Protective Measure and Criteria Development
the experience relating to the accident at the Chernobyl NPP

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Part 1

FMBA of Russia in mitigation of the accident at the Chernobyl NPS

Consequences of explosion of the detonating mixture during accidents at ChNPS and FNPS reactors

Assessment of the radiological accident severity by the INES scale

- The Japanese official authorities classified the accident at “Fukushima-1” NPS as the event of level 7, the highest level of INES scale proposed by IAEA in order to keep the public informed about a radiological accident.
- By nowadays only two reactor accidents (at the Chernobyl and Fukushima NPS) have been identified as the accidents of 7 level INES scale.
First operative information on the accident at the ChNPS (quote from the journal of the duty of the FMBA of Russia)
Clinic hospital No 6 - now FMBC of FMBA of Russia (1986)

Emergency response within the system of FMBA of Russia
## Radiation accidents

<table>
<thead>
<tr>
<th>Types of incidents</th>
<th>Number of victims</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Total</td>
<td>Acute radiation syndrome</td>
<td>Died</td>
</tr>
<tr>
<td>1. Radioisotope plant incidents</td>
<td>170</td>
<td>51</td>
<td>16</td>
</tr>
<tr>
<td>2. Roentgen plant incidents</td>
<td>50</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3. Reactor incidents</td>
<td>82</td>
<td>73</td>
<td>13</td>
</tr>
<tr>
<td>5. Nuclear submarine</td>
<td>133</td>
<td>85</td>
<td>12</td>
</tr>
<tr>
<td>6. Other accidents</td>
<td>17</td>
<td>7</td>
<td>2</td>
</tr>
<tr>
<td>7. Chernobyl accident</td>
<td>134</td>
<td>134</td>
<td>28</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>754</strong></td>
<td><strong>350</strong></td>
<td><strong>71</strong></td>
</tr>
</tbody>
</table>

- **FMBA Branch register of workers in nuclear industry affected by radiation exposure following the accident at the Chernobyl NPS (operates since 1987)**

- **Monograph**
  - «Severe Radiological Accidents: Consequences and Protective Measures» issued in Japan in Japanese

- **Workers of other Rosatom’s facilities** 66%
- **Workers of the NPS** 34%
Part 2

Evolution of the emergency measures and protective criteria

- soil contamination
- dose criteria
- foods
- conceptions, laws
- nowadays regulation

137Cs spots in Belarus, Russia and Ukraine following the ChNPS accident

International Symposium on Decontamination - Fukushima, Japan  16 – 17 October 2011
### Zoning of the area by radioactive contamination levels and expected radiation exposure

<table>
<thead>
<tr>
<th>Areas of</th>
<th>since 1991</th>
</tr>
</thead>
<tbody>
<tr>
<td>control</td>
<td>1-5</td>
</tr>
<tr>
<td>restricted residence</td>
<td>5-20</td>
</tr>
<tr>
<td>re-settlement</td>
<td>20-50</td>
</tr>
<tr>
<td>exclusion</td>
<td>&gt;50</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>since 986 $\sigma^{137}Cs$, $kBq \ m^{-2}$ ($Ci \ km^{-2}$)</th>
<th>Dose, $mSv/y$</th>
</tr>
</thead>
<tbody>
<tr>
<td>37-185 (1-5)</td>
<td></td>
</tr>
<tr>
<td>185-555 (5-15)</td>
<td></td>
</tr>
<tr>
<td>555-1480 (15-40)</td>
<td></td>
</tr>
<tr>
<td>&gt;1480 (&gt; 40)</td>
<td></td>
</tr>
</tbody>
</table>

**Map of the agricultural lands contamination with $^{137}Cs$ of the affected Russian regions, 2007**
Temporary emergency dose regulations (1986-1989)

<table>
<thead>
<tr>
<th>Year</th>
<th>Permissible dose</th>
<th>External doses</th>
<th>Internal doses</th>
</tr>
</thead>
<tbody>
<tr>
<td>1986</td>
<td>100</td>
<td>50</td>
<td>50</td>
</tr>
<tr>
<td>1987</td>
<td>30</td>
<td>17</td>
<td>13</td>
</tr>
<tr>
<td>1988</td>
<td>25</td>
<td>17</td>
<td>8</td>
</tr>
<tr>
<td>1989</td>
<td>25</td>
<td>17</td>
<td>8</td>
</tr>
</tbody>
</table>

1986 – External exposure
- 20 mR · h⁻¹ – exclusion area
- 5–20 mR · h⁻¹ – area of temporary evacuation
- 3–5 mR · h⁻¹ – strict control zone

1986 r. – Internal exposure
- $^{137}$Cs kBq m⁻² (Ci km⁻²) = 15 (555)
- $^{90}$Sr kBq m⁻² (Ci km⁻²) = 3 (111)
- $^{239, 240}$Pu kBq m⁻² (Ci km⁻²) = 0.1 (3,7)

- Over 1986, 116317 residents have been resettled from 187 settlements
### Radionuclides in foodstuffs

**Bq·kg⁻¹ (Bq·L⁻¹)**

#### Temporary Permissible Levels
**10 years after Chernobyl**

<table>
<thead>
<tr>
<th>Foodstuff</th>
<th>*1986</th>
<th>87-88</th>
<th>1991</th>
<th>1993</th>
<th><strong>137Cs</strong></th>
<th><strong>90Sr</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>Milk</td>
<td>370</td>
<td>370</td>
<td>370</td>
<td>370</td>
<td>100</td>
<td>25</td>
</tr>
<tr>
<td>Meat</td>
<td>3700</td>
<td>1850</td>
<td>740</td>
<td>600</td>
<td>160</td>
<td>50</td>
</tr>
<tr>
<td>Potatoes</td>
<td>3700</td>
<td>740</td>
<td>600</td>
<td>600</td>
<td>120</td>
<td>40</td>
</tr>
<tr>
<td>Fish</td>
<td>3700</td>
<td>1850</td>
<td>740</td>
<td>600</td>
<td>130</td>
<td>100</td>
</tr>
<tr>
<td>Mushrooms</td>
<td>18500</td>
<td>1850</td>
<td>1480</td>
<td>600</td>
<td>500</td>
<td>50</td>
</tr>
<tr>
<td><strong>Grains inc rice</strong></td>
<td><strong>370</strong></td>
<td><strong>370</strong></td>
<td><strong>370</strong></td>
<td><strong>370</strong></td>
<td><strong>70</strong></td>
<td><strong>40</strong></td>
</tr>
</tbody>
</table>

* May 1986 - **131I** – milk & water - 3700 Бк·л⁻¹

** Standards are considered as acceptable levels below which any actions should not be applied to foodstuffs distributed in national trade

#### Permissible Levels since
**1996 –> 2011...**

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*International Symposium on Decontamination - Fukushima, Japan  16 – 17 October 2011*
Conclusions on Implementation of the Temporary Permissible Levels for foods

- Strict TPL for milk for the purpose of maximum reduction of public doses
- Establishment of preventive prohibitive measures (removal of dairy cattle, grading, withdrawal of agricultural farms from circulation) and advisory measures (restriction of individual consumption)
- Advantages in terms of emergency management and public perception
- However were not in fully compliance with the optimization principle, which requires the best decisions in each specific situation
Nowadays - Regulatory documents (2002)

Requirements safety and food value of foodstuffs

13 categories, 141 foodstuffs inc. not only permissible levels of specific activities $^{90\text{Sr}}$ and $^{137\text{Cs}}$

Radiation control $^{90\text{Sr}}$ and $^{137\text{Cs}}$ Foodstuffs

Sampling guidelines
Preparation of samples to be measured and their measuring
Compliance with the requirements

Soil contamination density with $^{137\text{Cs}}$, kBq/m$^2$

<table>
<thead>
<tr>
<th></th>
<th>Average content of $^{137\text{Cs}}$ in game, Bq/kg</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>37–555</td>
</tr>
<tr>
<td>500–3500</td>
<td></td>
</tr>
</tbody>
</table>

Permissible specific activity of $^{137\text{Cs}}$ in meat

160 Bq/kg

Food radioactivity after 1992

<table>
<thead>
<tr>
<th>Foods</th>
<th>Affected (Bryansk) Russian region</th>
<th>Pure regions (Moscow, Twer, Voronez, Rostov)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$^{137\text{Cs}}$</td>
<td>$^{90\text{Sr}}$</td>
</tr>
<tr>
<td>Milk</td>
<td>49.0</td>
<td>1.5</td>
</tr>
<tr>
<td>Meat</td>
<td>36.5</td>
<td>2.3</td>
</tr>
<tr>
<td>Fish</td>
<td>84.6</td>
<td>2.3</td>
</tr>
<tr>
<td>Bread</td>
<td>4.5</td>
<td>1.8</td>
</tr>
<tr>
<td>Potato</td>
<td>8.4</td>
<td>1.7</td>
</tr>
<tr>
<td>Wild berries</td>
<td>614.4</td>
<td>2.3</td>
</tr>
<tr>
<td>Mushrooms</td>
<td>3376.0</td>
<td>2.2</td>
</tr>
</tbody>
</table>
Evolution of the protective criteria
(1986 – 2011)

Over 25 years since the accident at the Chernobyl NPP, the views have evolved and revised significantly:

- Over the first 3 years after the accident, temporary annual dose limits were in use; the compliance with these limits has led to violation of the traditional public life.
- Then – the concept of the life dose limit, which assumed to refuse the restrictions for some areas. Application of the dose limits in the emergency situation seems to be inappropriate (illegal) now.
- 1991 – the concept of annual average effective dose and account of the intervention situation. Focus on social and psychological factors, including, enhanced medical care, ensuring adequate nutrition, measures aimed at reduction of social and psychological stress, and other social and economic measures (social benefits, monetary or other compensation, guarantees).
Radiation zoning in Laws on Social Protection (1992, 1997)

- **Radiation control zone** – from 1 to 5 mSv – monitoring of the environment, agricultural products, optimization principle
- **Area of the restricted residence** – from 5 to 20 mSv – voluntary entry for permanent residence is not limited. – Health risk is explained to individual
- **Area of resettlement** – from 20 to 50 mSv – entry is forbidden. – Permanent residence of persons of reproductive age and children is forbidden
- **Exclusion zone** – more 50 mSv - Permanent residence is forbidden, economic activity and natural resources are regulated by the special acts
Criteria aimed at medical protection and rehabilitation of the public

Categories of citizens included in the National radiation and epidemiological register according to their accumulated dose:

- effective dose > 50 mSv for acute exposure or 70 mSv for chronic exposure
- children injured > 10 mSv *in utero*
- dose to the thyroid > 0.5 Gy for adults and – 0.2 Gy for children

Among the mentioned categories, the groups of the *increased risk* are selected:

- > 250 mSv of acute exposure,
- > 50 mSv *in utero*,
- adults/children > 2.5 / 1 Gy to the thyroid
Part 3

Decontamination, countermeasures and remediation strategies after the accident at the Chernobyl NPP

Current radiation situation in RF:

- In 2 of 14 Russia subjects prescribed to the area of radioactive contamination, 10% samples of the local foods exceed norms by cesium-137 (milk, wild foods)
- In more than 300 settlements, dose is > 1.0 mSv/year (max=9.4 mSv/year)
Decontamination – early stages of the accident

- May 29, 1986: Resolution of the USSR Council of Ministers "On the Performance of Decontamination Works ...»
- Works were carried out in 30-km zone and in the strict control zone (>15 Ci per km²) by chemical forces and civil defense units
- Criteria: (1) belonging to the strict control zone, (2) socio-economic significance of objects, (3) exceeding of the surface contamination regulations
- Regulations: Temporary permissible dose rates (mR/h) and the surface contamination density of objects (part. / min· cm²)

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>mR/h</td>
<td>mR/h/particles</td>
<td>mR/h/particles</td>
<td>particles</td>
</tr>
<tr>
<td>Roads</td>
<td>1.5 – 0.2</td>
<td>0.2 / 2000</td>
<td>0.1 / 1000</td>
<td>-</td>
</tr>
<tr>
<td>Inside buildings</td>
<td>0.3 – 0.1</td>
<td>0.04 / 400</td>
<td>- / 200</td>
<td>100</td>
</tr>
<tr>
<td>Outside buildings</td>
<td>0.7 – 0.5</td>
<td>0.5 / 5000</td>
<td>0.2</td>
<td>-</td>
</tr>
</tbody>
</table>
The extent and effectiveness

- In total, after the accident, in western Bryansk regions (RF) decontamination of 472 settlements was carried out.
- Washing of buildings, cleaning of contaminated soil and roads, disinfection of water sources.
- Disposal in the special trenches with clay castles and the clay pillow, where lowering of relief is absent and groundwater level is low.
- Coefficient of contamination reduction was 1.2 – 1.6.

Decontamination being carried out over 3 years since the accident can reduce the 70 year-expected external dose to the public by 10% on average.
Parallel with Fukushima

- According to the Basic Policy for Emergency Response on Decontamination Work, August 26, 2011 in Japan decontamination is being performed in terms of the committed dose: **20 mSv/year** decontamination is required; from **1 to 20 mSv/year** – residents may live in these areas, decontamination – depending upon the dose dynamics; up to **1 mSv/year** – no decontamination

- The Environment Ministry has decided to decontaminate areas where people could be exposed to radiation of **5 mSv/year** and >

- Having the dose principle in mind, decontamination was being performed in the Russian areas under the committed dose from 5-20 mSv/year and higher. In the areas with dose < 1 mSv/year – not
Decontamination - nowdays

The way to reduce external doses to the residents:

- removal of the contaminated soil near houses and public buildings, where the population spends a considerable time
- as well as cleaning of roofs and other parts of buildings

Decontamination justified in rural settlements, where soil contamination with $^{137}$Cs is $1 \text{ MBq/m}^2$ and higher, where it has not previously been carried out (Project RER/09/59, IAEA, 2001)

- involves generation of large mass of low level waste
Agricultural countermeasures

- organizational (changing land using, selection of species)
- agro-technical and agro-chemical (plowing virgin land, draining of wet and liming of acid soils)
- countermeasures in animal husbandry (additional feeding with pure feeds)
- technological (treatment of the products)
- information

Application of ferrocine for private cows helps to reduce internal dose to the public by 50%

Truthful and convincing information to the public, aimed at overcoming of the residual, including psychological, consequences of the Chernobyl accident is very important.
Effectiveness of countermeasures at the late stage of mitigation of the Chernobyl accident*

<table>
<thead>
<tr>
<th>Protective measure</th>
<th>Reduction multiplicity</th>
<th>Action period</th>
<th>Costs (€)(^a)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Radical improvement</td>
<td>2–8</td>
<td>4 or 7 years</td>
<td>350–2350(^b)</td>
</tr>
<tr>
<td>Application of ferrocine for cows</td>
<td>2-3</td>
<td>To the extent of application</td>
<td>30–60(^b)</td>
</tr>
<tr>
<td>Pure feed for pigs</td>
<td>3</td>
<td>To the extent of application</td>
<td>6–20(^c)</td>
</tr>
<tr>
<td>Mineral fertilizers for potatoes</td>
<td>2</td>
<td>1 year</td>
<td>0.8–2.5(^c)</td>
</tr>
<tr>
<td>Information campaign on mushrooms</td>
<td>1.5</td>
<td>2 years</td>
<td>3(^c)</td>
</tr>
<tr>
<td>Decontamination of area</td>
<td>1.5</td>
<td>unlimited</td>
<td>525(^c)</td>
</tr>
</tbody>
</table>

\(^a\): costs as of 2004  
\(^b\): costs for one cow depend on the country. For radical improvement, cost depends on availability of drainage  
\(^c\): costs for a single resident depend on the country

*Fesenko S et al., 2009; Project TC RER 3004, IAEA, 2009

International Symposium on Decontamination - Fukushima, Japan  16 – 17 October 2011
Effectiveness of the measures: reduction of $^{137}\text{Cs}$ contents in feeds and milk; and annual public internal doses in the control settlements of three countries (Project TC RER 9074, IAEA, 2006)

Optimisation of the remedial action application is being performed on the basis of their radiological and economic effectiveness, as well as the extent of their acceptability by the public and authorities
Calculated estimates show that in the areas affected by the Chernobyl accident, a large number of settlements remain, where remedial actions are needed in large volumes and for a long time.

- **At different levels of decision making on remedial actions, the public opinion should be taken into account.**

- The price estimates of the adverted collective dose comply with the international level of the economic justification for use of the protective measures (about **20 thousand € man-Sv**⁻¹)

- The decision making support system *ReSCA - Remediation Strategies after the Chernobyl Accident*, which has been developed by the experts from Belarus, Germany, Russia and Ukraine under the IAEA aegis (Ulanovsky A, Jacob P, Fesenko S et al., 2008)

*Fesenko S et al., 2009; Project TC RER 3004, IAEA, 2009*
Today, the guidelines “Assessment of the Radiological effectiveness of the Protective Measures (Countermeasures) taken in far future after the Accident at the Chernobyl NPP”, 2010 are in force

- Removal of the upper soil – if it is not used in the economic activity (80% radioactivity is within the 5-cm soil layer) – the dose rate reduction by 10-30 times
- Plowing (digging) of soil – disadvantage: disposal of the topsoil - the dose rate reduction by 2-5 times
- Filling with a “pure” soil, cover with asphalt or concrete – if radioactivity is deepened - the dose rate reduction by 5-10 times
Part 4

Regulatory issues

Normative Basis of Regulation

RF Laws, Orders of the RF President, RF Government Directives

- Radiation Safety Standards (NRB-99/2009)
- Sanitary Rules for Radioactive Waste Management (SPORO-2002)

ICRP Annals of the ICRP
ICRP Publication 103
The 2007 Recommendations of the International Commission on Radiological Protection (ICRP)

ICRP Safety Standards
International Basic Safety Standards for Protection against Ionizing Radiation and for the Safety of Radiation Sources

BSS-2017
- Three types of exposure situation
- Dose constraint & reference levels
- Terminology

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Russian Radiation Safety Standards

- There is no comprehensive guidance for the existing exposure situation
- The optimized protective and remedial measures are recommended at annual dose over the range $1 - 20$ mSv
- At dose $>20$ mSv, residence at the territory is forbidden

What Else is Needed

- To introduce the existing exposure situation into the national standards in harmony with the ICRP system
- To develop criteria for site remediation and return, by stages, to uncontrolled uses
- To consider possibilities and methods of optimization for the remediation strategies under development
Norms of remediation- nuclear legacy

<table>
<thead>
<tr>
<th>Variant of remediation</th>
<th>Category of persons</th>
<th>Due to residual contamination</th>
<th>Due to new operation involved radiation sources</th>
<th>Total</th>
<th>Dose limit from (NRB-99)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conservation</td>
<td>Workers</td>
<td>2</td>
<td>-</td>
<td>2</td>
<td>20</td>
</tr>
<tr>
<td></td>
<td>Public (SA territory)</td>
<td>0,1</td>
<td>-</td>
<td>0,1</td>
<td>1</td>
</tr>
<tr>
<td>Conversion (“brown lawn”)</td>
<td>Personnel group A</td>
<td>3</td>
<td>7</td>
<td>10</td>
<td>20</td>
</tr>
<tr>
<td></td>
<td>Personnel group B</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>Public (SA territory)</td>
<td>0,1</td>
<td>0,15</td>
<td>0,25</td>
<td>1</td>
</tr>
<tr>
<td>Liquidation (“green field”)</td>
<td>Public (former STS territory)</td>
<td>1</td>
<td>-</td>
<td>1</td>
<td>Lack of norms in NRB-99</td>
</tr>
<tr>
<td></td>
<td>Public (the rest territory)</td>
<td>0,1</td>
<td>-</td>
<td>0,1</td>
<td></td>
</tr>
</tbody>
</table>

(2006) taking into account the up-to-date ICRP approaches

Criteria of RW ascription to the VLLW category

<table>
<thead>
<tr>
<th>Waste category</th>
<th>Specific β-activity, kBq/kg</th>
<th>Superficial contamination, β-part/m.cm²</th>
<th>Py from the package surface, μSv/h</th>
</tr>
</thead>
<tbody>
<tr>
<td>VLLW</td>
<td>0.3 – 12</td>
<td>50 – 500</td>
<td>0.1 – 1</td>
</tr>
<tr>
<td>Cleared waste</td>
<td>≤ 0.3</td>
<td>≤ 50</td>
<td>≤ 0.1</td>
</tr>
</tbody>
</table>

Site of SNF and RW Temporary Storage
Former military
Methodology for comprehensive monitoring of the environment and public health as an important evidence of safe nuclear engineering development
Conclusions

1. At the early and interim stages of the Chernobyl accident, the following criteria were the most important in the public protection decision making process:
   - density of the radioactive contamination of the area with $^{137}\text{Cs}$
   - annual effective dose to the residents
   this helped to plan the emergency measures

2. At the late stage of the radiological accident, the optimization principle shall be applied in radiation protection and remediation

3. The main dose criterion – reference level of annual dose

4. Criteria of the food safety – exemption levels for the existing exposure situation

5. Application of the countermeasures – the main means to return the excluded areas in the economic use
Recommendations

Main types of remedial activity after the Fukushima accident may be:

- measures to ensure safe agriculture and forestry, both in terms of protection of workers, and in terms of safety of products including the implementation of regulations on foods
- RW management originated from the vital activity and from remediation
- environmental radiation monitoring and monitoring of the public exposure
- Interaction with the public (explanatory work on mode of living and nutrition, providing PPE)

These measures intended to contribute to the sustainable development of the territories, but there should not be intervention violating normal mode of the human life
Thank you for attention