Reducing caesium contamination of food products in the Chernobyl area

Under a collaborative project involving the IAEA, FAO, and other bodies, Prussian Blue compounds are being used in Belarus, Russia, and Ukraine to reduce caesium levels in milk and meat products

Radioactive materials dispersed by the Chernobyl nuclear plant accident in April 1986 caused problems for many countries of Europe. Some were short-term problems related to iodine contamination. Others concerned the deposition of caesium-137, a long-lived radionuclide that migrates through the food chain and accumulates in milk and meat.

A number of countries are dealing with these problems today. In certain mountain areas of southern Norway, for example, reindeer and sheep were found in 1992 to be heavily contaminated with radioactive caesium. Levels of up to 20 000 becquerel per kilogram (Bq/kg) were measured in reindeer, and up to 10 000 Bq/kg in sheep. Following this discovery, a countermeasure was developed to lower the levels of radiocaesium in these animals, a method based on the use of compounds known as "Prussian Blue" (PB). PB in the form of bolus, salt lick, or concentrate is now being given routinely in Norway to between 100 000 to 150 000 sheep, 5000 reindeer, and 10 000 to 20 000 cattle.

In the three most heavily contaminated former Soviet republics — Belarus, Russia, and Ukraine — authorities have recently approved PB's widescale use for livestock to reduce the content of caesium-137 in milk and meat. The action was taken by each State's Minister of Agriculture in the summer of 1992, and followed successful experiments in 1990 and 1991, large-scale field trials, and training sessions. The trials involved 3000 cows in 21 settlements in the Leltchitsy region of Belarus; 10 000 cows in 54 settlements in the Rovno and Volyn regions of Ukraine; and cattle in seven districts in the south-west region of Russia.

The widespread use of PB now will be fully implemented at the beginning of the 1993 grazing season at all private farms in the territories affected by the Chernobyl fallout. Its application will allow significantly greater amounts of "clean" milk and meat to be made available to small farmers and their families, and to rural communities in the three States.

The work is being carried out within the framework of a collaborative project involving the IAEA, the Food and Agriculture Organization (FAO) of the United Nations, the Agricultural University and Radiation Hygiene Institute of Norway, the Ukrainian Research Institute of Agricultural Radiology in Kiev, the Byelorussian Branch of the All-Union Institute of Agricultural Radiology in Gomel, and the All-Union Institute of Agricultural Radiology in Obninsk. The project's implementation now is being led by the FAO, with the IAEA providing technical support. The Joint FAO/IAEA Division of Nuclear Techniques in Agriculture, the IAEA Division of Nuclear Safety, and the IAEA's Seibersdorf Laboratories have provided expert services, equipment, and materials to the major counterpart institutes in the three States for making boli.

This article highlights selected aspects of this project, one of many being conducted in conjunction with a co-ordinated effort of the United Nations as part of the ongoing international response to the Chernobyl accident. *(See box.)*

The context of problems

In Belarus, Russia, and Ukraine, there are two principal livestock production systems, dairy and beef, and each is practiced on both collective and private farms. *(See tables.)* After

This article is based on a draft technical document — *The Use of Caesium Binders to Reduce Radiocaesium Contamination of Milk and Meat from the Territories of Ukraine, Belarus, and the Russian Federation* Further information may be obtained from the Agriculture Laboratory of the IAEA's Seibersdorf Laboratories.

The continuing international response to Chernobyl

Nearly seven years after the Chernobyl accident in 1986, scientists, physicians, engineers, and other specialists from around the world are actively involved in more than 50 projects to assist people in the affected areas. They range from health and agricultural projects to nuclear plant safety reviews and economic and industrial development programmes. A number of them are being executed by international organizations and co-ordinated by a United Nations' Task Force on International Cooperation for Chernobyl. Others are being carried out by non-governmental organizations and national governmental institutes in Belarus, Russia, Ukraine, and other States of the former Soviet Union.

The list includes:

- an international programme on the health effects of the Chernobyl accident, initiated in 1990 by the World Health Organization (WHO) and chiefly funded by the governments of Japan and Finland. Several other health-related projects are being carried out in the Chernobyl area, including those funded by the International Federation of Red Cross and Red Crescent Societies, the Council of Europe, Japan's Sasakawa Foundation, and the governments of Germany, Netherlands, and France.
- a programme including some 30 projects, initiated by the United Nations Educational, Scientific and Cultural Organization (UNESCO). Also being developed is a project to create an economic and social development zone in Russia.
- an industrial development programme for Belarus, Russia, and Ukraine, proposed by the United Nations Industrial Development Organization (UNIDO) and awaiting funding.
- a Chernobyl humanitarian asistance and rehabilitation programme, initiated in 1990 by the International Federation of Red Cross and Red Crescent Societies, with funding support from the governments of Germany, United Kingdom, and Finland.
- a research programme on radiation effects of some 80 000 immigrants from the affected areas to Israel, being carried out by the Ben Gurion University, Beer-Sheba, Israel.
- a programme covering projects in radiation protection research, nuclear safety, and health-related consequences, being carried out by the Commission of the European Communities.
- studies related to leukaemia, epidemiology, and long-term health consequences, being carried out by the International Cancer Research Institute in Lyon, France.
- a bilateral assistance programme for studying the link between radiation exposure and thyroid cancer and leukaemia, carried out by the US Ministry of Health and Social Provision. Separately, similar studies are being done by the Cancer Registry, Ministry of Health, in Sweden.

For its part, the IAEA has a number of projects directed at improving the safety of nuclear power plants in the former Soviet Union and in Eastern Europe. In other areas, a project of the Joint FAO/IAEA Division on Nuclear Techniques in Agriculture on the use of Prussian Blue compounds to reduce caesium levels in milk and meat products in Belarus, Russia, and Ukraine is planned for full implementation in 1993. Also planned for 1993 is the publication of an international guide on agricultural countermeasures following the accidental release of radioactive materials into the environment. Much of the work follows the completion in 1991 of the International Chernobyl Project to assess the accident's radiological consequences; the project was undertaken under IAEA auspices by 25 countries and seven international organizations.

The faces of some families living in former Soviet republics visited by scientific teams during the 1990-91 International Chernobyl Project under IAEA auspices. (Credit: Pavlicek, IAEA)

Dairy cattle and milk production

	Total no. of animals in contaminated area	Average milk production/ animal (litres/annum)	Temporary premissible level, TPL (Bq/litre)	No. of animals above TPL
Belarus				
Collective	393 000	3 000	185	3 000
Private	84 000	3 600	185	26 000
Ukraine				
Collective	120 000	3 000	370	1 000
Private	120 000	3 000	370	20 000
Russian Federation				
Collective	200 000	2 700	370	500 - 1 000
Private	25 000	3 000	370	

Cattle used for meat production

	Total no. of animals in contaminated area	Animal weight at slaughter (kg)	Temporary permissible level, TPL (Bq/kg)	No. of animals above TPL
Belarus	700 000	420	600	4 400
Ukraine	500 000	400 -420	740	3 000
Russia	300 000	400 - 450	740	5 000

Note Data were recorded during field studies in 1991.

Overview of livestock in contaminated areas of Belarus, Russia, and Ukraine

the Chernobyl accident, many different countermeasures were instituted to ensure that foodstuffs produced for general consumption would have radiocaesium levels below each State's legal levels (called "temporary permissible levels" or TPLs).

For example, pastures have been improved on State and collective farms by deep ploughing and re-seeding of the land, and fertilizers have been applied to reduce the contamination of grassland. These improvements have led to a situation where the levels in milk and meat produced on these farms are mostly lower than the TPLs.

Nevertheless, in both Belarus and Ukraine, approximately 50 000 dairy cows (mostly kept by small-scale private farmers to provide milk for their families) are producing milk that exceeds the TPLs, which are 185 Bq/l in Belarus and 370 Bq/l in Ukraine. In Russia, only 3000 animals produce milk with levels above that State's TPL of 370 Bq/l.

In all three States, the sale, processing, and/or consumption of milk that exceeds these TPLs is illegal. Consequently, most (but not all) contaminated milk is either used directly for animal feeding or exchanged by the state/local authority for clean milk and used subsequently for animal feeding. There is currently no price difference between clean and contaminated milk.

The systems of marketing animals for meat are similar throughout the affected areas. Animals from collective and private farms are purchased by the state/local authority and gathered either at local abattoirs for slaughter or at fattening centres. As a rule, no distinction is made between the two types of production systems. Beef production and marketing are much less affected in the contaminated areas than is the case for milk. This is because animals generally are fed clean forage/grain for 2-3 months before slaughter, allowing time for contamination levels to fall below the TPLs. Nevertheless, even under this system around 12 000 animals per year exceed the TPLs for meat (600 Bq/kg in Belarus, and 740 Bq/kg in Ukraine and Russia). Consequently, these animals must be maintained on clean feeds for substantially longer periods and they are slaughtered only when acceptable levels are reached. Again, there is no price difference between clean and contaminated animals at the time of marketing, although in Belarus, any meat found to exceed the TPLs before distribution is sold at a fraction of the normal price.

In all three States and under all production systems, manure from animals kept in contaminated areas is used as fertilizer.

Associated with these post-Chernobyl changes in production and marketing of animal products, each State has introduced systems for monitoring radiation levels in animals, milk, and meat. Milk is monitored on entry to the dairy, and any that does not meet the appropriate standards is sent to collective farms for animal feed. In addition, milk from animals on private farms is monitored by local food hygiene authorities (under the Ministries of Health). At least 10 samples from 10% of the animals in each village are taken twice a month. Farmers are informed of the results, and they receive compensation from the State when the milk is contaminated above the TPL.

The control of meat contamination also is systemized. When a private farmer wishes to sell an animal for slaughter, it is sent to a centre for screening by local authorities. It is then fed on clean fodder for 2 to 3 months or until its bodily caesium content falls below a pre-defined criterion (which may require further months of feeding).

While such feeding practices guarantee production of meat that complies with the TPLs for radiocaesium, they are not problem free. There are severe shortages of concentrate feeds (estimated at 4 million tonnes in Belarus alone). Moreover, the active privatization of land will

Relationship between levels of pasture contamination and caesium-137 levels in milk and meat, and the effect of administering PB boli

		Meat		Milk	
Level of pasture contamination (Bq/kg)	* Intake per day (kBq)	Caesium-137 level equilibrium (Bq/kg)	Caesium-137 level following boli treatment (Bq/kg)	Caesium-137 level equilibrium (Bq/l)	Caesium-137 level following boli treatment (Bq/l)
250	17.5	280	90	112	34
500	35	700	234	280	94
1000	70	1400	460	560	186
1500	105	2100	700	840	280
2000	140	2800	920	1120	374
3000	210	4200	1400	1680	560
5000	350	7000	3000	2800	920
10 000	700	14 000	4600	5600	1860

Note: The levels were measured in 1991 during field trials *Assumes daily intake of 70 kg fresh herbage per animal.

Concentration levels of caesium-137 in contaminated areas of Belarus, Russia, and Ukraine

bring about rapid changes in the patterns of agriculture and meat production, thereby reducing the potential for food production in the three States.

Interest in Prussian Blue compounds

After the Chernobyl accident, Prussian Blue (PB) compounds were used for reducing the radiocaesium content of animal products, particularly in Scandinavia. Following the radiological accident in Goiânia, Brazil in 1987, they also were effectively used on humans to reduce their radiocaesium body burdens. The method has been licensed for use as an animal feed additive in Norway, Sweden, Germany, and Austria. Researchers in a number of other countries, including France, Germany, Hungary, and the United Kingdom, have studied the use of PB compounds. In Belarus, Russia, and Ukraine, initial experiments began in 1990 and widespread use was agreed upon in 1992.

The term "Prussian Blue" refers to a number of ferric hexacyano ferrates having distinct properties. Ammonium ferric cyanoferrate, or AFCF, is perhaps the most studied caesium-binding compound. In solutions such as those found in the gastrointestinal tract, AFCF is in a colloidal-soluble form and reacts with ionic caesium forming a complex that does not penetrate biological membranes.

When used in animals, PB compounds act primarily by reducing the rate of gastrointestinal absorption of radiocaesium, and therefore they basically have the same effect as feeding clean feeds. Caesium that is excreted in manure remains bound to PB for an extended period of time, during which it is taken up at a reduced rate by plant roots.

PB compounds can be administered in three ways:

Addition to concentrate. The easiest and cheapest method of feeding is by direct incorporation of PB into concentrate during manufacturing. In this way, it is not necessary to give any special instruction to the farmer on how to use the PB. This procedure is currently in use in Norway, where a special concentrate with one gram per kilogram of PB is provided to dairy goats and cattle. The animals need to receive the concentrate every day, and the procedure is therefore only suitable for intensive production systems.

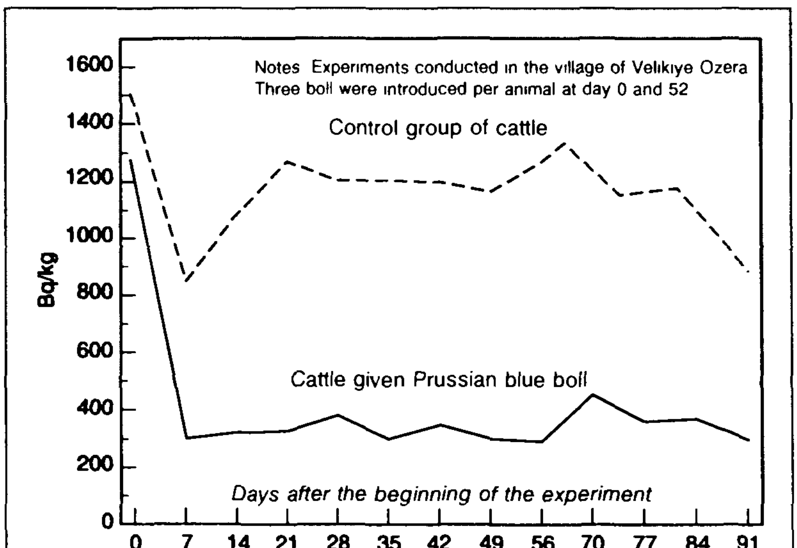
Salt licks. If concentrate is not available or not possible to apply because animals are grazing freely over long periods of time, salt licks can be used. About 100 tonnes of salt lick with 2.5% PB have been used annually for more than 300 000 sheep in Norway. The lick has sufficient physical strength to withstand varying weather conditions in the mountains for the full length of a grazing season. In inland areas where the sodium content of the vegetation is low, sheep and cattle are accustomed to visiting places where salt is made available. In Norwegian mountain pastures, where this countermeasure has been used for three consecutive grazing seasons, a twofold reduction in radiocaesium content has been achieved. The efficiency of the salt lick depends upon frequent visits to the licks. In a grazing herd there will always be some animals that are not interested in the salt. Consequently, the use of salt licks must be accompanied by some monitoring of milk and meat.

Sustained release boli. The low daily doses of PB that are required make caesium binders well-suited for administration by slow-release boli placed in the rumen. In these studies, boli with 15% or 20% AFCF remain in the rumen for at least 2 months. The release of AFCF during this period reduced radiocaesium accumulation in meat by 50% to 80% over a 6-8 week period in Norwegian field experiments and by up to 90% in experiments in Northern Ireland. In large scale experiments in Norway, treatment with sustained-release boli reduced the levels of the whole herd, and the frequency of failures was below 1% when live monitoring was performed 6 weeks after treatment. A bolus is now authorized for routine use in cattle, sheep, and reindeer in Norway. Boli for cattle weigh 200 grams and have been tested in dairy and beef animals.

Regarding PB's health effects, studies on its metabolic and possible toxicological effects date back to the early 1960s. Studies were initiated to use PB for reducing radiocaesium content in agricultural products, and to reduce the radiocaesium burden of individuals who may have been accidentally contaminated. Experiments were carried out with laboratory rodents, domestic animals, and humans.

In summary, it can be concluded from these studies that PB compounds have no adverse effects on animal health and production; have no toxic effects in humans when used experimentally or therapeutically (PB is recommended as a therapeutic antidote for thallium poisoning); and that the consumption of milk and meat from PB treated animals would not be expected to have any effects on the health of humans.

Concentration of caesium-137 in cows' milk: Results of field trial in the Ukraine



Trials in Belarus, Russia, and Ukraine

The first PB studies in Belarus, Russia, and Ukraine under the collaborative international project evaluated the use of sustained release boli based on AFCF and ferrocyne for reducing the radiocaesium content of milk and meat. Investigations also were done in a number of other areas: the transfer of radiocaesium from soils to plants through manure of animals treated with such boli; the monitoring of the technique's possible effects on milk and meat composition; the physiological well-being of cattle; and the possible toxicological effects, which was examined by feeding rats with milk and meat from animals treated with boli. Boli for treating cows contained PB synthesized in Ukraine; production of the boli took place at the Agricultural University of Norway.

The studies confirmed that caesium binders reduce the levels of contamination in meat, milk, and in crops fertilized with the resulting manure. The results imply a number of practical benefits:

Dose reductions. In theory, if the concentration of radiocaesium in meat and milk is reduced by a factor of three, then so too are the doses to consumers of this food. Assuming that 50% of the annual dose currently is due to external irradiation and 50% from internal irradiation, and that 90% of the internal dose is due to milk, one can calculate that reducing the radiocaesium content of milk and meat by a factor of three would imply an overall reduction in dose of about 30%. For territories where there is a high uptake of caesium from soil to pasture grass, then this overall dose reduction would be higher (probably greater than 50%).

Saving of other resources. The bolus technique can save significant resources currently being expended on reducing caesium contamination of milk and meat. The cost effectiveness of using caesium binders depends upon prevailing levels of feed contamination, the costs of production and distribution of the binders, and the cost of alternative strategies. However, given economic difficulties in the three States, it is extremely difficult to quantify the benefits in local currency. In Western Europe, PB costs about US $50/kg. Since each bolus contains around 40 grams of PB and up to 9 boli (or about 400 grams of PB) are required for a 6-month grazing season, the approximate cost of PB per animal is US $20. The estimated cost of other materials and manufacturing is also about US $20, whereas the additional cost of producing some 1800 litres of milk suitable for human consumption is US $40. Since this milk has a current market value of about US $1800 in Western Europe, the use of PB boli would provide a benefit to cost ratio of 45:1.

Based on the number of animals in Belarus, Russia, and Ukraine that are producing milk above TPLs, considerable benefits could be expected. By making PB boli available to private farmers, an additional 50 million litres of milk could be provided annually for local marketing and human consumption in the three States at extremely low cost. The States would no longer have to buy this milk from the farmers at considerable expense.

With respect to the marketing of animals for meat, the effective use of the PB technique will be on the 10% to 20% of land which is owned by small farmers. On other lands, each of the three States has already made huge investments for the provision of relatively clean herbage by ploughing, draining, fertilizing, and reseeding of natural pastures. These efforts have succeeded in reducing contamination in herbage, and hence in milk and meat, to within the TPLs, and they also will serve to improve animal productivity over the long term.

The bolus technique would allow the use of important parts of these territories for meat production, since treated animals may be taken directly from pasture to slaughter with radiocaesium levels which can comply with the TPLs. In areas where caesium levels remain too high in spite of bolus treatment, the period required for using clean feeds will be shortened by approximately 40 to 50 days, thus saving considerable amounts of harvested feeds.

It is difficult to accurately quantify the cost of providing and/or transporting clean feed for animals in the private sector. Nonetheless, it can be estimated that in Belarus and the Ukraine such countermeasures involve between 100 000 and 200 000 animals. They require 200 000 to 400 000 hectares of additional clean pasture, about five times more land than would be required if PB boli were used. Based on Western land development and maintenance costs over a 10-year period, it can be calculated that the production of meat that satisfies TPLs under the present approach will cost an additional US $1/kg in each of the three States. The alternative, administering PB boli for up to 3 months before slaughter, would cost an additional US10 cents/kg, approximately ten times less.

Sociological and psychological considerations. In the contaminated areas, there is clearly anxiety about the levels of caesium contamination in the environment and fears about the possible presence of other less publicized radionuclides, particularly strontium and plutonium. There is uncertainty about the long-term health consequences of the high level of exposure in the early weeks following the accident. Some of the countermeasures currently used, such as prohibiting subsistence farmers from consuming milk and meat produced from their own animals, have considerable negative psychological, social, and financial consequences.

During the field trials under the PB project, it was clear to the participating scientists that the farming community welcomed the opportunity to use the caesium binders. Indeed there was considerable dissatisfaction from the owners of the "control groups" of animals that they were not allowed the opportunity of using the binders. While the possibility exists of anxieties surfacing over the use of chemical compounds, the "fear" of radiation and the disturbing influence of alternative countermeasures on people's lives appeared to be of more importance during the field trials.

Given such existing conditions, it is important that information on the caesium binder technique, the scientific/technical basis for its effectiveness, its non-toxic nature, its method of application, and local administrative procedures are made available to the public. Activity levels in milk and meat also should be communicated, as well as information on how these levels compare with national, regional, and international standards.

By using the PB technique, some 50 000 farmers should be able to return to their traditional farming practices, with a corresponding improvement in their sense of well-being and quality of life.

Continuing studies

Based on work under the project, the bolus technology is well suited for the present and future infrastructure of dairy and beef production in the three States. At the same time, potential additional benefits could be realized from using boli to deliver other compounds that would increase the productivity of agriculture in the three States:

- Bolus technology might be used to deliver strontium-90 binders to grazing animals in combination with PB.
- Several micro-minerals are in short supply in contaminated areas, and agricultural countermeasures have reduced the availability of microelements in the soil. Bolus technology could be used to provide cattle with the small daily amounts required.

Studies could be done with the aim of investigating the effects of both radionuclide contamination *and* improved mineral content of meat and milk. Additionally, investigations should continue on the long-term binding of radiocaesium to PB in soil. ❐