainian SSR and Byelorussian SSR as a Result of Chernobyl Fallout" was issued on 30 May 1986 by Gosagroprom. These recommendations were based mainly on radioecological knowledge derived from rehabilitation work in the southern Urals after the Kyshtym accident in 1957 (see Section 15.1 above). Unfortunately, the document was rather general and in any case there were administrative and scientific deficiencies that hindered the implementation of any recommendations.

In order to improve the situation, in May–August 1986 more than 40 technical directive and instruction documents were prepared and distributed. They set out the principal rules and procedures for harvesting, and ways of utilizing and processing the main agricultural crops and provided basic advice concerning the breeding and feeding of animals in contaminated regions. The principal objective of these documents was to provide agricultural workers with knowledge and advice on how to produce crops which would meet the required standards of contamination.

No conceptual basis for long term agricultural countermeasures had been established by the time of the first post-accident harvesting season in July–October 1986. This was due to lack of knowledge and experience of long term planning of agricultural production under the adverse conditions caused by the multiple impacts, including social and economic stresses, of wide-scale radioactive contamination of land.

The Temporary Recommendations of 30 May 1986 were reviewed several times as experience in countermeasures was gained. The latest version was issued in 1991 as "Guidance on Agricultural Production Under the Conditions of Radioactive Contamination of the Territories of the Russian Federation, Ukrainian SSR and Byelorussian SSR". According to this document, farmlands with ^{137}Cs contamination greater than 1480 GBq/km^2 should be abandoned for agricultural production.

After the disintegration of the Soviet Union in 1991, work on improving instruction documents was continued separately in each of the independent States of Belarus, the Russian Federation and Ukraine in accordance with their own national laws regulating social and economic problems in contaminated regions.

15.2.1.3. Major countermeasures in agriculture and forestry

The major agricultural products in the contaminated regions are milk, meat, potatoes, fodder crops, permanent grass, cereals and sugar-beet. The soils are mostly relatively poor, podzolic, sandy, loamy, peat and peat-bog.

The main efforts have been directed to prevent, or at least reduce, the transfer of radionuclides through the food chain soil–plants–animals–milk–meat. Three categories of countermeasures were introduced from the very beginning:

- prompt reploughing of arable land and cultivation of pastures;
- correcting lime deficiency, where necessary complemented with increased application of mineral fertilizers, mainly potassium and phosphorus;
- change of land use where these two countermeasures might be expected to be insufficient.

Abandoning natural and low-productive pastures was a principal countermeasure in animal production. In the first weeks and months following the accident there was no adequate monitoring network for milk contamination so a decision was taken to forbid the consumption of unprocessed milk in areas with ^{137}Cs deposition levels above 185 GBq/km^2. All milk produced in contaminated areas was bought by the State. Subsequently, contaminated milk was processed in State dairies into butter, cheese and other products which were shown to contain low residues of radionuclides. This countermeasure was quite efficient in reducing the contribution of milk to the collective dose of internal irradiation. As a result, the anticipated economic loss was reduced substantially.

Countermeasures for meat production were much less effective than those for milk production. First, because of a lack of comprehensive data on contamination levels, about 120 000 cattle were allowed to graze for several weeks after the accident in extensive contaminated areas outside the 30 km exclusion zone around the Chernobyl plant from where they had been evacuated. Mainly because of the lack of stored forage at the time of the accident, livestock evacuated from the exclusion zone could not be given sufficient uncontaminated forage to reduce the content of ^{137}Cs in meat by the in vivo self-purification process. Therefore, 120 000 evacuated livestock were slaughtered in May–June 1986. As a result, about 30 000 t of meat contaminated above permitted levels were stored. About 90% of this meat was subsequently utilized in products such as sausages and tinned meat while the remaining 10% was discarded. On the basis of this experience, in later years the principal countermeasure to reduce meat contamination was accepted to be the use of clean feed for 3–4 months before slaughtering.

Change of land use proved to be the most economically effective countermeasure on large farms, particularly where the patterns of soil properties and deposition levels were very heterogeneous.

Cultivation of natural pastures and meadowlands to depths dependent on the thickness of the turf layer and topography of the soil surface reduced the ^{137}Cs transfer into perennial grass by a factor of 4–12. This was sufficient to ensure that 'clean' milk could be produced in all areas where contamination levels were sufficiently low to allow the population to remain.

Another effective measure to reduce contamination of milk and meat was to select feed with regard to the final product, species and age of the animal. For example, young cattle could be raised by grazing in areas with rather high ^{137}Cs deposition levels, provided the levels were safe for the farm workers. The concentration of ^{137}Cs in meat could then be reduced in the 3–6 months of fattening by feeding progressively cleaner forage by gradual transfer from contaminated to relatively clean farmlands.

In general, it was well established that the effectiveness of countermeasures depended greatly on adequate monitoring of contamination at all stages of the production system from soil, feed and raw products through to the final foodstuffs, including in vivo monitoring of live animals.

15.2.2. Austria

15.2.2.1. Fallout and contamination of foodstuffs

Contaminated air masses first reached Austria in the early afternoon of 29 April 1986. This was registered by the Austrian Early Radiation Warning System, an on-line γ exposure rate measurement network that covers the range from natural background radiation up to more than 10 Sv/h. Nuclide specific analysis of aerosol samples also began on 29 April. Most of the radioactive debris was deposited by 8 May.

Owing to the heterogeneous precipitation pattern over Austria during the passage of the radioactive clouds, there was a large variation in the contamination of agricultural areas. Deposition values for eastern Austria, which is the most important agricultural area for cereals and vegetables but is of less importance for milk production, were rather low (around 4 kBq/m^2 for ^{137}Cs). The other large agricultural area in northern Salzburg/western Upper Austria (primarily for the production of milk, cereals and vegetables) was affected more heavily (approximately 40 to 100 kBq/m^2 ^{137}Cs). Most of the other agricultural areas had intermediate levels of contamination. Some Alpine pastures received depositions of up to 150 kBq/m^2 ^{137}Cs but they are used for grazing only during the summer.

In the plains and hills of the large river basins cows were already grazing at the time of the accident and old uncontaminated hay was available only in small amounts. In the mountainous areas cattle were still indoors and predominantly fed on hay from 1985. Cereal crops were still immature, but vegetables such as spinach and lettuce were close to harvest.

First measurements of contamination of milk and, in same places, grass were made on 30 April (in addition to the monitoring of exposure rate, air and precipitation).

Daily average values for ^{131}I in cow's milk in the beginning of May 1986 were approximately 150 to 320 Bq/L with maximum values around 2000 Bq/L (sheep's milk: up to 41 800 Bq/L). For ^{137}Cs, daily average values in June 1986 were around 100 Bq/L in cow's milk and around 150 Bq/kg in beef meat. For sheep, for which there are only a few unrepresentative data available, the average was about 2200 Bq/kg ^{137}Cs in May and 700 Bq/kg in June 1986.

At the beginning of May, ^{131}I contamination of spinach was around 80 000 Bq/kg and about 3000 Bq/kg for ^{137}Cs. Corresponding values for lettuce were 4000 Bq/kg and 700 Bq/kg.

15.2.2.2. Emergency institutions

Soon after the first information about the accident had reached Austria, an emergency board of experts was set up (morning of 30 April) in the Federal Ministry of Health and Environmental Protection, which at that time was responsible for radiation protection. This board of experts, which included specialists in radiation protection, activity measurements, agriculture, military matters, administration and so on, advised the Minister in a nearly continuous session. One of its first actions was to warn against the use of drugs containing stable iodine for thyroid blockage and to state that in no place in Austria was there acute danger caused by external radiation or air contamination.

Within most of the provincial governments (Landesregierungen) similar boards of experts were established to help with local decision making.

15.2.2.3. Countermeasures

A catalogue of countermeasures was under preparation by the Ministry at that time. It was nearly finished but was not to be released because of its size.

Partly guided by that catalogue, partly by the expertise of the scientists within the emergency board and partly influenced by psychological reasons, various measures concerning agricultural activities and food control were taken (Table XVII).

15.2.2.4. Legislation

The application of all of the above mentioned countermeasures was based on the Austrian Radiation Protection Law (1969) which states that in the event of intensities of radioactive contamination that might lead to a deterioration of the health of the population, countermeasures have to be taken by the provincial governor (Landeshauptmann). Such countermeasures include traffic restrictions, restrictions on persons, goods and food as well as on feedingstuff and the use of water.

Although the Austrian Radiation Protection Act (1972), which contains annual limits on intake and derived quantities for artificial radionuclides, was not formally applicable in the case of the Chernobyl accident, it was decided to take its 1.67 mSv concept for the general public as a basis for maximum exposures. In addition to the ingestion of contaminated food, external exposure and inhalation as well as the behaviour of high risk groups (infants, children, pregnant and nursing women) were included.

15.2.2.5. Derived intervention levels

In the early phase after the accident it was not clear if the maximum levels could be kept below 1.67 mSv (effective dose) and 10 mSv (thyroid dose), mainly because of the lack of information about the timing of the emissions at Chernobyl and the development of the meteorological situation and the uncertainty about the fate of the second reactor (there were rumours that it also had begun to burn).

Thus, on the basis of the exposure limits given by the Radiation Protection Act, maximum permissible activity concentrations for the most important foodstuffs were derived for the two indicator radionuclides ^{131}I and ^{137}Cs (or ^{137}C + ^{134}Cs) taking into account the annual consumption rates in risk groups and the contributions of the other radionuclides involved.

Derived intervention levels (DILs) for infant food were deliberately set extremely low.

Text cont. on p. 99

TABLE XVII. SUMMARY OF AGRICULTURAL COUNTERMEASURES IN AUSTRIA AFTER THE CHERNOBYL ACCIDENT

Date	Type	Action	Validity
30.04.86	Consumption restriction	Warning against consumption of fresh vegetables	
	Feeding restriction	Warning against grazing of dairy cattle	
	General restriction	Warning against contact with dust	
01.05.86	General restriction	Warning against contact with rain puddles	
	Consumption restriction	Warning against drinking rain water (water supply in elevated Alpine areas)	
	Feeding restriction	Recommendation against grazing of animals and against feeding with green fodder	
	Consumption restriction	Recommendation to wash vegetables thoroughly before consumption	
	Monitoring	Measurement programme for all milk tanks from all 214 dairies on a daily basis	
02.05.86	DIL	370 Bq/L for ^{131}I in milk	Changed
	DIL	Recommendation to use milk below 185 Bq/L ^{131}I for drinking purposes	26.05.86
03.05.86	Sales restriction	Order to provincial governors to stop milk distribution if DIL is surpassed	
	Feeding restriction	Order to provincial governors to prohibit feeding with green fodder if DIL is surpassed	
	Import restriction	Order to provincial governors to prohibit imports of milk, milk products, fresh fruit, fresh vegetables from Bulgaria, Czechoslovakia, Hungary, Poland, Romania, USSR	22.05.86 afterwards DIL
	Sales restriction	Warning against buying fresh milk directly from farmers	

TABLE XVII (cont.)

Date	Type	Action	Validity
04.05.86	Feeding restriction	Repetition of order to provincial governors to prohibit grazing and feeding fresh fodder	07.05.92
	Consumption restriction	Warning against consumption of sheep's and goat's milk products	
06.05.86	Sales restriction	Prohibition of selling leafy vegetables grown in the open air (especially spinach, salad, cabbage), cauliflower, pulses and tomatoes	22.05.86 afterwards DIL
	Import restriction	Order from 03.05.86 extended to Italy and Yugoslavia	
07.05.86	Feeding restriction	Cancellation of prohibition of grazing and feeding green fodder (due to problems with hay supplies), but thorough recommendation not to feed dairy cattle with green fodder	
	Import restriction	Order from 03.05.86 extended to Albania, Greece and Turkey	
08.05.86	Sales restriction	Prohibition of sale of sheep's and goat's milk as well as sheep's and goat's cheese	Until 15.05.86
12.05.86	Feeding restriction	Prohibition of feeding whey to pigs in two Salzburg districts	
15.05.86	Sales restriction	Cancelling of sales restriction on sheep's and goat's milk and cheese for uncontaminated products	17.07.86
16.05.86	Shooting restriction	Prolongation of the close season for game	11.06.86
	Import restriction	Prohibition of import of game from east European countries and the USSR	15.07.86
	Feeding restriction	Recommendation of not feeding whey to pigs	

TABLE XVII (cont.)

Date	Type	Action	Validity
21.05.86	Feeding restriction	Repetition of recommendation to avoid green fodder as long as possible	
	Agricultural practice	Recommendation to take the first cut of hay as soon as possible and to store it separately	
	Agricultural practice	Recommendation to delay transferring cattle to the Alpine pasture until results of further studies available	
23.05.86	DIL	11.1 Bq/kg (0.3 nCi/kg) for ^{137}Cs in infant food	
		185 Bq/kg (5 nCi/kg) for ^{131}I in vegetables, fruit, mushrooms and produce thereof	Changed 05.06.86
26.05.86	DIL	DIL for ^{131}I in milk and fresh milk products lowered to 185 Bq/L	Still valid
27.05.86	Feeding restriction	Warning against using whey as feed for pigs	
31.05.86	Feeding restriction	Prohibition to feed whey to pigs (province of Salzburg)	
	DIL	185 Bq/L for ^{137}Cs in milk and fresh milk products but preference should be given to milk below 74 Bq/L ^{137}Cs for drinking purposes	Still valid
	DIL	370 Bq/kg for ^{137}Cs + ^{134}Cs in cheese and curds	Changed in June 1986
02.06.86	Feeding restriction	Prohibition to feed whey to pigs (all Austria)	Cancelled soon afterwards
03.06.86	DIL	185 Bq/kg for ^{137}Cs + ^{134}Cs in pork and poultry	Still valid
	DIL	555 Bq/kg for ^{137}Cs + ^{134}Cs in other meat (beef, veal, mutton, lamb, game, wild boar, etc.)	Changed 09.06.86

TABLE XVII (cont.)

Date	Type	Action	Validity
05.06.86	DIL	Changed to 74 Bq/kg for ^{131}I in vegetables, fruit, mushrooms and produce thereof	Still valid
	DIL	111 Bq/kg for ^{137}Cs in vegetables, fruit, mushrooms and produce thereof	Still valid except for nuts and currants
06.06.86	DIL	Changed to 592 Bq/kg (16 nCi/kg) for ^{137}Cs + ^{134}Cs in cheese	Still valid
09.06.86	DIL	592 Bq/kg for ^{137}Cs + ^{134}Cs in honey	Still valid
	DIL	Changed to 185 Bq/kg for ^{137}Cs in fresh cheese and curds	Still valid
	DIL	Changed to 592 Bq/kg for ^{137}Cs + ^{134}Cs in other meat besides pork and poultry (beef, veal, mutton, lamb, game, wild boar, etc.)	Still valid except for game (cancelled 15.07.86)
11.06.86	Shooting restriction	Cancellation of prolongation of close season for game if DILs were kept	15.07.86
12.06.86	Feeding restriction	Prohibition to feed whey to pigs (all Austria (restated))	
16.06.86	Consumption restriction	Warning against consumption of wild mushrooms	
	Consumption restriction	Recommendation to feed infants with infant food	
23.06.86	Feeding restrictions	Exceptions for prohibition of feeding whey to pigs if whey or skimmed milk with concentrations of less than 37 Bq/kg ^{137}Cs + ^{134}Cs was used and the DIL for meat was kept	

Date	Type	Action	Validity
26.06.86	Sales restriction	DIL for ^{137}Cs elevated to 370 Bq/kg (10 nCi/kg) for currants if sold to enterprises that produce jam, juice or fruit syrup thereof	
02.07.86	Consumption restriction	Recommendation to consume self-harvested wild mushrooms only up to 1 kg per month	
08.07.86	Consumption restriction	Recommendation for higher contaminated areas not to feed children with home grown fruit	
15.07.86	Restrictions on game	Cancellation of all restrictions on game and recommendation that adults could eat game in the normal small amounts, but the risk groups (pregnant and nursing women, infants and children) should consume game only rarely or not at all	
17.07.86	DIL	DILs for milk and milk products also valid for sheep's and goat's milk and cheese	
	Agricultural practice	Prohibition of using sewage sludge on agricultural areas	Partly changed to maximum levels
18.09.86	Sales restriction	DIL for nuts changed to 592 Bq/kg for $^{137}Cs + {}^{134}Cs$	Still valid
03.10.86	Monitoring	Live animal monitoring compulsory for beef and veal in larger slaughter-houses on a random basis	Until 30.06.87

Date	Type	Action	Validity
Autumn 1986	Feeding practice	On the basis of feeding experiments and fodder measurements feeding plans for the winter season 1986/1987 were set up by the Federal Ministry of Agriculture and Forestry. A programme to supply highly affected areas with low contamination feed was introduced	
Winter 1987/1988	Feeding practice	After animal tests with Giese salt showed no indication of cancer induction, this salt was used as a feed additive in an area with elevated milk contamination. It was not intended as a means to be able to keep in accordance with DILs but rather as an effectiveness study	
Summer 1988	Consumption restriction	Recommendation concerning restriction of consumption of wild mushrooms and game	

Besides a dose reduction for the average population in general, the implementation of DILs also served other purposes:

— protection of individuals or particular groups (limiting peak exposures);
— enforcement of countermeasures at the producer level;
— guidance for producers and consumers in a new area;
— protection of the domestic market from highly contaminated imports;
— facilitation of trade inside the country and of exports.

The DILs mentioned above are still valid in Austria. Since they have been derived in relation to the Chernobyl accident they would have to be revised in the event of another accident producing a different radionuclide composition.

15.2.2.6. Funding

Costs that arose from countermeasures, directly or indirectly, in general were covered by Government funds. Compensation for the disposal of food that exceeded a DIL was administered by local authorities.

... were financed by the Ministry of Agriculture and operated through the provincial Chambers of Agriculture (Landwirtschaftskammer). For instance, 180 000 t of relatively uncontaminated fodder for milk production and 20 600 t of corn silage for meat production were supplied at reduced prices to the most affected areas.

TABLE XVIII. EFFECTIVENESS OF COUNTERMEASURES IN AUSTRIA
(Average reduction of exposure, from Ref. [80], Table XXVI, abridged)

Countermeasure and radionuclide	Reduction of effective exposure (mSv)		
	Adult[a]	Child 5 y	Child 1 y
Prohibition of green fodder			
^{131}I	0.021	0.047	0.215
$^{137}Cs + ^{134}Cs$	0.012	0.004	0.010
Prohibition of sale of leafy vegetables			
All radionuclides	0.129	0.197	0.152
Warning against consumption of farmers' fresh milk			
^{131}I	0.009	0.020	0.094
$^{137}Cs + ^{134}Cs$	0.021	0.008	0.017
Selection of fresh milk with lower contamination			
^{131}I	0.009	0.020	0.094
$^{137}Cs + ^{134}Cs$	0.083	0.030	0.070
Feeding plans for milk production	0.027	0.010	0.024
Feeding plans for meat production	0.014	0.007	0.0012
DIL for ^{131}I in milk	0.0069	0.011	0.049
DIL for ^{137}Cs in milk	0.0011	0.004	0.001
DIL for ^{137}Cs in infant food	—	—	0.085
DIL for ^{137}Cs in vegetables and fruit	≤0.0046	≤0.015	≤0.019

[a] Average values for whole population.

15.2.2.7. 'Problem' areas in Austria in 1992

Until recently, milk from cows grazing on some Alpine pastures in Austria still surpassed the DIL of 185 Bq/L for ^{137}Cs. In general, such milk was not used for direct consumption but went into local cheese production. Owing to the rather low DIL for ^{137}Cs in mushrooms (111 Bq/kg), species such as *Xerocomus badius*, *Rozites caperata* and *Cantharellus cibarius* frequently surpass the limit and batches have to be destroyed. Relatively high concentrations of ^{137}Cs (a few thousand Bq/kg) still occur in game (especially in roe deer) in several Austrian forests. Since there is no DIL for game this does not pose an administrative problem.

In some areas, ^{137}Cs concentrations in milk still exceed 11.1 Bq/L which is the limit for milk used in infant foods.

15.2.2.8. Final remarks

After the Chernobyl accident a catalogue of countermeasures was compiled by the Austrian Radiation Protection Commission (Strahlenschutzkommission) giving general guidance for the establishment of emergency plans for cases of large accidental contamination. Estimates of their effectiveness are given in Table XVIII. This guidance is continually updated and is published by the Federal Ministry of Health, Sports and Consumer Protection (Bundesministerium für Gesundheit, Sport und Konsumentenschutz). To date it considers accidents in nuclear facilities, crashes of satellites with radioactive components (such as Cosmos 954) and crashes of airborne carriers of nuclear devices without detonation of the nuclear warhead (such as Palomares).

In addition, the warning system at Government level (which also deals with other non-nuclear events) has been improved since the accident. As an aid for decision making, the German radioecological model ECOSYS has been adapted to Austrian needs and will be available in the future.

15.2.3. Norway

15.2.3.1. Fallout and administrative responses

Winds from the south-east during the first few days following the Chernobyl accident, and heavy precipitation in parts of southern and central Norway gave rise to an uneven fallout pattern. The combined deposition of ^{134}Cs and ^{137}Cs in soil generally varied from 0 to 100 kBq/m^2, with local peak values up to 1000 kBq/m^2. The areas affected by the fallout were mostly seminatural ecosystems used as pasture for sheep, goats, reindeer and, to a lesser extent, cattle.

Because the accident occurred in early spring, cows were being fed indoors with clean fodder when the fallout occurred, so there was no contamination of milk by ^{131}I. Although a local ban on directly contaminated salad was introduced by the health authorities in May 1986, the major problems with agricultural produce were the contamination of sheep, goats, reindeer, freshwater fish, and to a lesser extent, cattle and milk, with ^{137}Cs.

Although the mean values for contamination were moderate, peak values in the most affected areas exceeded 1000 Bq/kg for cattle and cow's and goat's milk, 1000 Bq/kg for mutton and lamb, 50 000 Bq/kg for freshwater fish and 80 000 Bq/kg for reindeer meat.

15.2.3.2. Establishment of derived intervention levels for food and implementation of countermeasures

By June 1986, after consultation with radiation protection and agricultural experts, the food control authorities established DILs for foodstuffs. They were 370 Bq/kg for milk and infant food and 600 Bq/kg for all other foodstuffs. Later, following ad hoc consultations with radiation protection authorities and representatives of the saami population, the DIL for reindeer was raised to 6000 Bq/kg in November 1986 and the same figure was set for game and freshwater fish in July 1987.

Late in 1986, two permanent Advisory Committees were established, one for the authorities concerned with the implementation of different agricultural countermeasures and one for the food control authorities concerned with monitoring programmes, food control routines, statistics for sampling and evaluation of monitoring results and revisions of the DILs. The Advisory Committees consisted of scientific experts, representatives of different authorities and of farmers' and producers' organizations. The development of methods for monitoring live animals has been of the utmost importance for the establishment of a proper monitoring system. Local food control and agriculture authorities were later made responsible for performing the monitoring and evaluation of the data using procedures for sampling and evaluation developed and established by the central authorities.

Although countermeasures were introduced in 1986, about 5% of the lamb and some reindeer slaughtered in 1986 were discarded. Subsequently, more cost effective countermeasures for reducing the contamination of live animals were developed. The fallout areas were divided into different zones for the implementation of countermeasures of different duration.

The countermeasures applied were:

— feeding with uncontaminated fodder;
— the use of feed and feed concentrate additives (bentonite and hexacyanoferrates, especially Giese salt);
— the use of Giese salt in salt-licks and boli;
— slaughter of reindeer early in autumn when the levels were relatively low;
— dietary advice.

The countermeasures have been introduced to the farmers as recommendations through central and local agricultural authorities, local advisory institutions and farmers' organizations. At an early stage, it was decided that the farmers should be given proper economic compensation from the Government for all expenses connected with the countermeasures.

To avoid high doses to critical groups (reindeer breeders, hunters and those with restricted diets or who ate meat and fish which had not been monitored by the food control authorities), pamphlets containing dietary advice were distributed. The acceptance of the advice was very good, the recommendations were effective and the cost of this measure was low.

Proper optimization and correct choice of the most cost effective countermeasures at an early stage proved to be difficult or almost impossible. Therefore, the cost–benefit assessments were made after implementation. The overall conclusion in Norway is that the cost of the countermeasures introduced has been reasonable compared to the benefit in saved collective dose.

Discarding foodstuffs is relatively expensive, compared to the decontamination procedures for live animals which have been developed and implemented on a large scale in Norway.

15.2.3.3. Legislation

In Norway, it was necessary to establish the legal status of the DILs, and provide a basis for the use of feed additives (bentonite and Giese salt). The DILs were established within the general food safety law, while the legal status of the additives was established by the pharmaceutical authorities.

15.2.4. United Kingdom (England only)

15.2.4.1. Fallout and administrative responses

Levels of contamination in most of the United Kingdom were quite low after the Chernobyl accident. However, rainfall during the passage of the plume caused much higher deposition of radiocaesium (up to 40 kBq/m^2) in certain upland areas. Government responsibility in the United Kingdom is divided between the regions and this section covers England only. Widespread monitoring of the environment and food chain in the immediate post-accident period showed that no agricultural produce was contaminated to an unacceptable level. Derived emergency reference levels (DERLs) had previously been recommended for many foodstuffs by the National Radiological Protection Board, which gives the Government independent advice on radiation protection. Levels of ^{131}I in milk peaked at less than 20% of the DERL and the contamination of leafy vegetables remained below 1% of the DERL, so no immediate intervention was required.

monitoring in the most affected areas showed that radiocaesium levels in lambs in a few well defined upland areas continued to rise because of the recycling of caesium in low-mineral, peaty soils. In due course, it became necessary to impose restrictions on the movement of sheep in these areas. A method of live monitoring of animals was developed to assist the implementation of the restrictions, known as 'mark and release'.

Responsibility for agriculture and for food safety in England rests with the Ministry of Agriculture, Fisheries and Food (MAFF). The immediate response of MAFF was to initiate the widespread monitoring described above. There were administrative divisions already established with responsibility for response to emergencies, as well as a scientific unit specializing in radioactivity in the food chain, so no new emergency institutions were required.

15.2.4.2. Decision making

No formal processes of decision making were considered necessary. Any decision to impose restrictions on contaminated food lies solely with the Minister of Agriculture. Advice was formulated by the Ministry's Scientific Unit on the basis of monitoring results and the established DERLs. There was no predetermined DERL for radiocaesium in sheep meat. The Ministry's decision to use 1000 Bq/kg was based on recommendations formulated by the European Community's Group of Experts set up under Article 31 of the Euratom Treaty. This was considered to be well below any level of concern regarding public health and therefore adequate to reassure the public. As a precaution, the areas covered by the restrictions were originally drawn quite widely, and subsequently reduced when monitoring showed that it was appropriate to do so.

15.2.4.3. Legislation and regulation

At the time of the Chernobyl accident, the Food and Environment Act, 1985 (FEPA), already gave the Minister of Agriculture power to place restrictions on the harvesting, movement or sale of any agricultural produce which might be contaminated or in any way a risk to public health. No new legislation was needed to enable the Minister to impose restrictions.

Compensation to farmers placed under restriction is not a legal entitlement under FEPA. For an accident within the United Kingdom, liability is the responsibility of the site operator; under the special circumstances of the Chernobyl accident, the United Kingdom Government agreed to compensate farmers within the restricted area for the cost of complying with the control system, and for the reduction in the sales value of their animals.

15.2.4.4. Decision options and decision taking

In the years since the Chernobyl accident, the system of mark and release used for control in the restricted areas has been very effective in ensuring that no meat contaminated above the intervention level reaches the consumer. As a result, no other countermeasures are currently considered necessary. However, it is desirable to reduce the restricted areas as much as possible. Certain agricultural countermeasures, such as the administration of Prussian Blue boli, or chemical treatment of the soil, show promise. Advice on their application will be made within the normal decision making structure of the Ministry, which currently consists of ad hoc committees of the responsible administrators and scientists, together with representatives of Scotland, Wales and Northern Ireland.

TABLE XIX. SUMMARY OF MARK AND RELEASE RESULTS FOR SHEEP MOVING OUT OF THE CUMBRIAN RESTRICTED AREA

	1986[a]	1987	1988	1989	1990	1991	Total
Number of animals	28 490	73 156	92 878	104 861	105 564	107 552	512 501
Number of failures	3526	2372	739	326	160	136	7259
% of failures	12	3.2	0.85	0.31	0.15	0.13	1.42
Highest result (Bq/kg)	3089	3379	2594	1864	1459	1479	

[a] Start of the scheme, September to December 1986.

TABLE XX. SUMMARY OF SLAUGHTERHOUSE MONITORING SINCE SCHEME BEGAN IN FEBRUARY 1989[a]

	1989	1990	1991	Total
Number of animals	10 535	10 159	10 871	31 565
Mean activity (Bq/kg)	65	49	58	—
Highest activity (Bq/kg)	456	467	438	—

[a] From three Cumbrian and three Lancashire slaughterhouses.

The mark and release system has been very effective in ensuring that public health has been protected. It has also been effective in restoring public confidence, and consumption of British lamb remains at the same level as before the accident. The system enables the farmers in the affected areas to maintain normal agriculture. Data concerning the monitoring programme are presented in Tables XIX and XX.

The existence of restrictions on the remaining small areas of Cumbria and north Wales is not considered to be a significant problem. The mark and release system has largely solved the major problems posed by the Chernobyl fallout. A research and development programme continues on methods for reducing ^{137}Cs levels in herbage on affected land which would allow all restrictions to be lifted.

GLOSSARY

absorbed dose. The mean energy, $d\epsilon$, imparted by ionizing radiation to matter in a suitably small volume element divided by the mass, dm, of the matter in that volume element:

$$D = \frac{d\epsilon}{dm}$$

activity. The number, N, of spontaneous nuclear transformations occurring in a given quantity of a radioactive nuclide during an incremental interval of time, dt, divided by that interval of time:

$$A = \frac{dN}{dt}$$

becquerel. The SI derived unit of activity is one radioactive disintegration per second. It has dimensions of s^{-1}, and its relationship to the traditional special unit, the curie (Ci), is:

$$1\ \text{Bq} = 2.7027 \times 10^{-11}\ \text{Ci}$$

curie. A unit of activity which has been superseded by the becquerel (Bq). The curie is defined as:

$$1\ \text{Ci} = 3.7 \times 10^{10}\ \text{disintegrations per second} = 3.7 \times 10^{10}\ \text{Bq}$$

decay law. The fractional rate of decrease of the number of radioactive atoms of a specific radionuclide is constant, independent of the age of the radionuclide and the surroundings and characteristic of the particular radionuclide:

$$\lambda = \frac{-1}{N}\frac{dN}{dt}$$

where N is the number of radioactive atoms of a specific radionuclide at time t and λ is the decay constant for the radionuclide. This equation can be integrated to give:

$$N = N_0 e^{-\lambda t}$$

where N_0 is the number of radioactive atoms present at $t = 0$.

deterministic health effect. Health effects of which the probability of occurrence rises rapidly from zero to unity as the dose increases above some threshold of dose. The severity also rises with the dose above the threshold.

gray. The SI derived unit of absorbed dose of ionizing radiation, being equal to one joule of energy absorbed per kilogram of matter undergoing irradiation. It has dimensions of J/kg, and its relationship to the traditional special unit, the rad, is:

$$1\ \text{Gy} = 100\ \text{rad}$$

activity to decrease to half its value by that process.

ionizing radiation. Any radiation, consisting of directly or indirectly ionizing particles, or a mixture of both.

isotopes. Nuclides having the same atomic number (i.e. the same chemical element) but having different mass numbers (i.e. same Z, different A).

nuclide. Any given atomic species characterized by: (1) the number of protons, Z, in the nucleus; (2) the number of neutrons, N, in the nucleus; and (3) the energy state of the nucleus (in the case of an isomer).

rad. Unit of absorbed dose, which has been superseded by the gray (Gy). The rad is defined as:

$$1 \text{ rad} = 0.01 \text{ Gy} = 0.01 \text{ J/kg} \; (= 100 \text{ erg/g})$$

radionuclide. A radioactive nuclide.

relative biological effectiveness. A factor which allows for the fact that radiations with different specific ionizations, i.e. with different linear energy transfers, will produce different effects in an organism for the same absorbed dose.

rem. Unit of dose equivalent which is used only for radiation protection purposes and which has been superseded by the sievert (Sv).

sievert. Unit of absorbed dose equivalent (1 Sv = 100 rem).

specific activity. The number of spontaneous nuclear disintegrations per unit mass of a given material per unit time interval. Expressed in becquerels or curies per mole or per gram.

stochastic health effect. Health effects which typically include a wide range of cancers and hereditary effects. The probability of an individual or subsequent generations of an individual's descendants developing one of these effects increases with the dose received.

REFERENCES

[1] FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS, Radioactive Fallout in Soils, Crops and Food, Soils Bulletin No. 61, FAO, Rome (1989).

[2] Environmental Contamination Following a Major Nuclear Accident (Proc. Symp. Vienna, 1989), 2 vols, IAEA, Vienna (1990).

[3] WORLD HEALTH ORGANIZATION, Derived Intervention Levels for Radionuclides in Food, WHO, Geneva (1988).

[4] UNITED NATIONS, Sources, Effects and Risks of Ionizing Radiation (Report to the General Assembly), Scientific Committee on the Effects of Atomic Radiation (UNSCEAR), UN, New York (1988).

[5] INTERNATIONAL ATOMIC ENERGY AGENCY, Intervention Criteria in a Nuclear or Radiation Emergency, Safety Series No. 109 (in press).

[6] FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS/WORLD HEALTH ORGANIZATION, Codex Alimentarius, General Requirements, Section 6.1, Guideline Levels for Radionuclides in Foods Following Accidental Nuclear Contamination, Joint FAO/WHO Food Standards Programme, Rome (1991).

[7] INTERNATIONAL ATOMIC ENERGY AGENCY, Generic Intervention Levels for Protecting the Public in the Event of a Nuclear Accident or Radiological Emergency, Interim Report for Comment, IAEA-TECDOC-698, Vienna (1993).

[8] ORGANISATION FOR ECONOMIC CO-OPERATION AND DEVELOPMENT, Good Laboratory Practice in the Testing of Chemicals, OECD, Paris (1982).

[9] PROEHL, G., MUELLER, H., JACOB, P., PARETZKE, H.G., "The dynamic radioecological model ECOSYS: A tool for the management of nuclear accident consequences", Environmental Impact of Nuclear Accidents (Proc. 4th Symp. Cadarache, 1988), CEA Centre d'études nucléaires de Cadarache, Saint-Paul-lez-Durance (1988) B43–50.

[10] WILKINS, B.T., HOWARD, B.J., DESMET, G.M., ALEXAKHIN, R.M., MAUBERT, H., Strategies for the deployment of agricultural countermeasures, Sci. Total Environ. **137** 1-3 (1993) 1-8.

[11] SEGAL, M.G., Agricultural countermeasures following deposition of radioactivity after a nuclear accident, Sci. Total Environ. **137** 1-3 (1993) 31–48.

[12] EDLEY, M.T., Review of SPADE Soil–Plant–Animal Models, ANS Rep. 2274-Rl to Ministry of Agriculture, Fisheries and Food, Associated Nuclear Services, Epsom, UK (1990).

[13] ARNOLD, L., Recommendations for Reduction of Agricultural Impact Subsequent to a Nuclear Accident, ANS Rep. 2387-R2 to Ministry of Agriculture, Fisheries and Food, Associated Nuclear Services, Epsom, UK (1991).

[14] WILLDROT, C., Agrotechnical countermeasures to be applied before and during deposition of radioactive fallout, Sci. Total Environ. **137** 1-3 (1993) 21-29.

[15] PRISTER, B.S., LOSHCHILOV, N., PEREPELYATNIKOVA, L., PEREPELYATNIKOV, G., BONDAR, P., Efficiency of measures aimed at decreasing the contamination of agricultural products in areas contaminated by the Chernobyl accident, Sci. Total Environ. **112** (1992) 79-87.

[16] PRISTER, B.S., PEREPELYATNIKOV, G.P., PEREPELYATNIKOVA, L.V., Countermeasures used in the Ukraine to produce forage and animal food products with radionuclide levels below intervention limits after the Chernobyl accident, Sci. Total Environ. **137** 1-3 (1993) 183–198.

[17] SANDALLS, F.J., "Review of countermeasures used in agriculture following a major nuclear accident", Environmental Contamination Following a Major Nuclear Accident (Proc. Symp. Vienna, 1989), IAEA, Vienna (1990) 129–140.

[18] CHAMBERLAIN, A.C., Radioactive Aerosols, Cambridge Environmental Chemistry Series 3, Cambridge University Press, Cambridge (1991).

[19] VOVK, I.F., BLAGOYEV, V.V., LYASHENKO, A.N., KOVALEV, I.S., Technical approaches to decontamination of terrestrial environments in the CIS (former USSR), Sci. Total Environ. **137** 1-3 (1993) 49-63.

[20] VAN DORP, F., ELEVELD, R., FRISSEL, M.J., Agricultural Measures to Reduce Radiation Doses to Man Caused by Severe Nuclear Accidents, ITAL Wageningen Rep. EUR 7370 EN, Commission of the European Communities, Luxembourg (1980).

[21] JONES, B.E.V., Management methods of reducing radionuclide contamination of animal food products, Sci. Total Environ. **137** 1-3 (1993) 227–233.

[22] LENGEMANN, F.W., WENTWORTH, R.A., COMAR, C.L., "Physiological and biochemical aspects of the accumulation of contaminant radionuclides in milk", Lactation: A Comprehensive Treatise, Vol. 3, Nutrition and Biochemistry of Milk Maintenance (LARSON, B.L., SMITH, V.L., Eds), Academic Press, London (1974) 159–215.

[23] VOIGT, G., Chemical methods to reduce the radioactive contamination of animals and their products in agricultural ecosystems, Sci. Total Environ. **137** 1-3 (1993) 205–225.

[24] LENGEMANN, F.W., Metabolism of radioiodine by lactating goats given iodine-131 for extended periods, J. Dairy Sci. **53** (1970) 165–170.

[25] WATSON, E.C., NELSON, I.C., WOOD, C.H., McCLELLAN, R.O., BUSTAD, L.K., Effect of varying stable iodine in diets of cows fed ^{131}I on uptake of ^{131}I in man drinking the milk: An abstract, Health Phys. **9** (1963) 1419.

[26] MAUBERT, H., VOVK, I., ROED, J., ARAPIS, G., JOUVE, A., Reduction of soil-plant transfer factors: Mechanical aspects, Sci. Total Environ. **137** 1-3 (1993) 163-167.

[27] JOUVE, A., SCHULTE, E., BON, P., CARDOT, A.L., Mechanical and physical removing of soil and plants as agricultural mitigation techniques, Sci. Total Environ. **137** 1-3 (1993) 65-79.

[28] ARNOLD, L., Methods to Reduce Agricultural Impact Subsequent to a Nuclear Accident, ANS Rep. 2367-RI to Ministry of Agriculture, Fisheries and Food, Associated Nuclear Services, Epsom, UK (1990).

[29] JOUVE, A., MAUBERT, H., MILLAN-GOMEZ, R., KUTLAKHMEDOV, Y., "Rehabilitation of soils and surfaces after a nuclear accident, some techniques tested in the Chernobyl zone", paper presented at Int. Conf. on Nuclear Waste Management and Environmental Remediation, Prague, 1993.

[30] DAVYDCHUK, V., "The natural conditions of the experiment on soil deactivation by the method of contaminated layer removal", Strategies of Decontamination, Annual Report to Commission of the European Communities DGXII (MAUBERT, H., Ed.), CEC Contract No. COSU-CT92-0018, Cadarache, France (1992) 12.

[31] SMITH, C.B., LAMBERT, J.A., "Technology and costs for cleaning up land contaminated with plutonium", Selected Topics: Transuranium Elements in the General Environment, Technical Note ORP/CSD-78-1, Environmental Protection Agency, Washington, DC (1978) 490–545.

[32] ALEXAKHIN, R.M., et al., Change in land use and crop selection, Sci. Total Environ. **137** 1-3 (1993) 169-172.

[33] ØHLENSCHLÄGER, M., The Transfer of Radionuclides in the Terrestrial Environment, Rep. Risø-M-2934, Risø Natl Lab., Roskilde (1991).

[34] ALEXAKHIN, R.M., Countermeasures in agricultural production as an effective means of mitigating the radiological consequences of the Chernobyl accident, Sci. Total Environ. **137** 1-3 (1993) 9-20.

[35] DESMET, G.M., VAN LOON, L.R., HOWARD, B.J., Chemical speciation and bioavailability of elements in the environment and their relevance to radioecology, Sci. Total Environ. **100** (1991) 105-124.

[36] NISBET, A.F., et al., Application of fertilizers and ameliorants to reduce soil to plant transfer of radiocaesium and radiostrontium in the medium to long term: A summary, Sci. Total Environ. **137** 1-3 (1993) 173-182.

[37] LEMBRECHTS, J., A review of literature on the effectiveness of chemical amendments in reducing the soil-to-plant transfer of radiostrontium and radiocaesium, Sci Total Environ. **137** 1-3 (1993) 81-98.

[38] NISBET, A.F., Effects of soil-based countermeasures on solid-liquid equilibria in agricultural soils contaminated with radiocaesium and radiostrontium, Sci. Total Environ. **137** 1-3 (1993) 99-118.

[39] KONOPLEV, A.V., et al., Influence of agricultural countermeasures on the ratio of different forms of radionuclides in soil and soil solution, Sci. Total Environ. **137** 1-3 (1993) 147-162.

[40] MINOTTI, P.L., CRAIG, D., KACKSON, W.A., High caesium uptake in wheat seedlings cultured with ammonium, Soil Sci. Soc. Am., Proc. **29** (1965) 220-221.

[41] EVANS, E.J., DEKKER, A.J., Effect of nitrogen on caesium-137 in soils and its uptake by oat plants, Can. J. Soil Sci. **49** (1968) 349-355.

[42] COMMISSION OF THE EUROPEAN COMMUNITIES, Comparative Assessment of the Environmental Impact of Radionuclides Released during Three Major Nuclear Accidents: Kyshtym, Windscale and Chernobyl, Rep. EUR 13574, CEC, Luxembourg (1991).

[43] INTERNATIONAL UNION OF RADIOECOLOGISTS, Effects of Countermeasures on Radionuclides Transfer to Animal Products, Working Group on Plant-Animal Transfer, Contract Report to Commission of the European Communities, DGXI (in press).

[44] WARD, G.M., JOHNSON, J.E., Validity of the term transfer coefficient, Health Phys. **50** (1986) 411-414.

[45] INTERNATIONAL ATOMIC ENERGY AGENCY, Handbook of Parameter Values for the Prediction of Radionuclide Transfer in Temperate Environments, Technical Reports Series No. 364, IAEA, Vienna (1994).

[46] COUGHTREY, P.J., Radioactivity Transfer to Animal Products, ANS Rep. 2223-RI to the Commission of the European Communities, DGXI, Associated Nuclear Services, Epsom, UK (1990).

[illegible], HOWELL, H., TEMPLETON, W.L., "District surveys following the Windscale accident", Proceedings of the Second United Nations International Conference on the Peaceful Uses of Atomic Energy, Vol. 18, United Nations, New York (1958) 296–308.

[76] CRICK, M.J., LINSLEY, G.S., An assessment of the 1957 Windscale accident reactor fire, Int. J. Radiat. Biol. **46** (1984) 479–506.

[77] IRANZO, E., ESPINOSA, A., IRANZO, C., "Evaluation of remedial actions taken in agricultural area contaminated by transuranides", Impact des accidents d'origine nucléaire sur l'environnement (Proc. 4th Symp. Cadarache, 1988), Vol. 2, CEA, Centre d'études nucléaires de Cadarache, Saint-Paul-lez-Durance (1988) F-1.

[78] ROMANOV, G.N., NIKIPELOV, B.V., DREZHKO, E.G., "Establishing criteria for judging the effectiveness of radiation protection measures following the Kyshtym accident", Proc. Int. Sem. on Intervention Levels and Countermeasures for Nuclear Accidents, 1991, Rep. EUR 14469, Commission of the European Communities, Luxembourg (1992) 155–181.

[79] INTERNATIONAL ADVISORY COMMITTEE, The International Chernobyl Project, Technical Report, IAEA Vienna (1991).

[80] MÜCK, K., "Abschätzung der Effektivität der nach dem Reaktorunfall ergriffenen Gegenmaßnahmen", Die Auswirkungen des Reaktorunfalls in Tschernobyl auf Österreich — Folgestudien, Forschungsberichte 6/89, Bundeskanzleramt, Vienna (1989) Section 7.

BIBLIOGRAPHY

RECENT SUMMARIES OF INFORMATION ON RADIOLOGICAL COUNTERMEASURES

ARNOLD, L., Methods to Reduce Agricultural Impact Subsequent to a Nuclear Accident, ANS Rep. 2367-Rl to Ministry of Agriculture, Fisheries and Food, Associated Nuclear Services, Epsom, UK (1990).

ARNOLD, L., Recommendations for Reduction of Agricultural Impact Subsequent to a Nuclear Accident, ANS Rep. 2387-R2 to Ministry of Agriculture, Fisheries and Food, Associated Nuclear Services, Epsom, UK (1991).

COUGHTREY, P.J., Land management following an accident, Proc. 2nd Int. IBC Seminar on Decommissioning of Nuclear Facilities, London, 1990, Associated Nuclear Services, Epsom, UK (1990).

DESMET, G. (Ed.), Improvement of Practical Countermeasures: The Agricultural Environment, Post Chernobyl Action, Final Rep. EUR 12554 EN, DGXII, Commission of the European Communities, Luxembourg (1991).

FNSEA/CNIEL, Agriculture, Environnement et Nucléaire: Comment Réagir en cas d'accident, Fédération Nationale des Syndicats d'Exploitants Agricoles, Centre Interprofessionnel de L'Economie Laitière, Paris (1990).

HOWARD, B.J., DESMET, G.M. (Eds), REACT: Relative Effectiveness of Agricultural Countermeasure Techniques, Sci. Total Environ. **137** 1–3 (1993).

LEISING, C., WIRTH, E., "Evaluation of countermeasures", Environmental Contamination Following a Major Nuclear Accident (Proc. Symp. Vienna, 1989), Vol. 2, IAEA, Vienna (1990) 103–110.

SANDALLS, F.J., "Review of countermeasures used in agriculture following a major nuclear accident", Environmental Contamination Following a Major Nuclear Accident (Proc. Symp. Vienna, 1989), Vol. 2, IAEA, Vienna (1990) 129–140.

HANDBOOKS GIVING GUIDANCE TO FARMERS ON AGRICULTURAL COUNTERMEASURES

ALEXAKHIN, R.M., Guidelines for agricultural practice in contaminated areas of the Chernobyl area 1991–1995, Moscow (1991).

Radiological Emergency Information for Farmers, Food Processors and Distributors, United States Department of Agriculture/Federal Emergency Management Agency, Washington, DC (1989).

[47] BISHOP, G.P., BEETHAM, C.J., CUFF, Y.S., Review of Literature for Chlorine, Technetium, Iodine and Neptunium, NIREX Radioactive Waste Disposal Safety Studies, Rep. NSS/R193, Associated Nuclear Services, Epsom, UK (1989).

[48] HOWARD, B.J., BERESFORD, N.A., HOVE, K., Transfer of radiocaesium to ruminants in natural and semi-natural ecosystems and appropriate countermeasures, Health Phys. **61** (1991) 715-725.

[49] HOVE, K., et al., Countermeasures for reducing radioactive contamination of farm animals and farm animal products, Sci. Total Environ. **137** 1-3 (1993) 249-260.

[50] JACKSON, D., JONES, S.R., "Reappraisal of environmental countermeasures to protect members of the public following the Windscale Nuclear Reactor Accident, 1957", Comparative Assessment of the Environmental Impact of Radionuclides Released during Three Major Nuclear Accidents: Kyshtym, Windscale and Chernobyl, Rep. EUR 13574, Commission of the European Communities, Luxembourg (1991) 1015-1039.

[51] SINGLETON, D.L., et al., Development of a laboratory method to predict rapidly the availability of radiocaesium, Analyst **117** (1992) 505-509.

[52] HOWARD, B.J., Management methods of reducing radionuclide contamination of animal food products in semi-natural ecosystems, Sci. Total Environ. **137** 1-3 (1993) 249-260.

[53] BERTILSSON, J., ANDERSSON, I., JOHANSON, K.J., Feeding green-cut forage contaminated by radioactive fallout to dairy cows, Health Phys. **55** (1988) 855-862.

[54] FIRSAKOVA, S.K., Effectiveness of countermeasures applied in Belarus to produce milk and meat with acceptable levels of radiocaesium after the Chernobyl accident, Sci. Total Environ. **137** 1-3 (1993) 199-203.

[55] JOHANSON, K.J., BERGSTROM, R., VON BOTHMER, S., KARDELL, L., "Radiocaesium in Swedish forest ecosystems", The Chernobyl Fallout in Sweden (MOBERG, L., Ed.), Swedish Radiation Protection Institute, Stockholm (1991) 477-486.

[56] HOVE, K., Chemical methods for reduction of the transfer of radionuclides to farm animals in semi-natural environments, Sci. Total Environ. **137** 1-3 (1993) 235-248.

[57] JOHNSON, J.E., WARD, G.M., FIRESTONE, E., KNOX, K.L., Metabolism of radioactive caesium (^{134}Cs and ^{137}Cs) and potassium by dairy cattle as influenced by high and low forage diets, J. Nutr. **94** (1968) 282-288.

[58] VAN DER BORGHT, O., COLARD, J., VAN PUYMBROECK, S., KIRCHMANN, R., "Recontamination from milk in piglets (swine): Influence of sodium alginate on the ^{85}Sr/^{134}Cs ratio of the body burden and on the comparative ^{85}Sr/^{45}Ca absorption", Radioecological Concentration Processes (ABERG, B., HUNGATE, F.P., Eds), Pergamon Press, Oxford and New York (1967) 583-593.

[59] THOMPSON, J.C., WENTWORTH, R.A., COMAR, C.L., "Control of fallout contamination in the post attack diet", Proc. Symp. on Survival of Food Crops and Livestock in the Event of Nuclear War (BENSON, B.W., SPARROW, A.H., Eds), Brookhaven Natl Lab., NY (1970) 566-595.

[60] MATTSSON, S., MOBERG, L., "Fallout from Chernobyl and atmospheric nuclear weapons tests: Chernobyl in perspective", The Chernobyl Fallout in Sweden. Results from a Research Programme on Environmental Radiology (MOBERG, L., Ed.), Swedish Radiation Protection Institute, Stockholm (1991) 591-627.

[61] STRAND, P., SELNAES, T.D., BCE, E., HARBITZ, O., ANDERSSON-SORLIE, A., Chernobyl fallout: internal doses to the Norwegian population and the effect of dietary advice, Health Phys. **63** (1992) 385-392.

[62] FOULQUIER, L., Etude bibliographique sur la capacité et les modalitées de la fixation de radiocaesium par les poissons, Rep. CEA-BIB-231 (2), Commissariat à l'énergie atomique, Paris (1979).

[63] LAMBRECHTS, A., Essai de modelisation du transfert du césium 137 dans les compartiments d'un écosystème d'eau douce simplifié, Rep. CEA-R-5268, Commissariat à l'énergie atomique, Paris (1986).

[64] ELLIOTT, J.M., et al., Radioactivity in fish from two Cumbrian lakes after Chernobyl: Sources of variability within the data, J. Appl. Ecol. **29** (1992) 108-120.

[65] DAVISON, W., HILTON, J., HAMILTON-TAYLOR, J., LIVENS, F., KELLY, M., Measurement, interpretation and modelling of Cs-137 transport through two freshwater lakes after Chernobyl, J. Environ. Rad. **19** 2 (1993) 125-153.

[66] GUILLITTE, O., et al., Decontamination methods for reducing radiation doses arising from radioactive contamination of forest ecosystems: A summary of available countermeasures, Sci. Total Environ. **137** 1-3 (1993) 307-314.

[67] GUILLITTE, O., WILLDROT, C., An assessment of experimental and potential countermeasures to reduce radionuclide transfers in forest ecosystems, Sci. Total Environ. **137** 1-3 (1993) 273-288.

[68] TIKHOMIROV, F., SCHCHEGLOV, A.I., SIDOROV, V.P., Forests and forestry: Radiation protection measures with special reference to the Chernobyl accident zone, Sci. Total Environ. **137** 1-3 (1993) 289-305.

[69] SHAW, G., Blockade by fertilizers of caesium and strontium uptake into crops: effects on the root uptake process, Sci. Total Environ. **137** 1-3 (1993) 119-133.

[70] RAVILA, A., HOLM, E., Flux of radionuclides in the forest industry, Sci. Total Environ. (in press).

[71] NOORDIJK, H., QUINAULT, J.M., "The influence of food processing and culinary preparation on the radionuclide content of foodstuffs: a review of available data", First Report of the VAMP Terrestrial Working Group, IAEA-TECDOC-647, Vienna (1992) 35-59.

[72] CAWSE, P.A., BAKER, S.J., GRANDISON, A.S., LEWIS, M.J., PATEL, S., "The influence of processing on the radionuclide content of food", Proc. Int. Sem. on Intervention Levels and Countermeasures for Nuclear Accidents, Rep. EUR 14469, Commission of the European Communities, Luxembourg (1992) 271-288.

[73] STRAND, P., BRYNILDSEN, L.I., HARBITZ, O., TVETEN, U., "Measures introduced in Norway after the Chernobyl accident: A cost benefit analysis", Environmental Contamination Following a Major Nuclear Accident (Proc. Symp. Vienna, 1989), Vol. 2, IAEA, Vienna (1990) 191-202.

[74] BENGTSSON, G.B., "Reduction of radionuclides in foodstuffs", Radioaktivt nedfall fra Tsjernobyl-ulykken. Følger norsk landbruk, naturmiljø og matforsyning (GARMO, T.H., GUNNERØD, T.B., Eds), Norges Landbruksvitenskapelige forskningsråd, Trondheim (1992) 129-148.