MAIN HIGHLIGHTS ON CHERNOBYL OVER 30 YEARS AND CURRENT SITUATION

B.J Howard
Chernobyl USSR, 1986

- Unit 4
- Atmospheric release (PBq)
  - $^{131}I$ - 1760; $^{134}Cs \sim 47$, $^{137}Cs \sim 85$; $^{90}Sr - 10$
Radioactive Iodine Food Chain

In spring 1986, children and adolescents in surrounding areas of USSR received substantial radiation doses to the thyroid due to the consumption of milk contaminated with radiiodine.
Deposition of $^{137}$Cs in Europe

- More than 200,000 km$^2$ of Europe ‘contaminated’ with $^{137}$Cs, mostly in FSU countries
- More than 5 million people live in ‘contaminated’ areas
Agricultural countermeasures – early phase

Partially effective in reducing radioiodine intake via milk
  – lack of timely information about the accident and countermeasures, particularly for private farmers

Most effective countermeasures in the early phase
  – exclusion of contaminated pasture grasses from animal’s diet
  – exclusion of milk (with further processing) based on radiation monitoring data
  – Feeding animals with "clean" fodder in some affected countries, but not in USSR due to lack of supply

Slaughtering of cattle was unjustified from a radiological point of view
  – hygienic, practical and economic problems (wastes)
Existing situation - features of contaminated USSR

<table>
<thead>
<tr>
<th>Population intensity</th>
<th>Moderate, no pressure to use land</th>
</tr>
</thead>
<tbody>
<tr>
<td>Terrain</td>
<td>Flat, forested and agricultural</td>
</tr>
<tr>
<td>Intensity of agriculture</td>
<td>Low - medium</td>
</tr>
<tr>
<td></td>
<td>- Collective farms</td>
</tr>
<tr>
<td></td>
<td>- Private subsistence farmers</td>
</tr>
<tr>
<td>Key products</td>
<td>Milk, meat, grain, potatoes</td>
</tr>
<tr>
<td>Lateral movement across landscape</td>
<td>Low</td>
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</tbody>
</table>

Population intensity: Moderate, no pressure to use land
Terrain: Flat, forested and agricultural
Intensity of agriculture: Low - medium
- Collective farms
- Private subsistence farmers
Key products: Milk, meat, grain, potatoes
Lateral movement across landscape: Low
Initial reduction in transfer due to weathering, physical decay, vertical migration of radionuclides down the soil and reductions in bioavailability in soil

Soil to plant transfer important with strong time dependence - $^{137}$Cs and $^{134}$Cs

Long term $^{137}$Cs in meat and milk - important contributors to internal dose
Characteristics of the contaminated landscapes -

**Internal exposure pathways**

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Exposure Level</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fraction of soils with high organic matter or sandy content</td>
<td>Moderate to High</td>
</tr>
<tr>
<td>K fertiliser usage</td>
<td>Very low to moderate</td>
</tr>
<tr>
<td>Radiocaesium availability for root uptake</td>
<td>Moderate to very high</td>
</tr>
<tr>
<td>Transfer to animal products</td>
<td>Moderate to High</td>
</tr>
<tr>
<td>Intake of local food</td>
<td>High to very high</td>
</tr>
<tr>
<td>Intake of wild food</td>
<td>Moderate to very high</td>
</tr>
</tbody>
</table>
Cs-137 in foodstuffs affected by:
- deposition density
- chemical form
- soil types
- management practices
- type of ecosystem

Major persistent problems
- extensive systems with high organic or sand content soils
- subsistence farmers with privately owned dairy cows grazing in unimproved pastures
Agricultural environment - other radionuclides

- $^{90}$Sr, plutonium isotopes and $^{241}$Am, mostly insignificant in terms of human dose
- Sr-90 could contribute to internal dose mainly in the exclusion zone
  — increase with time

Dynamics of $^{90}$Sr transfer factor into grass in the 30-km zone (Kashparov et al., 2004).

$^{239/240}$Pu > 3.7 KBq/m$^2$
Extensive systems – “wild” animals

- Reindeer
- Grouse
- Roe deer, wild
- Moose

USSR, fSU, Western Europe

High RCs transfer, seasonal trends, long effective half lives

Semi-domesticated, free-ranging animals
Forests

- high RCs uptake by mushrooms, berries
- persistent recycling of RCs for several decades
- wood ash can contain high amounts of RCs
- External doses to workers needs to be considered
- importance of forests contribution to radiological exposures of population increased with time
- timber etc. gives only small contribution to exposure
- radiological consequences of forest fires unlikely to be high except possibly close to the fire

Cs uptake into mycorrhizal, parasitic, saprophytic mushrooms
Barnett et al 1992
Aquatic bodies

• Rapid reduction in [RCs] due to dilution, reduction in bioavailability in catchment and settling to sediments
• Lower weathering rate of fuel particles than in terrestrial ecosystems
• The most contaminated lakes have no inflowing and outflowing streams and an organic soil catchment
  ➢ long ecological half lives and potential significant source of dose to local population
PATHWAYS LESSONS LEARNED

• Severe impact of I isotopes in private milk
• High and sustained transfer of RCs to animal products in some areas close and far from the NPP
• Importance of soil type, extensive systems and wild food identified
• Deposition density plus soil type both critical
• Models giving site-specific spatial and temporal predictions are invaluable
Variation in relative internal and external doses.

*Internal and external doses in some areas affected by the Chernobyl accident normalized to $^{137}$Cs contamination density, 1996-2000, MBq m$^{-2}$ (Fesenko et al., 2000)*
Contamination of agricultural animal products often a major contributor to ingestion dose

% contribution to daily $^{137}\text{Cs}$ intake by population of Milaych, Ukraine (ECP9)
Remediation strategy

• Some hundred of thousands of people were living in areas with > 1 mSv/y
  • Need to remediate to reduce their effective dose rate - long term goal <1mSv/y
  • To enable residents of contaminated areas to return to a normal life
  • Secondary concern to return people to evacuated areas

• weighting of averted dose versus remediation costs was an important part of the remediation strategy
### Chernobyl designation of remediation areas

<table>
<thead>
<tr>
<th>137Cs kBq/m²</th>
<th>Designation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Below 37</td>
<td>Not contaminated</td>
</tr>
<tr>
<td>37 - 185</td>
<td>Remediation for areas with “sensitive soils” (eg. wet peat, acid sandy)</td>
</tr>
<tr>
<td>185 - 555</td>
<td>Remediation applied for sandy soils and light loam soils</td>
</tr>
<tr>
<td>555 - 1480</td>
<td>Full scale remediation</td>
</tr>
<tr>
<td>&gt;1480</td>
<td>No economic activity</td>
</tr>
</tbody>
</table>

Set definition of contaminated land at 37 kBq/m²

Identified settlements where annual dose rate was > 1 mSv. Izrael 1990

<table>
<thead>
<tr>
<th>Ambient dose rate μSv/h</th>
<th>2.2 corresponding to lifetime additional dose of 350 mSv (applied in 1989)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temporary permissible levels for effective annual dose</td>
<td>1986 – 100 mSv</td>
</tr>
<tr>
<td></td>
<td>1987 – 30 mSv</td>
</tr>
<tr>
<td></td>
<td>1988- 1989 – 25 mSv</td>
</tr>
<tr>
<td></td>
<td>1991- 1 mSv</td>
</tr>
</tbody>
</table>
## Permissible levels in food – changes with time

<table>
<thead>
<tr>
<th>TPL</th>
<th>4104-88</th>
<th>129-252</th>
<th>TPL-88</th>
<th>TPL-91</th>
</tr>
</thead>
<tbody>
<tr>
<td>Date of adoption</td>
<td>06.05.1986</td>
<td>30.05.1986</td>
<td>15.12.1987</td>
<td>22.01.1991</td>
</tr>
<tr>
<td>Nuclide</td>
<td>$^{131}$I</td>
<td>β-emitters</td>
<td>$^{134}$Cs + $^{137}$Cs</td>
<td>$^{134}$Cs + $^{137}$Cs</td>
</tr>
<tr>
<td>Milk</td>
<td>370–3700</td>
<td>370–3700</td>
<td>370</td>
<td>370</td>
</tr>
<tr>
<td>Meat and meat products</td>
<td>–</td>
<td>3700</td>
<td>1850–3000</td>
<td>740</td>
</tr>
<tr>
<td>Fish</td>
<td>37000</td>
<td>3700</td>
<td>1850</td>
<td>740</td>
</tr>
<tr>
<td>Eggs</td>
<td>–</td>
<td>37000</td>
<td>1850</td>
<td>740</td>
</tr>
<tr>
<td>Vegetables, fruits, potato, root-crops</td>
<td>–</td>
<td>3700</td>
<td>740</td>
<td>600</td>
</tr>
<tr>
<td>Bread, flour, cereals</td>
<td>–</td>
<td>370</td>
<td>370</td>
<td>370</td>
</tr>
</tbody>
</table>

### Country, International body

<table>
<thead>
<tr>
<th>Year of adoption</th>
<th>EU</th>
<th>Belarus</th>
<th>Russia</th>
<th>Ukraine</th>
</tr>
</thead>
<tbody>
<tr>
<td>Milk</td>
<td>370</td>
<td>100</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>Infant food</td>
<td>37</td>
<td>40–60</td>
<td>100</td>
<td>40</td>
</tr>
<tr>
<td>Dairy products</td>
<td>600</td>
<td>50–200</td>
<td>100–500</td>
<td>100</td>
</tr>
<tr>
<td>Meat and meat products</td>
<td>180–500</td>
<td>200</td>
<td>150</td>
<td></td>
</tr>
<tr>
<td>Fish</td>
<td>150</td>
<td>130</td>
<td>150</td>
<td></td>
</tr>
<tr>
<td>Eggs</td>
<td>–</td>
<td>80</td>
<td>6 Bq/egg</td>
<td></td>
</tr>
<tr>
<td>Vegetables, fruits, potato, root-crops</td>
<td>40–100</td>
<td>40–120</td>
<td>40–70</td>
<td></td>
</tr>
<tr>
<td>Bread, flour, cereals</td>
<td>40</td>
<td>40–60</td>
<td>20</td>
<td></td>
</tr>
</tbody>
</table>
### Agriculture remediation measures

<table>
<thead>
<tr>
<th>Remediation for animal products</th>
<th>Clean feeding</th>
<th>Live monitoring of domestic animals</th>
<th>Prussian Blue binder to animals</th>
</tr>
</thead>
<tbody>
<tr>
<td>Remediation of agricultural land</td>
<td>Radical improvement – ploughing, reseeding, additional fertilisation</td>
<td>Soil treatment with additional K and P</td>
<td>Soil amendment with liming</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Application of sorbents and organic fertilisers</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Drainage of wet peats</td>
</tr>
</tbody>
</table>

**LL** – combined highly effective and practical measure

Avoided measures which generated large amounts of waste (eg top soil removal)
Extensive agriculture remediation measures

- Free ranging animals
- New binder delivery systems
- Increase food action levels
- Live monitoring
Amounts of milk and meat exceeding action levels

NB Russia includes private produce
Forest remediation

Restrictions on
• Access, harvesting of food products, collection of firewood

Local monitoring
Fire prevention

Optimisation approach
Site specific settlement information on:
• Spatial variation in contamination
• Which mushroom species to avoid
• Where and when to collect wood, wild products and hunt game animals
• Tree felling schedules
• Restrictions on consumption of fish remain, in a few cases for several decades (closed lakes)
  • but such restrictions not always adhered to

• measures generally ineffective and expensive and relatively high exposures to implementing workers.
• Restrictions on consumption of freshwater fish
• Public information important
CURRENT SITUATION

• Since 1991, the proportion of animal products with $^{137}$Cs exceeding action levels has been <10% of the gross output from contaminated areas.

• Technologically based remediation measures applied to forests and surface waters not practicable on a large scale.

• Since mid-1990s, use of agricultural measures considerably reduced. Application rates inadequate for both conventional food production and remediation so some increase in $^{137}$Cs transfer occurred.

• Remediation ongoing in some areas with still high radiocaesium transfer from soil to vegetation.
- Since mid-1990s, use of agricultural measures considerably reduced.
- Application rates inadequate for both conventional food production and remediation

> **some increase in $^{137}$Cs transfer**

### Soil amendments – decline with time

#### liming

![Graph A](chart1.png)

#### Mineral fertilizers

![Graph B](chart2.png)
Use of Prussian Blue

Number of treated cows, th. heads

Russia
Ukraine
Belarus

Years

0
5
10
15
20
25
30
35

Centre for Ecology & Hydrology
NATURAL ENVIRONMENT RESEARCH COUNCIL
Settlement based information

The three fSU countries have developed “catalogues” for each remediated settlement – compiles annual effective doses due to both external radiation and ingestion of radiocesium, -strontium and plutonium.

Map of the 541 study settlements, with dose of the representative person from $^{137}\text{Cs}$ as calculated with ReSCA for 2004 (Jacob et al 2009 STOTEN 408)
REMEDIATION CURRENT SITUATION

• Most land previously contaminated with radionuclides is now safe for habitation and economic activities
• Still many people in settlements in Belarus and Ukraine with annual effective dose $> 1$ mSv
• However, in Chernobyl Exclusion Zone and isome limited areas of fSU some restrictions on land-use likely to be retained for decades
• In some areas with still high $^{137}$Cs transfer from poor sandy/peaty soils to vegetation remediation measures remain efficient
Changing emphasis with time

- Whilst cost benefit analysis was key factor during first decade, importance of considering social aspects increased thereafter.
- Long term adherence to banning the collection and/or consumption of products has reduced.
- Focus on providing readily understandable information and guidance on how people can themselves reduce their radiological risk

## Ranking of practicability

<table>
<thead>
<tr>
<th>Countermeasure</th>
<th>Belarus</th>
<th>Russia</th>
<th>Ukraine</th>
</tr>
</thead>
<tbody>
<tr>
<td>Radical improvement</td>
<td>High</td>
<td>High</td>
<td>High</td>
</tr>
<tr>
<td>Drainage</td>
<td>Low</td>
<td>Low</td>
<td>High</td>
</tr>
<tr>
<td>(for wet peat only)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Prussian blue</td>
<td>High</td>
<td>High</td>
<td>Moderate</td>
</tr>
<tr>
<td>Supply clean milk</td>
<td>Low</td>
<td>Low</td>
<td>Low</td>
</tr>
<tr>
<td>Clean feed for animals</td>
<td>Moderate</td>
<td>Moderate</td>
<td>Moderate</td>
</tr>
<tr>
<td>Mineral fertiliser for potatoes</td>
<td>Moderate</td>
<td>Moderate</td>
<td>High</td>
</tr>
<tr>
<td>Restrict mushroom consumption</td>
<td>Low</td>
<td>Low</td>
<td>Low</td>
</tr>
<tr>
<td>Food monitors</td>
<td>Moderate</td>
<td>Moderate</td>
<td>Moderate</td>
</tr>
<tr>
<td>Removal of soil</td>
<td>Low</td>
<td>Low</td>
<td>Low</td>
</tr>
</tbody>
</table>

Fesenko et al, 2006
• Remediation planning and identification of priorities for implementation essential
  – facilitated by available expertise in USSR
• Early application of previously identified suitable measures can substantially reduced internal doses to the population
• Implementation of effective measures may depend on availability of pasture and fodder – seasonally dependent
• Remediation may be required for many years after contamination occurs, depending on the soil types and agricultural production characteristics of the contaminated area
• Benefit of models which include effect of remediation measures (eg. ReSCA)
• Optimizing requires consideration of technical (e.g. effectiveness, cost, feasibility), environmental and social (e.g. acceptability, opportunities for self help) factors
  – *varies between countries*
• Importance of local monitoring and information, trusted professionals
• Success of remediation in private sector of subsistence rural farmers dependent on compliance of rural population - can only be achieved by:
  – *involvement in decision making process*
  – *providing good information*
  – *opportunity to discuss the implications of their decisions*
• Best measures depend on agricultural, environmental conditions and social/cultural perspectives

One solution does not fit all