AGRICULTURAL COUNTERMEASURES

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One of the lessons of Chernobyl is that farming is vulnerable to the effects of a nuclear accident hundreds, even thousands, of miles away from the site. Therefore plans are needed for countermeasures that can reduce contamination of agricultural produce, regardless of whether or not a country has its own nuclear programme. The primary aims of such plans should be to minimize radioactive contamination of crops and animal products and return the land to productive use as far as, and as soon as, possible. These aims must balance the costs to governments with the benefits to human health, and the disruption to daily life with the well-being of communities. The plans need to specify radiation levels for foods and feedstuffs at which intervention is necessary and to include a range of countermeasures to be taken to protect agriculture under a range of possible post-accident situations.

Criteria for setting intervention levels have been established internationally. In general, food legislation prohibits unsafe levels of contamination and does not distinguish between contaminants whether they are pesticide residues, heavy metals, mycotoxins, pathogenic microorganisms, or radionuclides. At low levels of contamination, where the risk to health is low or difficult to eliminate altogether, contaminant levels are set which allow for foods to be sold, bought, and consumed. The limits must be unambiguous so that they can be easily understood by all concerned in administering them.

The FAO/WHO Codex Alimentarius Commission has developed international standards for radionuclide contamination to be applied to food moving in international trade. *(See table.)* Many countries have adopted these in their national legislation, not least because internationally recognized intervention levels help to maintain credibility, confidence, and trust in national authorities and prevent anomalies that might otherwise occur along borders of neighbouring countries. In addition Codex standards will be applied by the World Trade Organization.

The levels are based on a number of conservative assumptions in order to be confident that there will be essentially no effect over a lifetime of exposure. Hence, if alternative food is not available, higher values would be acceptable in the short term. On the other hand, lower levels may be appropriate, for example if external radiation makes a high contribution to the total dose.

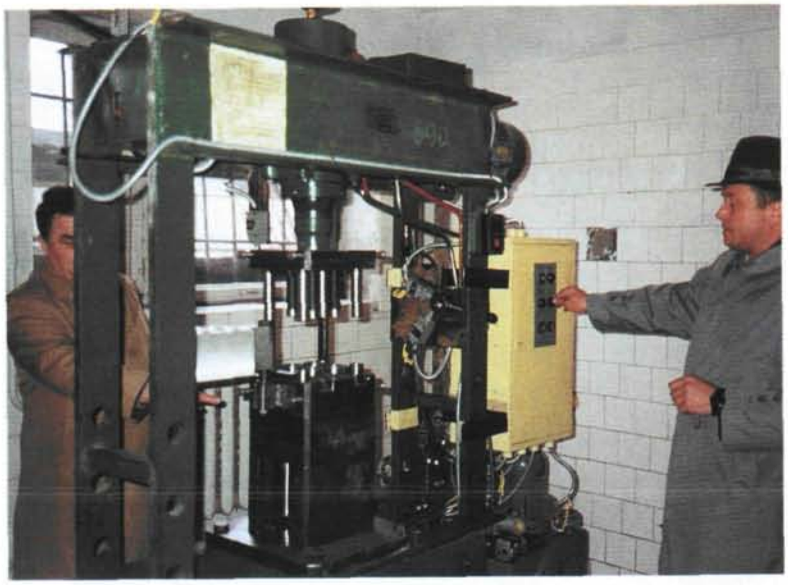
Against this background it can be seen that an important purpose of agricultural countermeasures is to maximize the quantity of food produced which passes intervention criteria.

Agricultural countermeasures

The Joint FAO/IAEA programme on nuclear techniques in food and agriculture has approached agricultural countermeasures in three ways. The first was to bring together as much as possible of the information and experience acquired after the Chernobyl accident in order to prepare guidelines for agricultural countermeasures. The second was to assist affected Member States to develop and implement particular countermeasures. The third was to support work to generate data that can be used to refine existing countermeasures or develop new ones.

Guidelines for Agricultural Countermeasures Following an Accidental Release of Radionuclides (IAEA Technical Reports Series No. 363, 1994). The Chernobyl accident stimulated considerable scientific research and much practical experience was obtained by those dealing with its consequences. This document, prepared by nearly 40 scientists from 19 countries, summarizes the information generated. It aims to give general advice on the development of emergency response plans. The main elements are a general strategy for the introduction of agricultural countermeasures, a review of available countermeasures for use in decision-making, and guidance for the preparation of specific national guidelines. (A Russian translation of the document is available as IAEA TEC-DOC-745.)

The effectiveness of measures taken to protect the agricultural sector (people, land, crops and livestock) from the effect of a nuclear accident depends on plans prepared in advance. The *Guidelines* outline a strategy for the development of such emergency plans which should not



In southern Belarus, where areas were affected by radioactive fallout from the Chernobyl accident, small farmholders are applying countermeasures to reduce levels of contamination in milk, meat, and other products. They are being assisted through projects supported by the Norwegian government and the FAO/IAEA programme. Shown here is a typical small farm in the region; equipment for mixing "Prussian Blue" compounds and for making boli which are used to reduce radiocaesium levels in cows; and scientists monitoring the body gamma radiation of livestock given Prussian Blue. *(Credit: Richards/IAEA)*

Guideline levels for radionuclides in foods following accidental nuclear contamination for use in international trade

Dose per unit intake factor	Representative radionuclides	Level (Bq/kg)
	Foods destined for general consumption	
10^{-6}	Americium-241, Plutonium-239	10
10^{-7}	Strontium-90	100
10^{-8}	Iodine-131, Caesium-134, Caesium-137	1000
	Milk and infant foods	
10^{-5}	Americium-241, Plutonium-239	1
10^{-7}	Iodine-131, Strontium-90	100
10^{-8}	Caesium-134, Caesium-137	1000

Notes These levels are designed to be applied only to radionuclides contaminating food moving in international trade following an accident and not to naturally occurring radionuclides which have always been 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

only specify criteria for taking prompt short-term action but also criteria for longer term action which will do much to sustain public confidence in the competence and integrity of the authorities

The *Guidelines* recognize two distinct phases in which to consider countermeasures. In the planning and preparation of responses to an accident, possible protective actions should be assessed in a general way in relation to a range of credible accident scenarios. From this, the first criteria for action to be used immediately and for a short time after an accident can be developed. These plans require a database which includes information about the transfer of the radioisotopes of caesium and strontium between local soil, water, plants, animals, and fish. These are the isotopes most likely to cause more than transient problems to agriculture. In addition, data on soils, weather patterns, local dietary preferences, and some feasible countermeasures with estimates of their costs should be included A network of laboratories for radionuclide analysis must also be identified.

The second phase begins some time after a real accident has happened when specific information on its nature and likely consequences is available. Specific protective measures can then be considered. However, in many cases the choice of countermeasures will be constrained by social factors and infrastructure of the region, so it is important that the database for decision-making includes this information too.

The *Guidelines* then go on to consider particular agricultural countermeasures with some assessment of their efficacy. Such countermeasures address long-term health effects in the human population; the more immediate impact of radiation exposure on plant and animal life is not directly considered.

Some measures can be taken before and during deposition of radioactive fallout, such as housing animals and covering feed/food stores. Given adequate warning, it may be possible to harvest a crop (grass, grain, cash crop) before deposition occurs.

Countermeasures applied during the first few weeks after deposition are concerned particularly with reducing exposure from short-lived radionuclides such as iodine-131. Thus, crops may be harvested and stored, or harvesting may be delayed, to allow for radioactive decay before consumption. Similarly, milk contaminated with iodine-131 can be converted to storable products (e.g. milk powder, cheese).

Once radioactive contamination is distributed through the biosphere, a wider range of countermeasures needs to come into play which takes into consideration the transfer of the relevant radionuclides from soils into the food chain. For example, since mineral uptake by plants is related to the total available and relative abundance of their different ions, the application of high levels of potassium fertilizer can reduce radiocaesium uptake; and liming, by increasing calcium levels can reduce radiostrontium uptake. Sometimes it is possible to use alternative crops or varieties that accumulate lower levels of radionuclides than those normally grown in a region — for example, cereals in place of leafy vegetables and pasture Another possibility is to grow crops such as sugar-beet or oilseed rape where the edible product is processed and contamination reduced. In order to maintain some form of agriculture wherever possible, the production of non-food crops such as flax and cotton for fibre, oilseed for lubricants or biofuel, and ornamental plants must be considered. Finally, burying the contaminated surface of the land by deep ploughing can be an effective procedure for large farms provided the proper ploughs are available

Contamination of animal products can be reduced most effectively by limiting their intake of radionuclides or reducing their absorption. Feeding uncontaminated stored feedstuffs is an example of the first category while the use

Level of pasture contamination (Bq/kg)	*Intake/day (kBq)	Meat		Milk	
		Caesium-137 level equilibrium (Bq/kg)	Caesium-137 level following boli (Bq/kg)	Caesium-137 level equilibrium (Bq/kg)	Caesium-137 level following boli (Bq/kg)
250	17.5	280	90	112	34
500	36	700	234	280	94
1,000	70	1,400	450	550	186
1,500	105	2,100	700	840	280
2,000	140	2,800	920	1,120	374
3,000	210	4,200	1,400	1,680	560
5,000	350	7,000	3,000	2,800	920
10,000	700	14,000	4,600	5,600	1,860

The table illustrates the relationship between levels of pasture contamination and caesium-137 levels in meat and milk, and the effect on meat and milk levels of administering boli.

*Assumes daily intake of 70 kg fresh herbage/animal.

Effects of countermeasures on caesium-137 levels in milk and meat

of Prussian Blue (discussed in more detail later) is an example of the latter. In the case of meat-producing animals, feeding uncontaminated feed may only be necessary close to the time of slaughter since the biological half-life of radiocaesium, for example, is of the order of two to four weeks depending on the species. Ideally this should be supplemented by monitoring live animals in the slaughterhouse or at the farm to identify those that require a further period of feeding with uncontaminated feed. With game animals, changing the hunting season may be effective where the animals have seasonal feeding habits. For example, mushrooms and lichens, which can be highly contaminated, are frequently most abundant in the autumn, so animals should not be hunted during this period.

These are merely examples of countermeasures; there are many more possibilities. However, decisions on whether to apply countermeasures and which ones are appropriate require information about the nature and extent of radioactive contamination. As a considerable infrastructure is necessary to produce an effective response, a large section of the *Guidelines* is concerned with organizational structures. Finally, the document briefly reviews the responses of selected countries to the Chernobyl accident.

Assistance with countermeasures in contaminated areas

The application of many different countermeasures in Belarus, Ukraine, and western Russia following the Chernobyl accident led to a significant reduction in radiocaesium contamination of milk and meat produced on State and collective farms. However, many of the countermeasures were difficult to apply by small-scale farmers for economic reasons. In 1990 up to 50,000 dairy cows were still producing milk that exceeded temporary permissible levels, or TPLs, (111 Bq/L in Belarus; 370 Bq/L in Ukraine and Russia). Therefore, an alternative approach was required which was simple, effective, and cheap.

A project sponsored by the Norwegian Government developed a countermeasure to lower the levels of radiocaesium in both domesticated and game ruminants using a mixture of compounds known as "Prussian Blue" (PB). Executed through the United Nations, the project involved the Norwegian Agricultural University and Radiation Hygiene Institute, the Ukrainian Research Institute of Agricultural Radiology in Kiev, the Belarussian Branch of the All-Union Institute of Agricultural Radiology in Obninsk, and Queen's University, Belfast. The IAEA's Seibersdorf Laboratories, the Joint FAO/IAEA Division of Nuclear Techniques in Food and Agriculture, and the IAEA's Division of Nuclear Safety provided co-ordination, expert services, equipment, and materials to the major counterpart institutes in three countries for conducting trials in the worst affected villages.

Successful trials were conducted in 1990-92 involving over 3,000 cows in 21 settlements in Belarus, 10,000 cows in 54 settlements in the Ukraine, and an unspecified number of cattle in villages in Russia. Thereafter, each State's

Benefit	Comment
Individual dose reduction	Overall reduction of about 60% (probably more than 80% in areas where the uptake factor from soil to grass is particularly high)
Collective dose	Perhaps a few hundred man Sv; relatively small because of the extremely low TPLs being used in the CIS. Nevertheless it is cost effective
Additional milk production	An additional 50 million litres of milk per annum would meet TPLs without the need for distribution of "clean" feed and milk.
Clean feed needed for milk production	The time needed for "clean feeding" could be reduced by 40-50 days, resulting in a reduction by a factor of 5 of the area of "clean" pasture needed.
Social/psychological	Some 50,000 farmers could return to traditional farming practices with a corresponding increase in their sense of well-being and improvement in their quality of life. Many farmers destined for translocation would no longer have to move house.
Compensation	The number of individuals receiving compensation for exceeding an annual criterion could be reduced by approximately 50%.

Summary of benefits of using Prussian Blue compounds

Minister of Agriculture authorized the widespread use of PB in livestock for reducing the content of caesium-137 in milk and meat.

The term "Prussian Blue" refers to a number of ferric hexacyano ferrates; ammonium ferric cyanoferrate (or AFCF) is perhaps the most commonly used caesium-binding compound. Given as a bolus into the rumen, in compounded concentrate feed, in salt licks, or simply sprinkled on the diet, AFCF reacts with consumed radiocaesium in the intestine to form a complex that is eliminated in the dung instead of passing into the animal's blood stream. The PB bound radiocaesium in dung is only slowly available to plants. Depending on the dose and type of PB compound given, radiocaesium reductions of two to eight times can be achieved in milk and meat from cattle grazing contaminated fodder. This significantly reduces the internal dose to the human consumer and is often enough to allow village communities to remain in contaminated areas. As a result, the need to translocate whole communities, with its attendant traumas, has been curtailed and huge costs have been averted. Not surprisingly, the benefits of employing PB compounds have been greatly welcomed by farmers and government alike.

While successful countermeasures have been applied on state and collective farms and foodstuffs with acceptably low radionuclide content are now grown on previously contaminated land, public acceptance of "clean" foods coming from these areas is still a problem. The Belarussian and Ukrainian authorities are thus anxious to use this land in other ways. Through its joint programme with Food and Agricultural Organisation, the IAEA's Technical Co-operation Department is currently supporting a project in Belarus to investigate the potential of oil seed crops (primarily rapeseed) as an alternative crop. Initial research indicates that oil produced from certain varieties of rapeseed on land with radiocaesium levels of 15-40 Ci/km^2 is devoid of the radionuclide (and radiostrontium); the contamination is restricted to the straw and residual oil seed meal. The Belarus authorities sowed about 20,000 hectares of contaminated land with rapeseed in 1995 and intend refining the oil into lubricants which currently have to be imported. Should the project be successful, the land area sown will be expanded two- to threefold for lubricant production.

IAEA assistance is also being given to Ukraine to improve the skills and facilities for the measurement, control, and consequently the reduction of radionuclides in foodstuffs. The programme is based on the Ovruch Milk Canning Integrated Works which processes 200-500 tons of milk per day, much of it from farms within the Chernobyl contaminated zone. The United States government is currently providing additional resources to assess a commercial magnetic separation system for decontaminating liquid milk.

Generation of data. Belarus is receiving assistance through the IAEA Technical Co-operation programme to obtain more data on the occurrence and migration of radionuclides in soils, forests, and water bodies. These will be used in forecasts of the likelihood of success and of the time required for the restoration of contaminated regions to normal economic activity.

Applying lessons learned

Values for the transfer of radionuclides between different components of the biosphere and experience in dealing with the consequences of a nuclear accident are largely confined to temperate regions, primarily in Europe. However, there are nuclear power stations in

In Belarus, an IAEA-supported technical co-operation project is investigating the use of rapeseed (in background) as an alternative rotation crop on some contaminated lands.
(Credit Richards/IAEA)

some parts of the world that could conceivably affect tropical countries in the event of an accident. Therefore, a Co-ordinated Research Programme (CRP) involving the IAEA Division of Radiation and Waste Safety and the Joint FAO/IAEA Division is in progress to measure transfer factors for radiocaesium and radiostrontium from soil to major tropical crops and also from water to tropical fish. These data will be of value for both planning countermeasures and for establishing permissible levels of radionuclides in industrial effluents in the tropics. There are also plans to establish a further CRP which will examine the efficacy in tropical conditions of countermeasures that have proved effective in Europe.

In devising and applying agricultural countermeasures, more consideration should be given to the management of the whole contaminated environment, especially forests and water bodies because of the interactions between them and agricultural land. There is a need to develop secondary reference levels (so-called "operational intervention levels") for animal feeds and pasture. This requires additional data on transfer factors or at least re-examination of existing knowledge.

A range of agricultural countermeasures is currently available to reduce the impact of radiocaesium contamination in the food chain. The same cannot be said for radiostrontium contamination. Considerable laboratory and field research and development are required to improve the situation. For example, a number of materials have been proposed for selectively absorbing/adsorbing strontium in foodstuffs but none can yet be recommended unequivocally because data are inadequate. Alternative approaches, such as filters and magnetic separators for liquid food products, are currently available commercially although they have not been evaluated critically under the conditions prevailing in the contaminated regions.

To conclude, the Chernobyl accident highlighted the need for each country to develop a set of agricultural countermeasures ready for immediate application in the event of a nuclear accident. Lessons have been learned on the usefulness of many countermeasures and the infrastructures needed to implement them. Work remains to be done to ensure that these lessons are applied. This is particularly important for tropical environments as most of our experience has been obtained in temperate climates. ❒