Biological effects of chronic exposure to radionuclides in plant populations

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What’s actually going on in the populations inhabiting radioactively contaminated sites?

What do we know about mutagenic effect of chronic low dose-rate radiation exposure?

What do we know about the fate of induced by radiation mutations in altered ecological conditions?

Can chronic low dose-rate radiation exposure be regarded as ecological factor changing the genetic make-up of a population?

In which way chronic radiation exposure can modify reproductive ability, species diversity and community structure?
<table>
<thead>
<tr>
<th>Species</th>
<th>Site &amp; Time</th>
<th>Assay and/or endpoints</th>
</tr>
</thead>
<tbody>
<tr>
<td>Winter rye and wheat, spring barley and oats</td>
<td>10-km ChNPP zone (28-4834 µGy/h), Ukraine, 1986-1989</td>
<td>Morphological indices of seeds viability, mitotic index, cytogenetic alterations in intercalary and seedling root meristem (Geras’kin et al., 2003a)</td>
</tr>
<tr>
<td>Scots pine, coach-grass</td>
<td>30-km ChNPP zone (2.5-27 µGy/h), Ukraine, 1995</td>
<td>Cytogenetic alterations in seedling root meristem (Geras’kin et al., 2003b)</td>
</tr>
<tr>
<td>Scots pine</td>
<td>Radioactive waste storage facility, Leningrad Region, Russia, 1997-2002</td>
<td>Cytogenetic alterations in needles intercalary and seedling root meristems (Geras’kin et al., 2005; Oudalova, Geras’kin, 2011)</td>
</tr>
<tr>
<td>Wild vetch, Scots pine</td>
<td>Radium production industry storage cell, Komi Republic, Russia (1-320 µGy/h), 2003-2009</td>
<td>Germination capacity, survival rate of sprouts, embryonic lethals, proportion of abortive seeds, cytogenetic alterations in seedling root meristem (Evseeva et al., 2009; Evseeva et al., 2011)</td>
</tr>
<tr>
<td>Scots pine</td>
<td>Bryansk Region radioactively contaminated in the Chernobyl accident (1-15 µGy/h), Russia, 2003-2012</td>
<td>Cytogenetic alterations in seedling root meristem, enzymatic loci polymorphism, abortive seeds (Geras’kin et al., 2010; Geras’kin et al., 2011; Volkova, Geras’kin, 2012)</td>
</tr>
<tr>
<td>Crested hairgrass</td>
<td>Semipalatinsk Test Site (0.5-32 µGy/h), Kazakhstan, 2005-2008</td>
<td>Cytogenetic alterations in coleoptiles of germinated seeds, length of sprouts (Geras’kin et al., 2012)</td>
</tr>
<tr>
<td>Phytoplankton communities</td>
<td>Industrial reservoirs, Southern Urals (2-130000 µGy/h), Russia, 2007-2012</td>
<td>Species diversity, abundance, biomass (Atamaniuk et al., under preparation)</td>
</tr>
</tbody>
</table>
What biological consequences can be expected in these populations experiencing chronic exposure over 25 years?
An increased level of cytogenetic alterations is a typical phenomenon for plant populations growing in areas with relatively low levels of pollution.

hatched bars – significant difference from reference level, p<5%
High mutation rates is intrinsic for progeny of the affected pine trees, and genetic diversity is essentially influenced by radiation exposure.

Could the high mutation rates revealed have any effect on population fitness? Are there any consequences for a reproductive ability of pine trees?

Chronic exposure at dose rates studied had no effect on the reproductive ability of the exposed populations.
Are there any relationship between reproductive ability and weather conditions?

2 years

R² = 0.1797
r = -0.42
p < 0.05

May

R² = 0.2318
r = -0.48
p < 0.05

August

R² = 0.3658
r = -0.60
p < 0.05

\[ IA = \frac{\sum P \times 10}{\sum T_n} \]
What do we know about biological effects in plants exposed to radiation over several generations in natural setting?

The 10 km Chernobyl NPP zone 1987-1989

Autumn 1989 Rye, wheat

Origin of plants from RIARAE’s experimental site

- **F₀**: Chernobyl, Red Forest, 1986
- **F₁**: Chernobyl, Red Forest Self-seeding in 1987, collection of seeds in 2004
- **F₂**: 2005 seeding in Moscow Region, 2010 transfer to the RIARAE’s experimental site
Mass appearance of morphological disorders in second generation after exposure

A memory of acute irradiation years ago may influence plant response in subsequent years and generations
<table>
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<tr>
<th>Exposure</th>
<th>Absorbed by phytoplankton dose rate, μGy/h</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>ShR</td>
</tr>
<tr>
<td>External</td>
<td>0.00015</td>
</tr>
<tr>
<td>Internal</td>
<td>0.0098</td>
</tr>
<tr>
<td>Total</td>
<td>0.01</td>
</tr>
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</table>
Under chronic exposure to radionuclides species diversity can reduced due to a loss of sensitive species, which leads to destruction of biocenotic connections, weakening of competition and intensive development of the most resistant forms.
What do we know about adaptation processes in plant populations under chronic exposure conditions?

Radioactive waste storage facility
Leningrad Region, Russia, 1997-2002

Scots pine *Pinus sylvestris* L.

![Aberrant cells, %](chart)

<table>
<thead>
<tr>
<th>Year</th>
<th>1997</th>
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<th>2002</th>
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<tbody>
<tr>
<td>Cells</td>
<td></td>
<td></td>
<td></td>
<td></td>
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</tr>
</tbody>
</table>

- Aberrant cells, %

- Leningrad NPP
- "Radon" Leningrad regional waste processing enterprise (LWPE)
The seeds from the impacted Scots pine populations show a higher resistance than seeds from the reference population. A divergence of populations in terms of radioresistance is connected with a selection on the effectiveness of repair systems.

Experimental plots:
1 – Bolshaya Izhora (control);
2 – Sosnovy Bor town;
3 – ‘Radon’ waste processing plant

Radium production industry storage cell territory
The Komi Republic, 2003-2009

up to 275 backgrounds

‘black’ dumps

Geras’kin et al. J. Env. Radioact. 2007. V. 94. p. 151-182
Comparison of findings from 1980 and 2003: the high levels of both genetic and morphologic intrapopulation variability still persist.

Seeds from the affected wild vetch populations show rather high radiosensitivity. An inherited character of this phenomenon was demonstrated.

Why sometimes we failed to detect any signs of radio-adaptation in plant populations?

- Increased fitness in unfavorable environment is associated with decreased fitness in favorable environment. As a result, there are situations in which enhanced radioresistance has not evolved or has not persisted.

- In situations where radio-adaptation is observed in one species often none is found in other despite equivalent opportunity.

- The response of a population to radiation exposure depends both on the type of organism and on the biophysical characteristics of the radiation.
Examples of lack of radio-adaptation in plant populations

γ-exposure of pine seeds from the Bryansk region (dose of 15 Gy, dose rate of 36 Gy/h)

γ-exposure of crested hairgrass seeds from the Semipalatinsk Test Site (2005, 2006 - dose of 69 Gy, dose rate of 2790 Gy/h; 2007 - dose of 50 Gy, dose rate of 39 Gy/h)


Geras’kin et al. J. Env. Radioactivity. 2012. V. 104. 55-63
Main sources of uncertainty in field studies - 1

Our ability to correctly estimate actual exposures:

- spatial and temporal heterogeneity of the factors influencing the effect under study;
- non-radiation factors that may modify the effect of radiation exposure;
- weighting factors for different radiation types;
- non-homogeneous radionuclides distribution within the organism;
- it is not always clear: to which organ and to what period of time we should assess the absorbed dose?
Main sources of uncertainty in field studies - 2

Our ability to correctly estimate biological effects:

- radio-adaptation;
- sinergistic and antagonistic effects of combined exposure;
- information about status of biological system before exposure;
- non-target effects: epigenetics, genomic instability, and bystander effect
Temporal heterogeneity in radiation exposure in early days after the Chernobyl accident

- The maximum biota exposure fell within the first 10–20 days after the accident.
- First large-scale and reliable estimation of radioactive contamination and dose rates were performed at the end of the period of acute exposure starting from 15 days after the accident.

We have very limited and poor information about the first, most important period when up to 90% of the doses absorbed by non-human biota was accumulated.

Geras’kin et al. Env. Internat. 2008. V. 34. 880-897
Non-radiation factors play an important role in biological effects formation in wild vetch population from radium production industry storage cell territory

Germination

Survival of seedlings
Multi-pollutant exposures

- acute $\gamma$-radiation
- chronic $\gamma$-radiation
- heavy metals
- pesticides
- artificial and naturally occurring radionuclides

Chlorella vulgaris
Allium cepa
Hordeum vulgare
Tradescantia (clon 02)

Synergetic and antagonistic effects are most often registered at combinations of low doses and concentrations.

Moreover, these nonlinear effects can make substantial contribution to a plant response.
Combined exposure *Hordeum vulgare* L.

(Geras’kin et al. Mutat. Res. 2005. V. 586. p. 147-159)

An application of findings from single impacts to predict biological effects of combined exposure is unacceptable and may cause essential deviations from actually observed data.
## Uncertainties related with ecological dosimetry issues

### The ERICA Tool, default values

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<tr>
<td>Internal</td>
<td>0.19</td>
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<td><strong>Total</strong></td>
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### Our calculations, weighting factor of 5 for α-radiation + actual data on radionuclides content in phytoplankton

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CONCLUSIONS

- To properly understand the effect of real-world contaminant exposures, we should consider actual field conditions. Specifically, we need to plan new well-directed field studies to fill a major gap in our knowledge.

- To reduce the uncertainties associated with the spatial and temporal heterogeneity it will be useful to develop the unified standards for sampling in field studies.
CONCLUSIONS-2

- To predict radiation exposure in a robust way it is necessary to develop a process-based transfer and dosimetric models taking into account current, a more profound understanding of environmental processes.

- To reduce the uncertainties associated with the biological effects assessment, we should pay more attention to fundamental research focused on mechanisms underlying such phenomena as radioadaptation, synergistic and antagonistic effects of combined exposure and non-target effects.

To address all these issues, a close international cooperation in radioecological research is needed.
That’s all!