

VIII. Environmental Impacts of Chernobyl¹

A. Background

282. On 26 April 1986, as a result of a combination of factors, a sudden, uncontrollable surge in power took place at unit 4 of the Chernobyl nuclear power plant, resulting in the destruction of the reactor and a fire in the graphite moderator. This caused a prolonged release of radioactive materials to the environment and was followed by further releases, associated with the high temperatures reached in the core, between day seven and ten after the initial event.

283. The environmental impacts of Chernobyl in Belarus arise from the deposition of radionuclides, carried over Belarussian territory from the explosion and fire at the Chernobyl nuclear power plant. Due to the various countermeasures taken during the accident to bring the fire under control and to mitigate its effect, the release of radionuclides was erratic. This erratic release, combined with temporal variations in weather and wind, led to a heterogeneous deposition of contamination over the affected regions. The variation in contamination levels is so large that it can vary by more than an order of magnitude within the same village thus making decisions regarding evacuation, remediation and compensation difficult and complex.

284. During the initial periods after the Chernobyl accidents, a considerable rise in exposure dose of gamma radiation was recorded across Belarus. Almost 47,600 km², or 23 percent of Belarussian territory, which was occupied by some 20 percent of the national population, was heavily contaminated, primarily by radioactive isotopes of short-lived iodine (mainly I-131) and long-lived cesium (Cs-134 and Cs-137). Strontium (Sr-90) contamination was more local and more limited, affecting about 10 percent of the nation's territory closest to Chernobyl, in parts of the Gomel and Mogilev regions. Plutonium contamination is still more limited, affecting around 2 percent of the nation's territory, primarily in the 30 km zone around the Chernobyl plant. The affected territory included some 3,600 settlements with some 2.5 million inhabitants, of which one-half million were children. Approximately 2,650 km² of agricultural land has been removed from use in these contaminated areas and around 17,200 km² of forests have been contaminated, 400 km² (23% of all forested area) of which are contaminated with C2-137 in excess of 40 Ci/ km².

285. Initially, as noted above, 23 percent of Belarussian territory was within a region considered contaminated above acceptable levels from the fallout from Chernobyl. Approximately 85 percent of this fallout was composed of radionuclides (radioactive isotopes) with half lives shorter than about a month (mostly I-131). Another 13 percent was composed of radionuclides with half lives of several months (Zr-95, Nb-95, Ce-144) and about 1 percent had half lives of around 30 years (Sr-90 and Cs-137), while about 0.001 percent had half lives greater than 50 years (Pu-239, Pu-240, Am-241). By 1996,

¹ Subsequent to the preparation of this report, a separate study was carried out by the Bank on the Chernobyl Accident and its Impacts. For this reason many of the detailed issues relating to Chernobyl have been shifted to that report and the focus here is on the environmental aspects of this event.

after 10 years of radioactive decay, the total of all radioactivity still present in the environment had fallen to about one percent of the total activity released and was mainly composed of long lived radionuclides (principally cesium, and to a lesser extent, strontium). Nonetheless, in 1996, 20 percent (or 46,500 km²) of Belarus territory was still reported as being contaminated with Cs-137 above acceptable levels, requiring either continued relocation of the population or periodic monitoring of exposure levels. Remaining radioactivity will decline more slowly as long-lived radionuclides make up an increasingly higher proportion of existing deposition.

286. The most contaminated area immediately closest to the Chernobyl plant (the Bragin, Khoyniki and Narovlya districts of the Gomel region) has been declared a 1,700 km² exclusion zone from which all persons were evacuated in 1986 and the lands taken out of economic activity save for basic safety and maintenance, forest fire fighting and scientific research activities. where there are no inhabitants. Specifically, where surface deposition of radioactive isotopes exceeded 15 Curies (Ci)/km², or 555 kilobecquerels (kBq)/m², evacuation was obligatory while in areas with levels of 5-15 Ci/km² or 185-555 kBq/m², voluntary settlement has been permitted. The impact of these surface contamination levels on humans is expressed in terms of radiation dose which is measured in sieverts. The criterion for permanent relocation is that the expected avertable lifetime dose should not exceed 1000 mSv. As noted in para. 70 in Chapter 3, zones where land use is totally excluded amounted to 2,640 km² and the area where some activity was permissible amounted to about 45,000 km².

287. To date, around 135,000 persons have been resettled including those evacuated from the exclusion zone, those from land deemed sufficiently contaminated to require resettlement, and those having the right to resettle. While contamination levels in much of the resettlement zone do not reach levels requiring relocation, people do have the right to relocate, and some have done so. Many of the vacated contaminated settlements have been razed to prevent re-use, but many are left standing, and a certain degree of re-occupation has occurred. In the most heavily contaminated Khoyniki region, for example, some 25 percent of the population has returned, along with a number of immigrants from Russia and Kazakhstan.

288. Exposure levels in the resettlement zone are high, though in fact not as high as the natural background radiation found in a number of inhabited regions of the world. In the contaminated territories outside the exclusion zone, the total anticipated lifetime exposure (internal and external, and assuming no countermeasures) for the most contaminated regions of Belarus are within the levels of exposure due to natural background radiation in parts of Western Europe, and only one-fourth as great as the highest of these natural background levels. This is not to minimize the impact of the Chernobyl accident on Belarus, but it is relevant to the discussion of efforts made since 1986 to reconstruct the livelihood of those affected by the contamination, and for assessing the countermeasures that might still be recommended.

289. Each of the four, major radioactive isotopes deposited by the Chernobyl plume has its own pattern of distribution and its own effects. These isotopes are worth mentioning as they affect both the need and the potential for different countervailing

efforts. In the case of radioactive iodine, the prominent radioisotope is I-131 which has a relatively short half-life (approximately 8 days). This short half-life precluded accurate measurements to determine levels of exposure because the I-131 had decayed to non-detectable levels by the time international teams arrived to measure the dose. Nonetheless, the major impact of exposure to radioactive iodine in Belarus was a significant increase in thyroid cancer – normally non-fatal and treatable – limited primarily to those who were under 15 at the time of exposure to fallout from the Chernobyl plume. The uptake of radioactive iodine may have been exacerbated among the affected population by a chronic iodine deficiency. The type of thyroid cancer induced by the Chernobyl fallout is not a frequently occurring cancer, which facilitates detection and monitoring of this effect as well as prediction of the total number of expected cases. As of 1998, there were more than 1100 cases in Belarus. A marked increase in thyroid damage was also found in cows in the initial period.

290. Unlike I-131, both Cs-137 and Sr-90 have long half-lives (30, 29 and 12 years respectively), so that contamination from these radionuclides will diminish gradually: in 100 years the levels of both radionuclides will be approximately one-tenth of their initial level. Analyses have shown that Cs-137 contamination greater than 1 Ci/km² in 1986 will decrease by 1.5 times by 2016 and by 2.4 times by 2046. In the interim, these radionuclides constitute the major source of radiation exposure in the environment and food chain for the population. These elements bind successfully with many of the soil types in Belarus and so are susceptible to uptake by certain plants, becoming concentrated in crops, pasture grasses and forest products, and ultimately in meat and milk. The level of external exposure will diminish as a function of environmental processes and radioactive decay over time. Internal exposure - intake of radioactive nuclides through the food chain - can be more readily adjusted through a variety of agricultural countermeasures. Since the principal pathway for internal exposure – (from 40 to 80 percent) is through milk, Belarus has concentrated a large part of its mitigation efforts in this area.

291. Americium-241 (Am-241) and the isotopes of Plutonium (Pu-238, Pu-239, Pu-240 and Pu-241) predominantly exist as isolated and chemically inert particles, which are very insoluble in the environment and therefore have very low uptake by plants and vegetation. In addition, the minute quantities of these radionuclides that are available are strongly bonded to the soil and therefore have limited possibility for re-suspension and air transport. The highest concentrations of these radionuclides are in the 30 km zone where human exposure (both external and internal) is precluded and therefore are not of concern for this report. In spite of this, however, some monitoring is justified as concentrations will increase over time and could be a factor in the inhabited territories in the future.

B. Environmental Effects

292. Health impacts and the broader social impacts from Chernobyl were covered in the Bank's 1993 Strategy Assessment and, since there is little, new information to add, they are not discussed in detail. It suffices to note that the focus of public health efforts and general population concerns to date, besides the detection and treatment of thyroid

cancers among exposed children, has been the assurance of a "clean" food supply for the population. Nor does this report focus on an extensive cataloguing of past damages. Rather, the intent is to note the progress made in environmental clean-up and the mitigation of the environmental impacts of Chernobyl since 1986, and to explore the potential for future mitigation activities. For purposes of discussion, the environment is divided into the natural environment and the agricultural environment. Both were affected by Chernobyl, but the available responses are different in the two cases.

293. Environmental impacts on non-human populations are not measured in terms of individuals but in terms of relevant populations. An extensive survey of flora and fauna in the resettlement and exclusion zones indicates that direct radiation injury of plants and animals was reported only in localized areas within the 30 km exclusion zone and within the first one to three years after the accident. Most damaged were conifers and some small mammals. The rest of the environmental damage came from deposition of radionuclides from the Chernobyl plume.

Natural (Non-agricultural) Environment

Forests and Forest Fires

294. Some 500-600 ha of trees in the vicinity of the reactor received very high doses of radiation resulting in the death of pine trees and partial damage to the crowns of other trees (especially birch and alder), the crowns being the part receiving the bulk of the deposition from the Chernobyl plume. Conifers are extremely sensitive to radiation. Over an area of 3,000 ha which received high doses, 25 to 40 percent of pine forests died, and 90 to 95 percent of the trees showed some damage to reproductive functions. By 1988/89, however, most had recovered their reproductive functions. The total of trees that died amounted to less than 0.5 percent of the forested area of the zone.

295. Nonetheless, radioactivity resides to varying degrees in the wood of affected trees, sometimes limited to the rings grown after 1986 and sometimes pervading the tree. Around 270 thousand ha of forest heavily contaminated with caesium-137 (mostly the Vetka, Chechersk and Narovlya forestry enterprises) were retracted from normal economic activity to avoid radiation exposure to personnel. Radionuclides also tend to concentrate in certain forest products, notably mushrooms, berries and game, which traditionally have formed part of the local diet. Levels of contamination in these products can be very high, and people are no longer permitted to forage or hunt for them except in declared safe areas.

296. There is a risk of redistribution of radioactive contamination from forest fires in the contaminated zones and consequently a large part of the land management effort in these areas is devoted to preventing forest fires. These efforts include making mineralized strips on quarterly cuttings, plowing around the resettlement villages, digging fire fighting reservoirs, maintaining roads to the most fire-prone sites, flooding part of the peat fields, ground patrols, and setting up fire-chemical stations. Both regional and national resources are devoted to fighting fires in the exclusion and resettlement zones. Monitoring stations are placed in the zone for early warning of such fires and monitoring the direction of the smoke, which is also tracked by the national environmental

monitoring system of Hydromet, though not as a priority. Hydromet has 8 passive air monitoring stations in the Gomel region, but only one active monitoring station capable of detecting elevated radionuclide concentrations. No specialized firefighting training program has been established for the Chernobyl areas.

297. As for other vegetation besides trees, some physical abnormalities were noted in plants subject to initial exposure, but no visible changes in growth or reproductive function were observed in most species of herbaceous plants. Within three years herbaceous plant seeds for most species had already regained relatively normal production and viability, though contamination levels remain high in some areas.

298. Small mammals such as mice with high initial doses of radiation were observed to have reproductive and genetic disorders, and population instability. In some cases, the populations returned to normal in a few years; longer term effects, as with humans, cannot yet be determined. Some species of frogs initially showed a 30 percent increase in sterility. Insect and spider populations in the 30 km zone, whose habitat of forest litter and topsoil accumulated radionuclides, showed marked declines in the first year after Chernobyl.

299. Aquatic organisms have shown high levels of tolerance to elevated levels of contamination without reproductive damage. Benthic organisms showed high levels of contamination reflecting concentration of radionuclides in bottom sediment. One mollusk population was seen to decline, but of the 31 species of fish examined in the 10 years after Chernobyl, none showed any damage or effects, despite high levels of Cs-137 uptake.

300. Within the exclusion zone, animals and birds have benefited greatly from the lack of human predators. Some 252 species of birds are found within the reserve, as are bison and wolves. Hoofed animals are being introduced.

Water and Floods

301. Direct deposition from the Chernobyl plume occurred in rivers, lakes and seas. Within one month or so of deposition, the concentration of radionuclides in surface waters had fallen dramatically with sedimentation, and within three years was negligible or undetectable even in the most contaminated Pripyat River. Flooding can be a serious problem in areas where agriculture has been extended to marginal, peat-bearing lands. After storms and floods, which roil the rivers and disturb bottom sediments containing settled out radionuclides, elevated amounts of radioactivity are detected, but at levels that, according to international standards, pose no hazard to human health even for persons using the Pripyat directly for drinking water during their lifetime. Concentrations of radionuclides in the Black and Baltic Seas (into which Belarus' rivers flow) register very low levels, and it is unclear how much of this can be attributed to transport of contamination from the Chernobyl region.

302. The government authorities took early and extensive steps to protect drinking water sources and underground aquifers from contamination. An intensive program was undertaken to first seal artesian wells and then shaft wells in the resettlement areas. At

present, the possibility of radionuclide contamination of drinking water in the resettlement zones does not seem to be a major concern either for the population or the authorities, whereas iron and nitrate contamination are serious.

Agricultural Environment

303. Contamination levels on agricultural lands immediately after the Chernobyl fire resulted in 2,650 km² of land being removed from productive activity, one-third of which was in the 30 km exclusion zone. Livestock and farm animals in this exclusion zone were destroyed and buried. In the resettlement zone, where contamination levels are lower, it has not been necessary to completely suspend agricultural activities. But some changes are needed in agricultural practices and crop and fertilizer choices, and food processing, in order to assure the production and sale of "clean" food products from these areas for consumption and sale in Belarus markets. The efficiency of these agricultural and processing practices in reducing contamination of final food products can be impressively high (see below).

304. Contamination of fields, pastures and cows by I-131 and Cs-137 immediately after Chernobyl was the first urgent concern for the agricultural sector, requiring stringent controls on milk, milk products and meat consumption, and on pasturing and harvesting practices. After six months, I-131 contamination was no longer a major concern. Instead, contamination of agricultural lands was primarily from Cs-137 and to a lesser, but increasing extent, from Sr-90 depositions was of major concern. As noted, the degree of contamination retained in the soil varies widely according to type of soil, soil moisture and uneven patterns of deposition. Uptake of radionuclides into crops can vary even more (by several hundred times) depending on the clay, organic, pH and moisture content of the soil, and especially on the type of crop. Since most of the radioactivity is typically in the top few cm of the soil, remediating natural hay fields and pastures, together with chemical blocking of radionuclides, can reduce uptake significantly.

305. Crops have widely different uptake patterns from soil to harvested food, due to variations in their radionuclide transfer factors for the soil-plant-fruit pathway. Thus, some crops, such as corn (maize) and apples have very low concentrations of radionuclides in the final fruit, while others such as beans, have exceedingly high levels. The uptake of cesium and strontium into plants can be partially blocked by using other chemicals (notably potassium and phosphorous) as fertilizer. Where such fertilizing is not economical or accessible, cows that graze on contaminated lands can still provide "clean" milk and meat if the cows are fed ferrocyanide compounds (commonly called "Prussian Blue") prior to milking or to slaughter in doses appropriate to the level and type of contamination. On dairy and cattle farms located in contaminated regions where none of these countermeasures are used, it has been observed that the milk contains excessive levels of Sr-90 and Cs-137, while the meat contains excessive levels of Cs-137.

306. Changing crops and fertilizers, coupled with food processing as discussed below, can thus result in foodstuffs that meet national and international standards, without major capital or technological investments. Nonetheless, access to and application of such countermeasures is not universal, even among collective farms, due in part to lack of funds or shortage of materials. Inertia in the traditional farming sector may also account

for part of the failure to apply countermeasures. In the two percent of farms in the affected regions that are individual farms, agricultural countermeasure practices are particularly scant, due in part to lower access to blocking fertilizers, deep plows and agricultural extension services.

C. Economic Impact

307. The State Chernobyl Committee of Belarus estimates that the cost to the economy in the aftermath of Chernobyl has been \$235 billion. This figure is broken down in Table 8-1 below.

Table 8-1: Social and economic damage to Belarus as a result of Chernobyl catastrophe by sectors of the economy (in billion dollars)

Sector	Period (years)				
	1986-1990	1991-1995	1996-2000	2001-2015	1986-2015
Public health	4.05	16.77	18.13	54.32	93.27
Agro-industrial complex	18.30	20.00	15.60	18.10	72.00
Forestry	0.58	0.68	0.70	2.15	4.11
Industry	0.06	0.13	0.11	0.33	0.63
Construction	0.15	1.25	0.32	0.96	2.68
Mineral raw materials and water resources	2.00	0.12	0.15	0.40	2.67
Transport and communications	0.93	1.20	0.36	0.90	3.39
Social sector	2.84	5.45	2.96	6.45	17.70
Decontamination of polluted areas	0.04	4.19	22.48	10.12	36.83
Radiological monitoring	0.05	0.21	0.19	1.27	1.72
Total	29.00	50.00	61.00	95.00	235.00

308. Public health, which includes the costs of resettlement, social benefits and compensation to the affected population, has over time accounted for a growing share of these aggregate damage estimates, amounting to some 40 percent of aggregate social and economic costs over the 1986 to 2015 period. Agricultural costs have also been high. It has not been possible to ascertain how much of these estimated damages are accounted for by actual financial outlays, how much by losses in production or productivity, and how much are external or opportunity costs. Where there are opportunity costs, it is unclear whether these would have materialized given the current structure of the economy. Indeed much of the assessment could be questioned and its validity challenged².

² The Mission could not establish the full economic rationale of the calculations and feels that some of these figures may be exaggerated significantly.

309. In terms of actual expenditures, rather than assessed damages, the total Chernobyl budget amounted to around \$100 million in 2000 at the end-year exchange rate. About 28 percent of this was for capital investments and the bulk of the rest (\$70 million) for social support for the affected population. Of the investment total, a major portion has gone to the construction of dwellings (83 percent in 1989, down to 73 percent in 1999). Of the balance, only a small amount has gone to agricultural countermeasures of the kinds identified above. Long range plans for rehabilitation of radioactively contaminated areas in Belarus require significant investment in revised agricultural practices and countermeasures to produce agricultural products that meet national and international standards for permissible levels of radioactivity. The plan is to increase the share of investment in this area substantially over the next three years (Ministry of Emergencies, 1999). This will, however, require external support given the size of funds required.

310. As far as the Mission could ascertain, no assessment has been made of the impact of different expenditures in terms of poverty alleviation. Is it more effective to shift funds at the margin on agricultural countermeasures than on social support programs with respect to this objective? Such a study is merited, and should be undertaken, but some preliminary evidence suggests that an increase in agricultural investment could provide a bigger benefit. First, much of the social support is not targeted towards the poor (see Box 2-4, Chapter II). Second, many other studies attest to the high effectiveness on poverty reduction of rising yields and the increasing value of marketable produce. Hence, on poverty reduction grounds, a shift in expenditures towards improving agricultural productivity would seem to be merited.

D. Agricultural Countermeasures: Producing "Clean" Food

311. Different opinions exist about whether people should occupy the resettlement zone at all. However, the fact is that people do inhabit this zone (in those areas where there is right of resettlement) and they will continue to do so. Moreover, they will continue to seek their livelihood largely through farming and by producing food for their own consumption. It is therefore important to assure that the food produced in this region, whether for marketing elsewhere or for local consumption, meets appropriate standards for acceptable levels of radioactivity.

312. Belarus has consistently maintained stringent standards for permissible levels of radioactivity in foodstuffs. However, where more stringent standards exist for particular foodstuffs in the Russian Federation, Belarus' most important trading partner for agricultural products, Belarus now aims to have its agricultural products meet those more stringent standards. This should improve the marketability of dairy and meat products from Belarus' contaminated areas in Russian markets. However, meeting these standards will require serious and widespread application of a variety of agricultural countermeasures in Belarus. This is not possible under present circumstances, and will be possible only through a long-term and targeted investment program.

313. Nonetheless, concerted efforts are being made. The Ministry of Agriculture has issued guidelines for agricultural practices and food processing techniques recommended for use on contaminated lands to produce "clean" food products that conform with

required standards. These guidelines proceed from the premise, based on experience in the early days after Chernobyl, that decontamination of the fields and pastures by removing the contaminated top few centimeters of topsoil is prohibitively expensive, difficult to manage and unnecessary. Rather, they build on extensive knowledge about relevant pathways for the transmission of radioactivity through the food chain. They describe in detail the range of techniques that block the uptake of radioactivity from one stage of the food chain to the next. These include: selection of soil composition, soil pH and ideal moisture content to block the uptake of radionuclides; selection not only of the type of crop, but crop brands, which vary widely in their blocking and uptake capabilities; selection of ideal planting times; optimal application of appropriate fertilizers; and a variety of intermediate and final product processing measures. Table 8-2 gives some details of sample countermeasures and their potential impacts.

314. To reduce the concentration of radionuclides in the soil, and in fodder, some of the countermeasures being applied include: re-grassing of hayfields and pastures; removing marginal lands from cultivation; and eliminating pasturing from wetland meadows, forests and lands adjacent to roads, where radionuclides tend to concentrate. Lands that are unsuitable for growing fodder within permissible levels, even after remedial measures have been taken, can still be used to grow crops such as rapeseed and other seeds for processing into oil, or grain for processing into alcohol.

315. To block the uptake of Cs-137 and Sr-90 from the soil to plants, one of the most effective measures used in Belarus is the application of potassium and phosphorous-based fertilizers to lands used to grow both food crops and fodder. These fertilizers reduce the uptake of radionuclides by around 1 to 6.5 times, while increasing the fertility of the soil, for a double benefit. The government has distributed or made available such fertilizers both to collective and to individual farms, though need outstrips available supply. Liming of acid soils can also be used to achieve the optimum pH level for reducing the uptake of radionuclides in a particular soil. Experiments are being tried with careful crop selection to further reduce uptake from the soil to the plant, as certain crops either do not take up these elements at all, or do not pass them on (at least not in detectable or significant quantities) to the final fruit. Apples and corn are two such crops. By contrast, bean plants tend to concentrate radionuclides in the bean, and so are not recommended for growing on contaminated lands. Local farmers and authorities acknowledge the need for specialization in "clean" products, but there is little evidence that major crop shifts have occurred to date in the affected areas.

316. At the next level of the food chain, cattle and hogs that have grazed on contaminated lands are "cleaned" and fattened prior to slaughter, much as range-fed cattle are corn fed before slaughter. This is a far more economically viable approach than mechanical decontamination of pasture lands. The "cleaning" is accomplished again by the use of chemical blockers and cesium binding preparations in the feed, such as ferrocyanides that adsorb the radionuclides and prevent their uptake in the animal tissue, effectively reducing their biological half lives by 50 to 97 percent. The cleaning process can take from a few days to a month or so, but can be extended for the duration of the fattening process. This practice reduces the transmission of radionuclides from animals to meat by a factor of 2 to 5. A similar application of chemical blockers reduces the

levels of radioactivity in milk from cows that have grazed on contaminated pastures. Reductions by a factor of 3 to 10 are not uncommon. However, sheep raising, unlike hogs and cattle, is not recommended in the contaminated regions, because the principal cash crop of wool from sheep raising cannot be readily decontaminated.

Table 8-2: Sample Countermeasures and Their Relative Effectiveness

AGRICULTURAL COUNTERMEASURE	RATIO OF DECREASE OF RADIO SORPTION	
SOIL TREATMENT AND PREPARATION	PRODUCT	REDUCTION FACTOR
Regrassing pasture land	Milk	1.5-1.7
Liming		6-7
Fertilizers		1.1-6.5
Deep plowing	Grasses, cereals	5-10
CROP SELECTION		5-100
"CLEAN" FEEDING		
Ferrocyanide and cesium binders	Meat	2-5
	Milk	3-10
FOOD PROCESSING	PERCENT REDUCTION IN RADIOACTIVITY FROM RAW PRODUCT	
Grain milling		60-90
Processing grain into alcohol		99-100
Potato pilling		20-98
Milk into butter and cream		93-100
Cooking and curing meat		20-80

Source: "Belarus and Chernobyl – the Second Decade" (Ministry of Emergencies); and "Guidelines on Agricultural Production in Conditions of Radioactive Contamination of the Ground in the Republic of Belarus, 1997-2000" (Ministry of Agriculture).

317. Wider spread use of these practices and technologies could improve the viability of the agricultural sector through utilization and processing of appropriate agricultural products even in the most contaminated areas. Agricultural products that exceed

permissible levels for food may be used as forage or seeds, or processed, thereby significantly reducing the radionuclide content of the final products.

318. Food processing is the final stage of the chain. Processing enterprises are of interest for several reasons. First, processing raw food can effectively decontaminate the final products. Second, processing provides some value added to the farm products, making sales potentially more profitable. Third, food processing can serve as an organizational focus for agricultural restructuring and for regional development.

319. Certain food processing practices in Belarus are highly effective in reducing radioactivity levels in final products. The effectiveness of these decontamination processes depends on the solubility of the radionuclides, which can be separated out in liquid form from remaining products. Milk, for example, can be processed into cheese and butter, since the contamination is largely in the whey, and not the curds. This whey can either be fermented or processed into caseine for making glue, further reducing the amount of radioactive liquid waste. Similarly, the refining of sugar from sugar beets produces sugar and a radioactive liquid waste product which may then be used for feed. Other technologies are being used to process contaminated grain into "clean" distilled grain alcohol, with the radionuclides left behind in the distillation process. Radioactive seeds, such as rapeseed or sunflower seeds, are being processed into "clean" oils, with the radioactivity concentrated in the sludge of the hulls. Margarine is also being made from contaminated grasses. Some of the residue from these processes is made into fodder.

320. Lack of processing facilities results in substantial losses to some farms, particularly in the Gomel region because of the difference in prices for food and forage grain. In the Khoyniki district, virtually all grain output (30,000 tonnes) fails to comply with permissible radionuclide levels for food grain. Distillation is clearly a preferred solution, but the facility for spirit production in Strelitchevo (Khoyniki district) has insufficient capacity for the Khoyniki and surrounding districts. Grain that cannot be distilled is used as animal feed. Milk producers would also benefit from distillation facilities. Whereas current processing plants produce cheese, cream and caseine, the whey from contaminated milk, a byproduct of cheese-making, could also be processed into spirit. Around 25,000 tons of contaminated whey are produced in the Khoyniki cheese factory alone, the discharge of which could be prevented or reduced by distillation.

321. Effective combinations of crop selection, fertilizer application, and intermediate and final product decontamination, can be designed to maximize the total decontamination effect. Effective decontamination of raw agricultural products can reach 30 percent by combining countermeasures. Processing of these products can then further reduce the radioactivity by a factor of 10. Thus application of such measures can and does produce final products that are well within permissible levels of radioactivity for foodstuffs. Successful application of these techniques has produced impressive results, but is severely hampered because of a lack of funds.

322. Dissemination of agricultural countermeasure techniques and food processing capacities lags seriously behind total farm production in the affected areas, a trend driven

largely by employment considerations. Nor have farm production levels been altered significantly to accommodate limited processing capacities. The Ministry of Agriculture estimates that countermeasures are applied to less than half of the agricultural production that needs decontamination. Contaminated grain is either processed or used as fodder, but cannot be used in food production. Farmers are thus operating at a loss since fodder prices are much lower than those for grain sold as food.

323. In another area, Belarus is experimenting with approaches for decontaminating and making commercial use of peat lands and wood, to provide employment as well as local, adequate and affordable energy supplies. Although the Yamal pipeline runs through this region, carrying natural gas from Russia to Western Europe, much of the region's inhabitants and enterprises are not connected to receive this gas. Within the State Committee on Chernobyl's present program, about 15 percent of the budget is scheduled to be allocated to a gasification program for areas where forests and peat lands are contaminated and are considered a hazard to health when used as energy sources. This program has been given high priority but even with increased access to gas for some of the regions, a need for these local sources will remain. Hence there would certainly be some value in looking carefully at technologies for decontaminating local fuels. Peat lands, which retain radionuclides in the top few centimeters from the surface, can be used by stripping off the contaminated layer, and making peat briquettes from the remaining, uncontaminated peat. Where it is possible to strip off the outer contaminated rings of trees, wood from contaminated areas can also serve as fuel. Neither option is necessarily cost effective or desirable from an environmental point of view, but they may serve as a useful stop-gap until the whole region has access to adequate quantities of natural gas.

324. It should also be noted that, while some of the forest area contaminated with radionuclides has been withdrawn from commercial activity (mostly in the Gomel region), a considerable amount of wood in the contaminated areas is fit for use. Its harvesting is highly mechanized and primary processing is done directly on site in order to substantially reduce individual and collective radiation doses. These activities could be expanded. Commercial lumber products are being exported from the region after the contaminated outer bark and rings have been removed. Plans are also being made for a plant to produce cellulose from local wood. While sufficient quantities of uncontaminated wood are available to supply such a plant, the process could, at least to some extent, use decontaminated local wood.

E. Monitoring

325. A separate, critical and significant aspect of dealing with the aftermath of Chernobyl has been to establish a national, regional and local system of monitoring and analytical laboratories. The objectives of the system include tracking the environmental dispersion of radionuclides and measuring the product contamination level of crops and animals, food inputs, food products, the inputs and outputs of food processing plants, products at local markets, and industrial inputs and outputs in industries such as metal recycling.

Environmental Monitoring

326. The national environmental and product monitoring systems sample air, water and soil at hundreds of sampling sites around the country. These samples are analyzed State Committee for Hydrometeorology (Hydromet) laboratories for a variety of radioactive and non-radioactive pollutants. Monitoring of food products and drinking water is the responsibility of the Ministry of Agriculture and Food, Ministry of Health, Committee of Forestry, Ministry of Communal Services and other agencies. The need to track radioactive contamination levels raises the costs of these sampling systems, a cost directly related to the impact of Chernobyl, but not considered directly as a Chernobyl-related expense.

327. The Center for Radiation Control and Environmental Monitoring in Hydromet in Minsk has five laboratories and four radiology labs. The five general environment labs include:

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- An air monitoring laboratory for the City of Minsk that analyses emission gases in air samples and toxic elements in air particulates collected at 10 permanent stations. The laboratory measures for formaldehyde (from industrial and vehicle exhausts), phenols, Pb, Cd, SO₂, NO, NO₂, NH₃, CO, and suspended particles;
- A physical and chemical analysis laboratory that performs toxic and heavy metal analyses for samples of water (precipitation and surface waters), air particulates and soils using atomic absorption spectrometry (AAS). Water and soil samples are analyzed for Cu, Ni, Pb, Cd, Mn, Zn, Na, K, and chloro-organic, triasin and phosphoro-organic pesticides. Air quality is measured in terms of Pb and Cd;
- Soil pollution laboratory that monitors soil contamination from man-made toxic substances in cities, within industrial areas and along roadsides, in addition to the concentration of pesticides in agricultural land.
- A hydrochemical laboratory that performs the following determinations in samples of surface waters and precipitation: anions (HCO₃⁻, Cl⁻, SO₄⁼, PO₄⁻⁻⁻⁻, NO₃⁻, NO₂⁻, NH₄⁺) and by titrimetry; chromium species (Cr(III) and Cr(VI)); organic contaminants including phenols and detergents; total suspended solids; pH; total dissolved oxygen; CO₂; biochemical oxygen demand, and conductivity; and
- A hydrobiology laboratory that studies surface waters and bottom sediments using bio-indication methods and associated hydrobiological indicators: phytoplankton, zooplankton, phytoperyphon and macrozoobentos.

328. The four radiological laboratories belonging to the Hydromet's Center for Radiation Control and Environmental Monitoring include:

- A radiochemistry laboratory that analyses Sr-90 and plutonium isotopes in samples;

- A radiometrology laboratory that monitors the levels and composition of all radionuclide concentrations in the air, mostly using passive and active samplers. Sampling is conducted across Belarus, including Gomel Oblast, as well as areas where nuclear power plants border neighboring countries. Between 20 and 35 air samples are taken and analyzed at the laboratory every day;
- A radio-spectrometry laboratory that measures gamma-emitting radionuclides (primarily cesium-137) in air filters, and soils and water samples. It analyzes some 1000 to 2000 samples a year; and
- A mobile radiological laboratory equipped with state of the art radiometric and spectrometric technology for direct field work and for emergency purposes.

329. These radiology laboratories, like the other laboratories of Hydromet, are sorely lacking in equipment and training. The radiochemistry laboratory has only one alpha-spectrometer of poor efficiency and resolution and no ancillary equipment or supplementary radiochemical supplies. Half the staff is near retirement, but all staff are qualified. The Head of laboratory attended a course in Germany on measuring radionuclides. Other staff could also benefit from such training. The radiometrology laboratory is not equipped with active air sampling stations, and the one in Gomel can only detect whether radionuclide concentrations in the air around Gomel are elevated relative to the levels of uncontaminated regions. . Virtually all of the equipment in the radio-spectrometry laboratory, largely already obsolete (installed in 1986), has failed. There are insufficient funds for repair or replacement, and the lab has only survived by taking from the mobile laboratory, which is now no longer functional as a mobile lab.

330. The extent of the monitoring and analysis effort in Belarus, including the number of samples tested, as well as the scope and quality of results, is impressive, particularly considering the age, scarcity and condition of equipment. In general, the size of the laboratories and qualifications of the staff in both the Center for Radiation Control and Environmental Monitoring and the Research Institute for Radiology in Gomel Oblast are adequate to meet the sampling and analysis requirements for environmental monitoring of radioactive pollutants. However, this is not the case for environmental monitoring of radionuclides in food products where a very limited number of trained and qualified staff are available to deal with a large sample load. This leads to considerable delays between the receipt of samples, their analysis and the reporting of results. As described below, this poses problems particularly for the monitoring of acceptable levels of radioactivity in milk and milk products.

Monitoring Radionuclides in Agricultural and Other Products

331. Immediately after Chernobyl, the USSR Ministry of Health established strict permissible levels for radionuclide content in foodstuffs, consistent with the international guidelines that recommend a *total* annual exposure for humans not to exceed 1 mSv. In 1990, Belarus obtained the right to set its own standards differing from those of the rest of the FSU. It continued to use the annual external exposure standard of 1 mSv. In 1999, Belarus tightened standards regulating permissible levels of cesium-137 and strontium-90 content in foodstuffs and drinking water. MPL-99 was standards were developed in accordance with international recommendations requiring that total exposure for humans

should not exceed 1 mSv/year. This maximum exposure is calculated as a function of what is called *external* exposure that comes from radionuclides deposited in the surrounding environment, and *internal* exposure through the food chain or inhalation. For Belarus, both factors in this equation can account for significant exposure levels. In other countries that establish similar standards but where *external* exposure is virtually nil, permissible levels of radioactivity for *internal* (from food) exposure can be and often are set higher. Belarus also bases its permissible levels on the highest rather than on average exposure levels. As noted above, since Belarus is now in an economic union with the Russian Federation, their principal trading partner, they are in the process of merging their requirements with Russian standards, which in some cases are even more stringent than those of Belarus.

332. Monitoring permissible levels in foodstuffs across the country entails a massive sampling and analytical effort. A network of hundreds of laboratories, including those of the Ministry of Agriculture and Food, Ministry of Health, BelKoopSouz and Forestry Committee are used for monitoring. The Ministry of Agriculture's network alone includes 928 laboratories with radiation monitoring capacity, which is used to conduct 3 million tests per year. The Ministry of Health conducts around 180,000 tests per year to measure the radionuclide content in food. In total, more than 1,400 stations exist to monitor radiation contamination in food products sold in Belarussian markets, as well as food produced for self-consumption on individual farms. Food products are monitored on the farm, at the input and output points of all food processing plants, and in markets prior to sale.

333. The RIR is responsible for monitoring food and environmental samples for the State Committee for Chernobyl. The staff of 15 carries out sample processing and measurement for gamma-emitting radionuclides on almost 3000 samples per year and radiochemical analysis of around 2000 samples per year for Sr-90. The Institute is just starting to analyze for plutonium. The samples consist of soils, milk and biological materials (plants). The laboratories are equipped with two gamma-spectrometers, one automated beta-counter for Sr-90 and three alpha-spectrometers for measurement of alpha-emitting radionuclides (plutonium, americium). They are in need of additional and more up-to-date equipment to improve sample analysis capabilities and reduce sample turnaround times. They also lack supplies and ancillary equipment, tracers, reference materials for quality control of measurements, and training for staff.

334. Monitoring foodstuffs for gamma-emitting radionuclides (e.g. Cs-137) is adequately performed at all four stages, since the analysis can be performed relatively quickly and simply, can be automated, and non-technical staff can be trained to perform the routine measurements. This is not the case, however, for the analysis of pure alpha (Pu) and beta-emitting (Sr-90) radionuclides. This requires tedious and time-consuming, destructive radiochemical separations, analysis and measurements, and well qualified staff who have been extensively trained in radiochemical analysis.

335. For Sr-90 in particular, laboratories in Gomel and Minsk often require two weeks to provide results on samples sent from food processing plants. This delay is unacceptable. These plants (especially those producing fresh milk) need to decide on an

appropriate course of action within a short period of time after receiving raw farm products for processing. In the case of milk, the level of Sr-90 and whether it exceeds permissible levels, will govern whether the milk will be processed as milk, cream, cheese, or caseine, or whether it needs to be destroyed. The acceptable delay for detecting Sr-90 levels in milk is no more than one day. Meeting the analysis needs of food processing industries for Sr-90 would require establishing many local laboratories, adequately equipped and with properly trained staff, capable of processing all samples received in one day.

336. To further improve monitoring of radionuclides in the agricultural sector, Belarus would also like to implement chemical and radiological testing of agricultural soils. This should permit pre-selection of land for growing fodder and allow for a more scientific selection of lands, crop types and brands, fertilizing and watering techniques, and cattle pasturing sites and feeding techniques, all aimed at reducing the overall uptake and transfer of radionuclides from soil to milk and meat. Grass could also be tested in the fields before pasturing and haymaking to determine its radionuclide content, and hence its best use or its need for additional treatment or processing. The Ministry of Agriculture estimates that regional agricultural chemical and veterinary laboratories could do this work if properly equipped and trained. Meeting increasingly stringent standards for meat production may also require the installation at slaughter houses of more sophisticated monitoring, such as life-cycle radiation control units for cattle supplied from contaminated zones.

337. Three laboratories performing environmental analyses were visited in the course of the mission, two in Minsk and one in Gomel. A detailed report on the three laboratories visited is available on request.

F. Future Implications And Outlook

338. The Ministry of Agriculture and the State Committee on Chernobyl have provided two proposals that offer interesting possibilities for agricultural land use reform, better application of agricultural countermeasures and forestry improvements:

- (i) radiation countermeasures for food production.
- (ii) support for agribusiness in the Gomel, Brest and Mogilev Oblasts.

339. Under the former, the following activities would be supported:

- Regrassing pasture land
- Liming
- Application of potassium and phosphorous fertilizers
- Remediation of natural hay fields and pastures
- "Clean" feeding of animals prior to slaughter

340. The government is already taking some action in all of these areas, but much more can be done. Technical support for agricultural enterprises, especially those that are privatized, could be initiated under this first proposal through demonstration projects.

341. In terms of the second proposal, that is supporting agribusiness in the Gomel, Brest and Mogilev Oblasts, the Mission identified a number of interventions in the area of food processing that could ameliorate the effects of radiation. Table 8-2 lists these as:

- Grain Milling
- Processing grain into alcohol
- Processing seeds into oil
- Potato pilling
- Processing milk into butter and cream
- Cooking and curing meat

342. As with the countermeasures at the farm level in the first proposal, the measures above to support agribusiness in the Gomel, Brest and Mogilev Oblasts are already being implemented to some extent. However, external support in the form of financial and technical assistance would greatly advance the adoption of new technologies through the transfer of knowledge to local enterprises. Greater seed fund support for the development of agro-processing is also needed.

343. In addition, there is a need for improved monitoring of radionuclides in the Gomel, Brest and Mogilev Oblasts. As noted above, monitoring of the radionuclides is of critical importance. Although the government continues to do its best, there are gaps and deficiencies. In particular, the timely monitoring of Sr-90 is not taking place owing to a lack of local laboratories with trained staff and required equipment. External support to establish local laboratories and provide equipment and training for the analysis of Sr-90 is urgently needed.

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