Remediation in areas affected by the Chernobyl Accident

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- Most effective remedial actions implemented to reduce internal and external exposures
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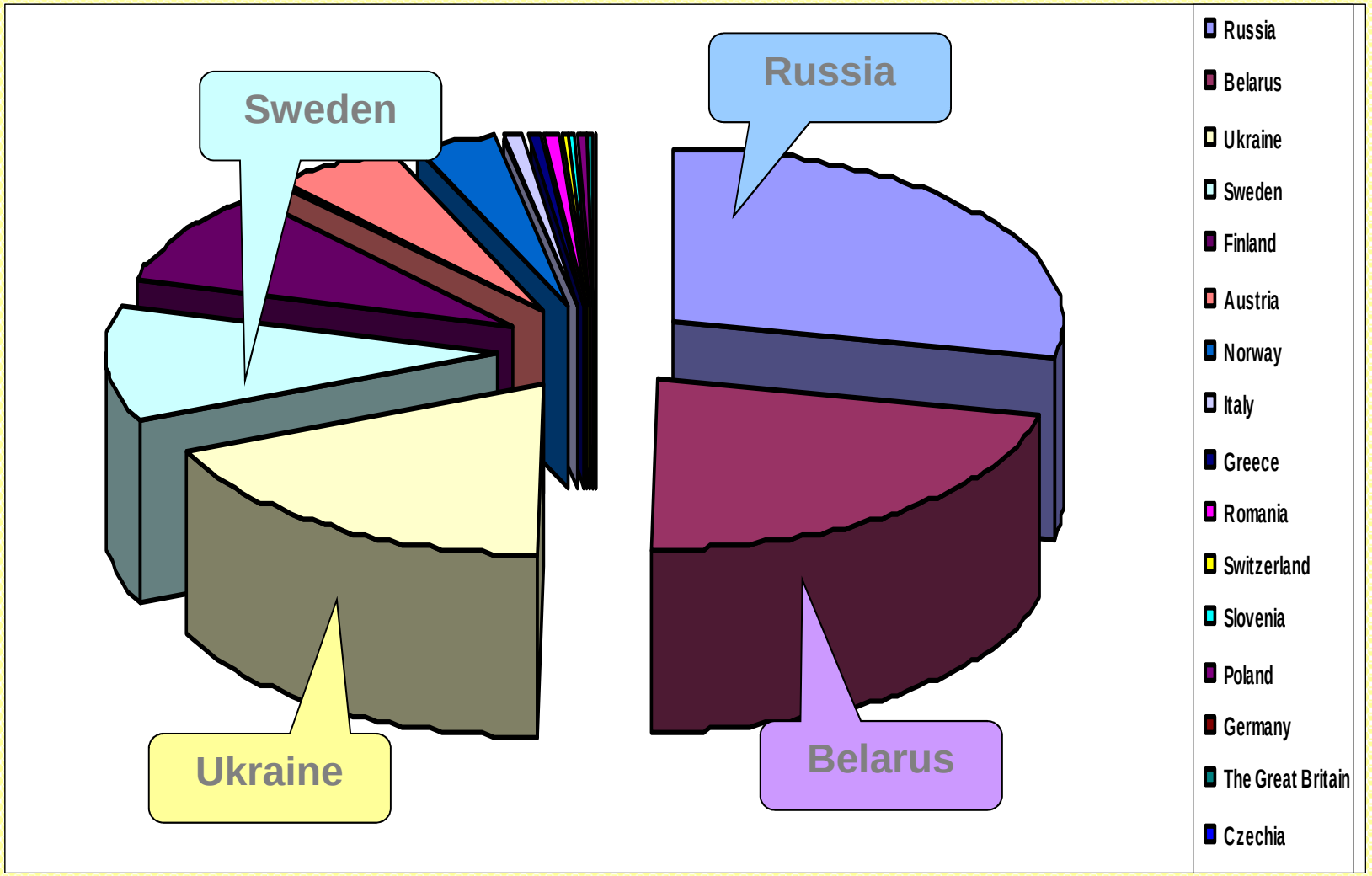
The accident at the Chernobyl NPP was the most serious radiation accident:

- Total activity more than 14×10^{18} Bq
- Radiologically most important radionuclides were ^{131}I and ^{137}Cs.
- 340 thousand people were evacuated or resettled.
- More than 5 million people still leaving in the affected areas.
- The Chernobyl NPP (ChNPP) was surrounded by vast tracts of agricultural land and forests
  - Extremely severe impact on the rural economy.
- The accident occurred in April at a very vulnerable period for farming - end of sowing campaign and start of cattle grazing.

Countries in with activities per unit area above 37 kBq/ m^2 *(Atlas., 1998)*



10^3 km^2
59.8
46.1
38.2
23.4
19
11.1
7.2
1.4
1.2
1.2
0.7
0.6
0.5
0.3
0.2
0.2
Σ 211.1

Acute phase

- During the first few weeks after the accident ^{131}I was the main contributor to internal dose.
- Along with radioiodine contamination, both plants and animals were also contaminated with Cs and Sr-isotopes which represented long-term radiation risk.
- Other radionuclides present such as ^{95}Zr, ^{95}Nb, ^{103}Ru, ^{140}Ba and ^{140}La, ^{141}Ce were of minor importance, due to their short physical half-lives.

Regulatory actions

The main goal - to reduce the external and internal doses of irradiation of population to prevent the deterministic effects and provide production of foodstuff with radionuclide content below TPL.

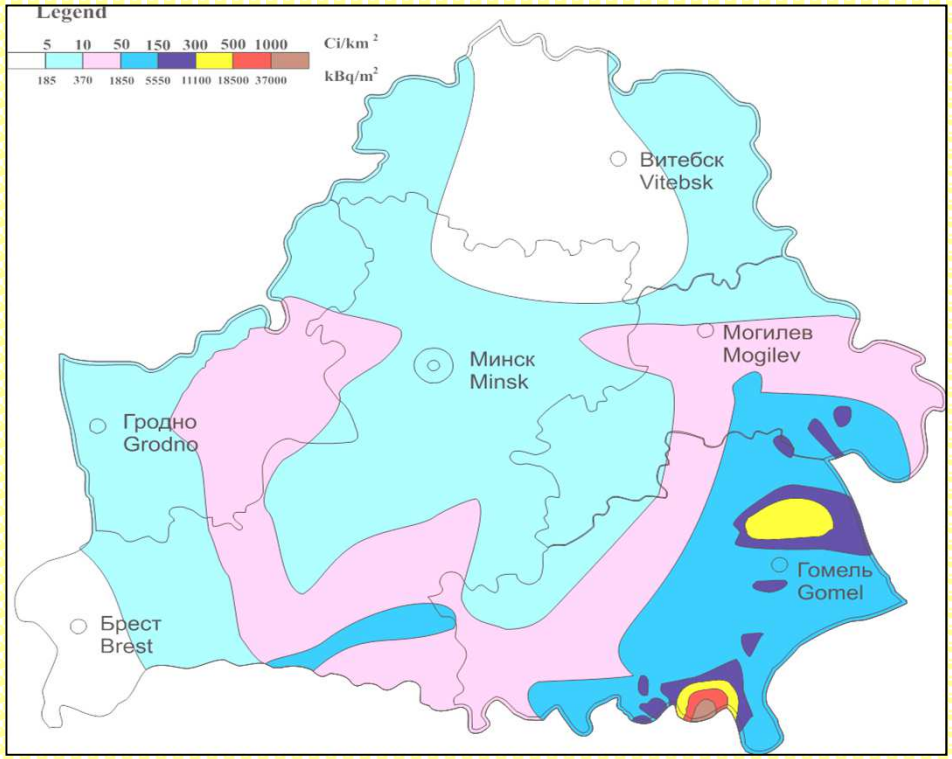
TPL (Bq/kg) of radionuclide content in food in USSR after Chernobyl (1986-1991)

Date of adoption	6.05.1986	30.05.1986	15.12. 1987	22.01. 1991	
Radionuclide	^{131}I	Beta emitters	^{134}Cs & ^{137}Cs	^{134}Cs & ^{137}Cs	^{90}Sr
Drinking water	3700	370	18.5	18.5	3.7
Milk	370-3700	370-3700	370	370	37
Meat and products	—	3700	1850-3000	740	—
Fish	37 000	3700	1850	740	—
Vegetables, fruit,	—	3700	740	600	37
Bread, flour, cereals	—	370	370	370	37
Expected internal dose, mSv		<50	<8	<5	

Permanent resettlement zone (after 22 May 1986) - exposure >0.2 mGy/h, Dose>100mSv.
Temporary resettlement zone if exposure 0.05 - 0.2 mGy/h, Dose >25 mSv.
Maximal doses of rural dwellers during 1986-1990 ≤ 175mSv/

Countermeasures in an early period of emergency (spring – autumn 1986)

Iodine-131 deposition in Belarus 10.05.1986



27- 28.04.1986. The lowest concentrations of ^{131}I in air on North of Belarus were 150-200 Bq/m^3. Safety limit is 7.3 Bq/m^3.
There was no Emergency preparedness for the protection of affected people in case of accident on Chernobyl NPP.

- Evacuation of 25 thousand inhabitants from 30-km zone of Chernobyl NPP
- Monitoring of radionuclide content in soil, water, food stuff (deficit of measurement devices. Soil maps of Cs and Sr deposition were prepared in August 1986).
- Feeding the milky cows with "clean" fodder (restricted use).
- Rejection of milk with ^{131}I content > PL and further processing for butter.
- Slaughtering of cattle from evacuated settlements (unjustified countermeasure).
- Information & recommendations for population on the contaminated territory (luck of experienced experts and reliable information, recommendations directed mainly to public sector of agriculture).

Countermeasures implemented during 1987-1989

- Relocation of people (470 settlements, 113 000 inhabitants started in 1989 and finished in 2001-2005).
- Exclusion of heavily contaminated agriculture land from use
  - 265 000 ha (1986-1991).
- Decontamination of schools, kinder gardens, farmer houses.
- Deep ploughing of meadows on peat soil (limited use).
- Exclusion of crops with high radionuclide uptake from soil (e.g.: legumes, buckwheat)
- Liming 682 000 ha & fertilization with higher doses of K.
- Restriction on the consumption of milk produced in private farms and milk processing.
- If ^{137}Cs-activity per unit area > 185 kBq/m^2
  - Use of clean feed for 45 days before slaughter
  - Live monitoring Animals
  - exceeding PLs were returned to the farm for further clean feeding

Main countermeasure to reduce external exposure

Decontamination of rural houses with dose monitoring were well accepted:

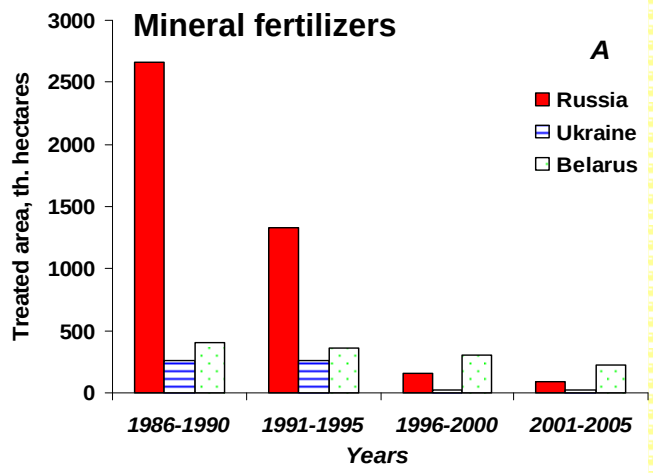
- Washing the roof, walls and pavement with high pressure water
- Removing contaminated dust with vacuum cleaners
- Removing topsoil from a 1 m strip around house
- Removing topsoil in garden (400-500 m^2 per house)

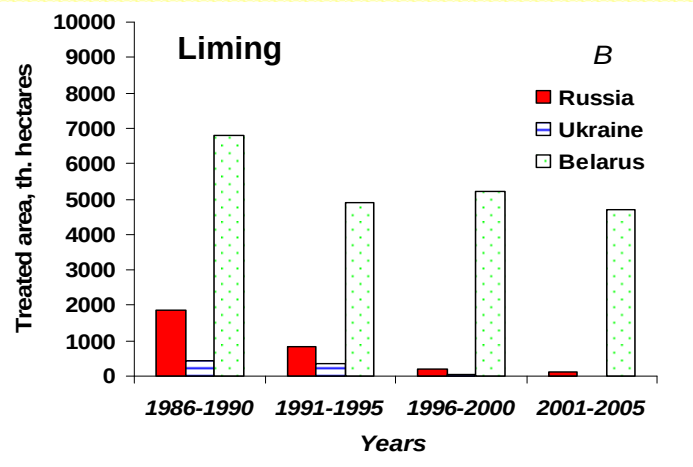
Dose reduction -DRF= 0.3-0.5 (80% of reduction due to decontamination of soil)

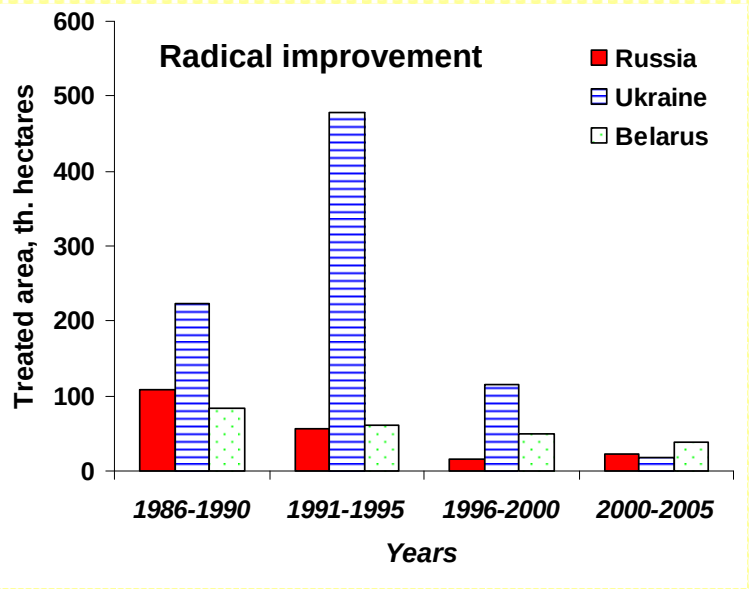
Summary of reduction factors of countermeasures used in FSU countries

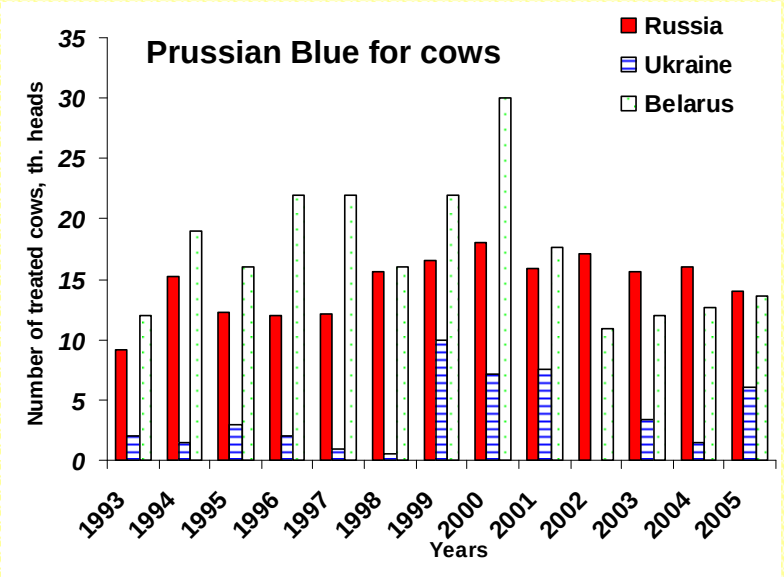
Countermeasure	**^{137}Cs**	**^{90}Sr**
Normal ploughing (first year)	2.5–4.0	
Skim and burial ploughing	8–16	
Liming, mineral and organic fertilisers	1,5–3,0	0,8–2,6
Radical improvement:		
– First year	1,5–9,0*	1,5–3,5
– Further applications	2,0–3,0	1,5–2,0
Surface improvement:		
– First application	2,0–3,0*	2,0–2,5
– Further applications	1,5–2,0	1,5–2,0
Change in fodder crops	3–9	
Clean feeding	2–5	2–5
Administration of Cs binders	2–5	–
Processing milk to butter	4–6	5–10
Processing rapeseed to oil	250	600

Changes with time in the extent of remedial actions applied in the FSU countries









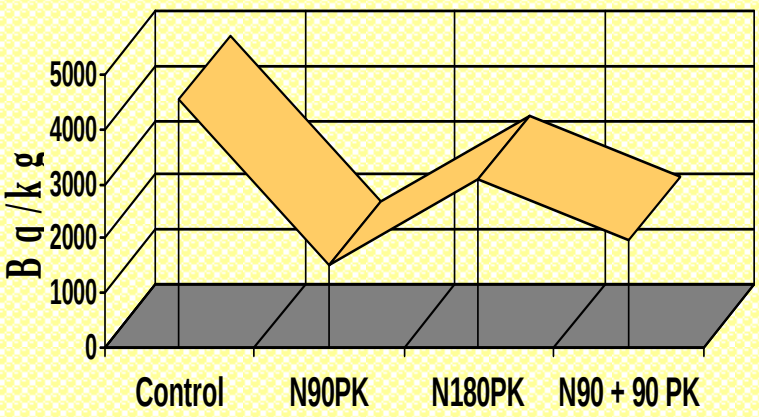
Radical improvement of pastures & meadows

The most efficient and acceptable by farmers remedial action.

- Liming of acid soils, fertilization, destruction old grass mat, sowing of new grass stand, and the regulation of soil water (drainage), if needed.
- Reduction of grass activity 2-10 times (depending on intensity)
- Usually, the **expenses** for pasture improvement are **covered by extra yield** of milk.

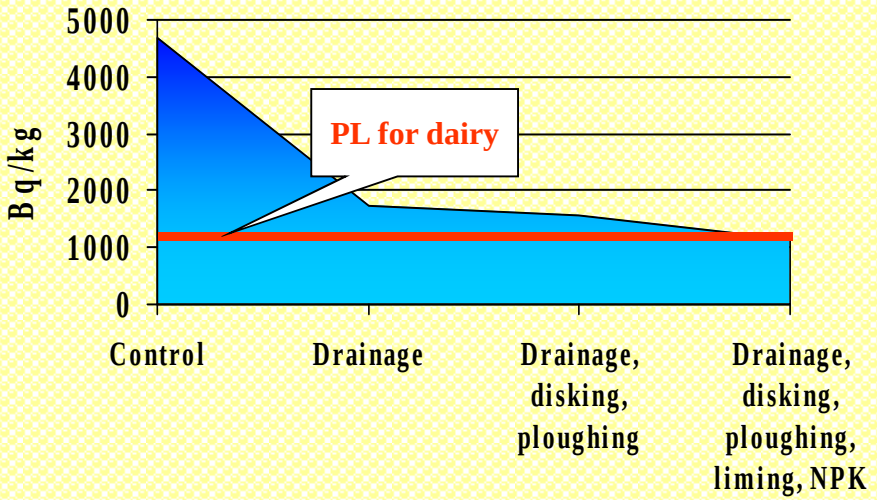
^{137}Cs concentration in hay depends on NPK fertilizer rates & ratios

(deposition by ^{137}Cs - 370 kBq.m^{-2})



^{137}Cs concentration in hay depends on type of meadow improvement

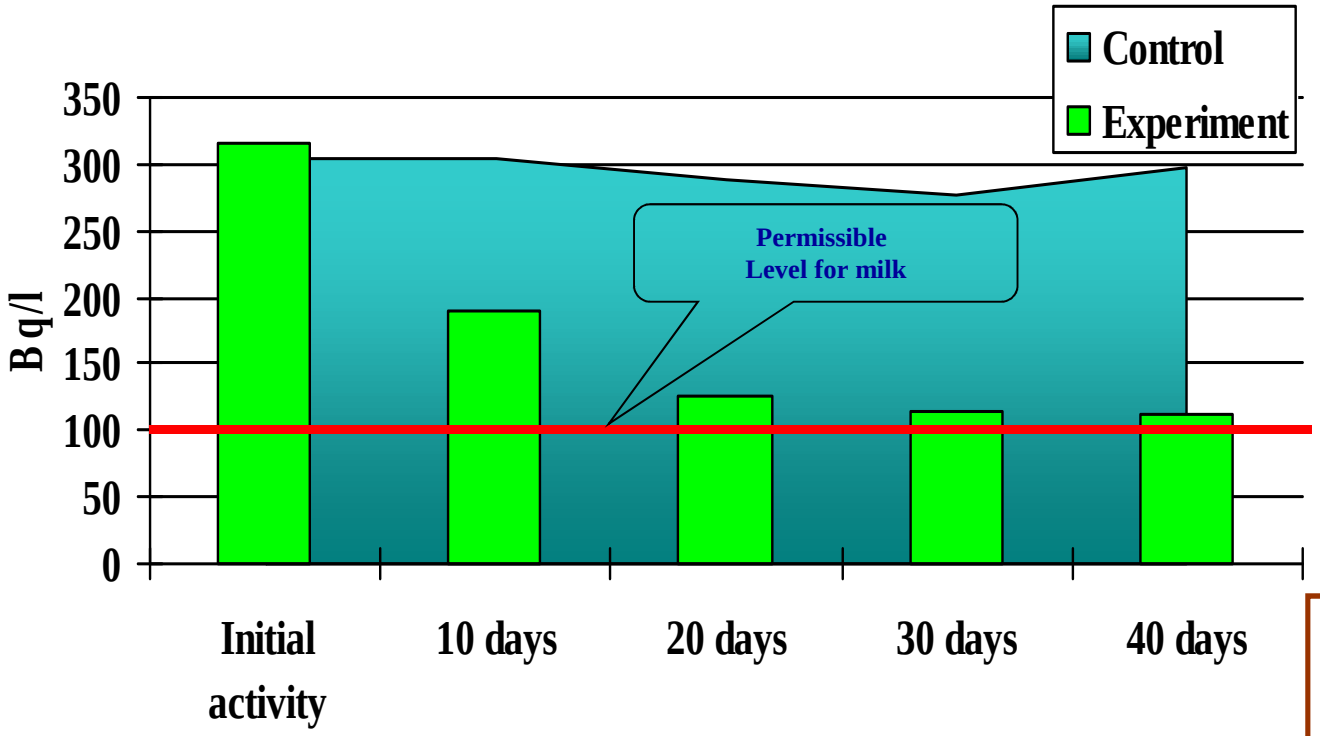
(deposition by ^{137}Cs - 370 kBq.m^{-2})



Prussian blue (PB) for cows

The easiest and cheapest remedial action is direct incorporation of Prussian Blue (Hexacyanoferrate compounds) into concentrate during manufacturing.

Dynamics of ^{137}Cs activity of milk after PB application



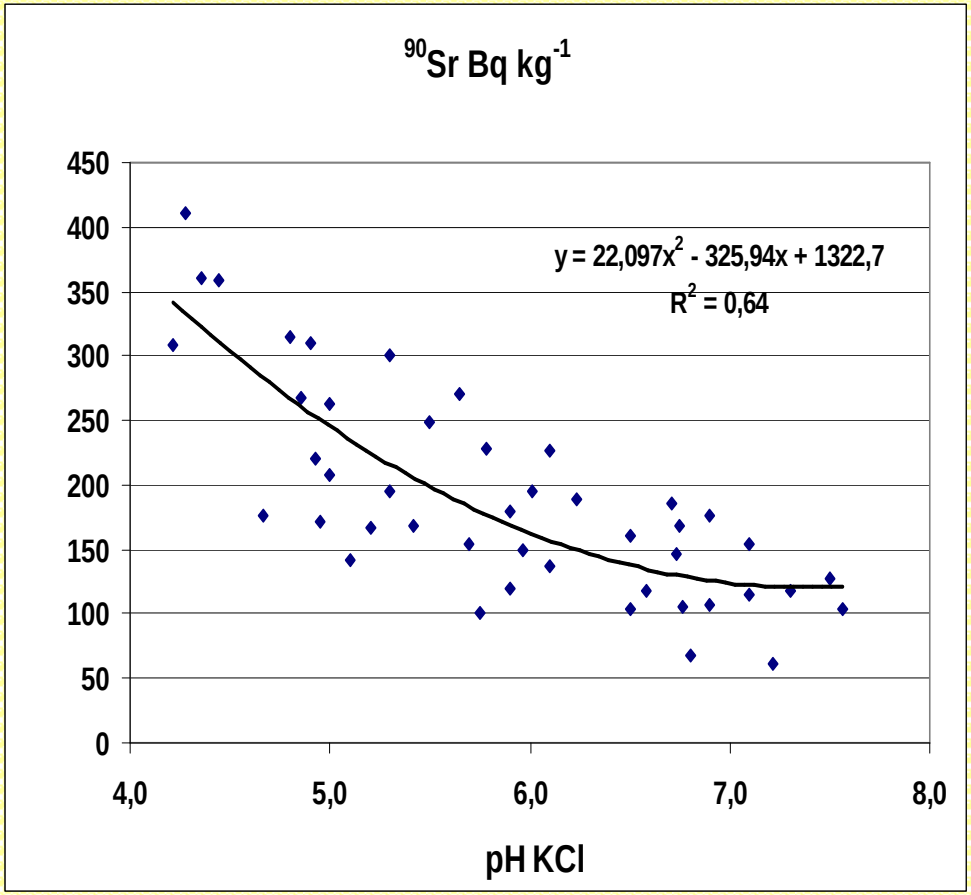
Reduction factor:

- **Milk: 3**
- **Beef: 2**

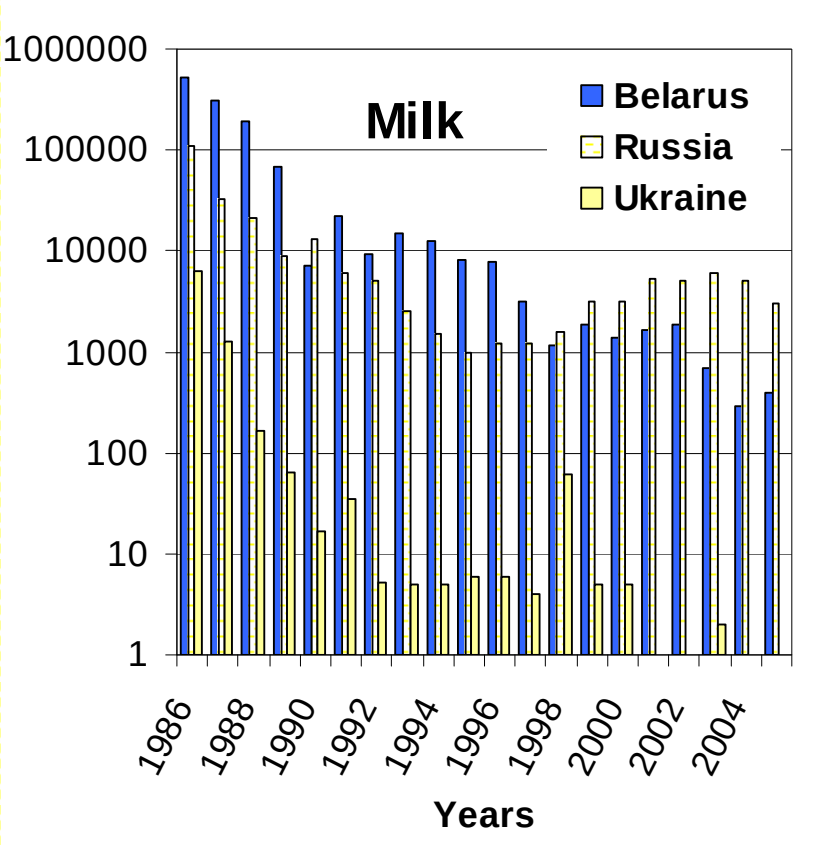
Liming

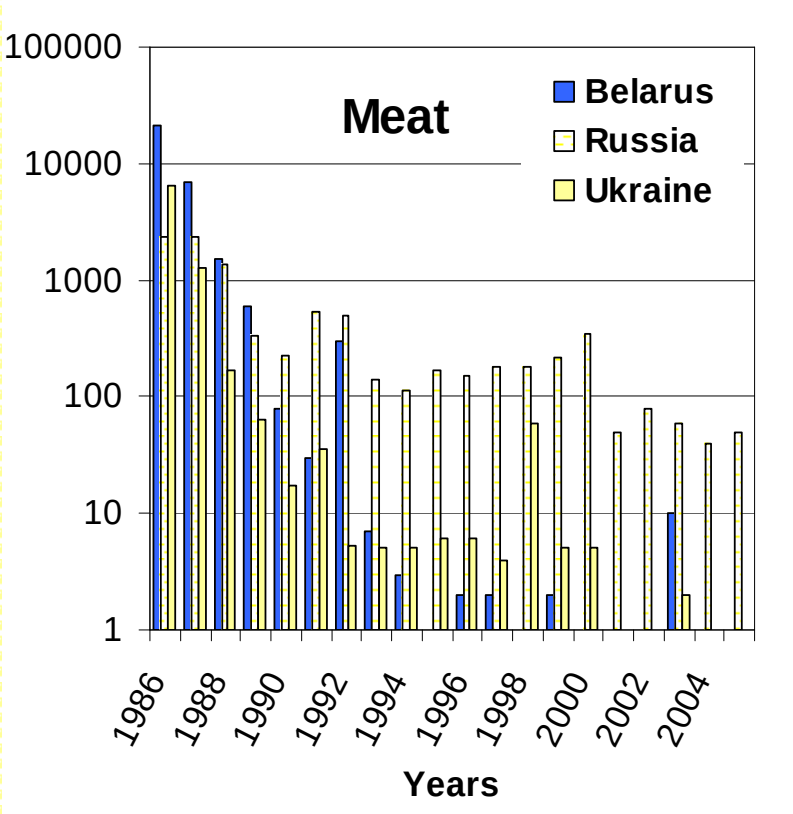
- Liming only efficient on acid soils (pH < 6.0)
- RF for ^{137}Cs and ^{90}Sr activities in plants 1.5-3.0.
- **Cost** of liming on such soils **covered by increased yield**
- Minimal uptake by plants at pH levels at 0.2-0.3 higher than maximum yield is achieved

Accumulation of ^{90}Sr in clover green mass in relation to reaction of Podzoluvisol loamy sand soil



Effect of remediation: Amounts of milk and meat exceeding action levels ***(tons)***





Optimizing remediation measures. Decision support for remediation planning – ReSCA

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ORIGINAL PAPER

ReSCA: decision support tool for remediation planning after the Chernobyl accident

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Rural areas affected by the Chernobyl accident: Radiation exposure and remediation strategies

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Justification of remediation strategies in the long term after the Chernobyl accident

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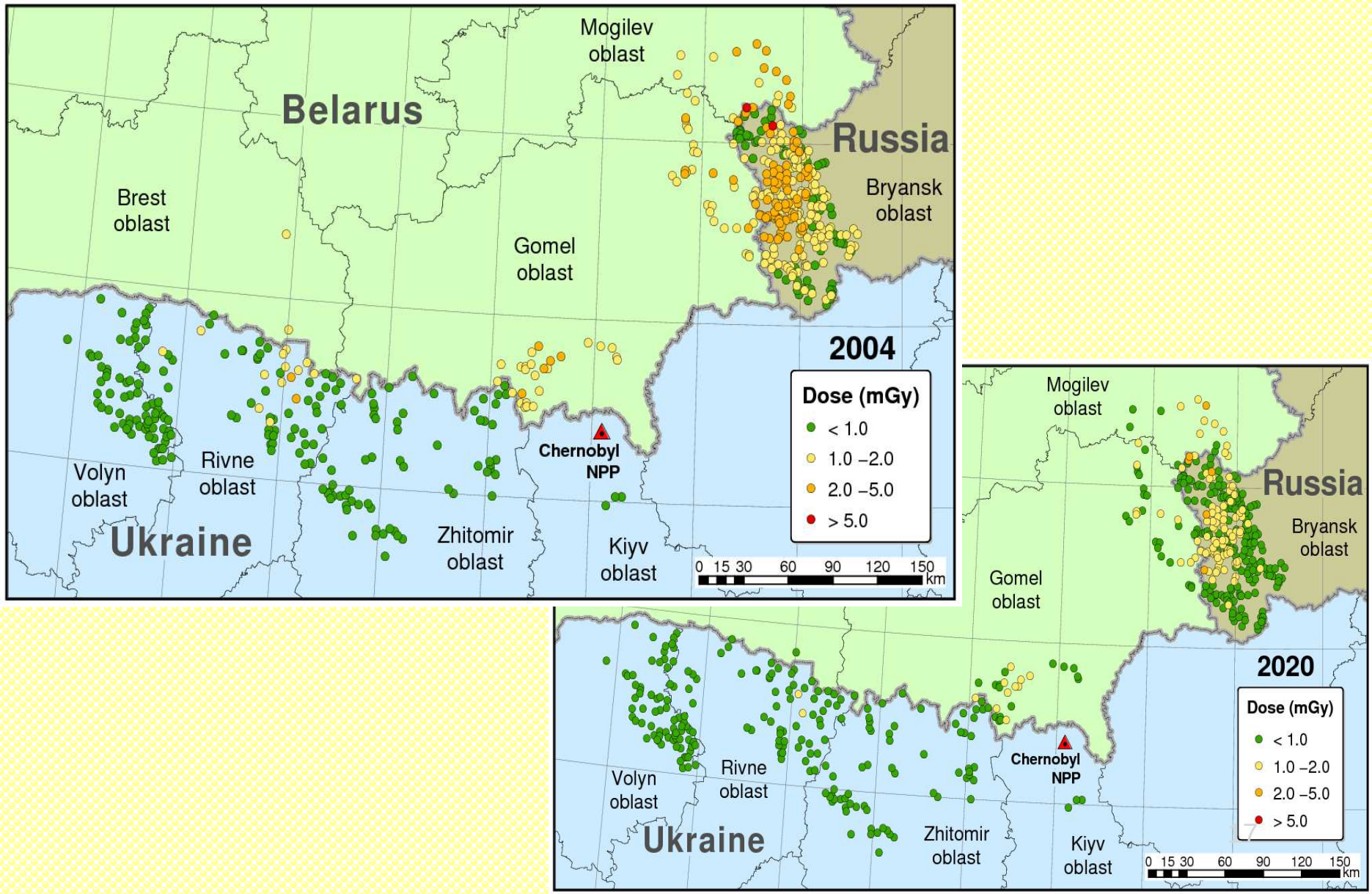
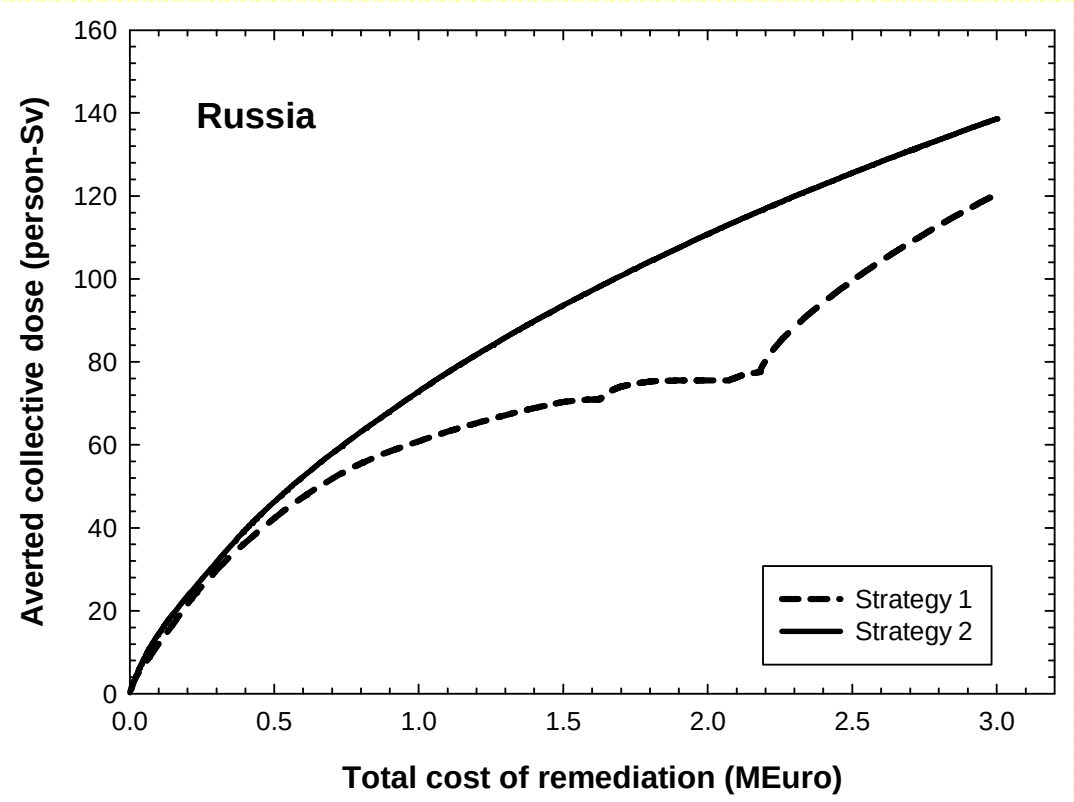
ARTICLE INFO ABSTRACT

Map of affected settlements, collared according to the annual dose as calculated with ReSCA



ReSCA software tool: Assessment effectiveness of the remediation strategies



Strategy 1:
- **Best acceptance**

Strategy 2:
- **Optimized from radiological view**

Variation in averted collective dose (person-Sv) depending on funds invested in remediation.

Lessons learned from Chernobyl

- Rural population around the ChNPP - external and internal exposure pathways are important.
- Production of foods with activities above action levels was considered as evidence that land and lifestyle had been severely affected.
- Rapid deployment of optimised countermeasures was a key mechanism to maintain social and psychological stability of the population of affected regions and decreased the level of stress of people inhabiting affected areas.
- Agricultural countermeasures and remedial options were the most efficient in reducing dose, averting 30-40 % of the collective internal dose to the affected population.
- Countermeasures in the early phase of the Chernobyl accident were only partially effective:
  - Little reduction of ^{131}I intake with milk due the lack of timely information on the accident and appropriate countermeasures
  - This led to significant radioiodine exposure of some people in the affected countries.

Lessons learned

- Application of **Prussian Blue** to cows started 6 years after the accident: its an effective alternative to the more expensive radical improvement,
  - Earlier application would have substantially reduced doses to the population.
- Until today, agricultural remedial actions are still effective
  - The application is necessary and justified in view of both national and recent international recommendations.
- It is advisable to use a harmonized approach for remediation planning. The example of such approach was given in this presentation. This approach is based on ICRP Publication 103.

- To identify priorities in remediation strategies with full involvement of all interested parties in planning is necessary.