EXPOSURES FROM CONSUMPTION OF FOREST PRODUCE

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Summary

Traditionally, the diet of people from a number of regions of Belarus, Russia and Ukraine includes the foodstuffs from natural environment. After the Chernobyl accident there are some increase of forest gifts consumption for several categories of population in these countries. As these products very often have the relatively high level of radioactivity compared with agricultural foods, they may play an important role in the intake of radioactivity and in the internal dose formation.

Data about the values of the transfer factor for different forest gifts during the years after the Chernobyl accident were obtained. For mushrooms two types of species according to high and low values of transfer factor were identified. For berries the clearly distinction in the transfer factor of different species were obtained also. The transfer factor for different species, gathered on hydromorphic soil higher than those gathered on automorphic soil. For game one transfer factor for all species was obtained.

We examined the modification of the radioactivity contamination of forest gifts during processing and culinary preparation and determined data about the frequencies of usage of different types of culinary practices for forest gifts. On the basis of obtained data the model for the calculation of the radiocaesium intake due to the forest gifts were proposed.

The created model may be useful for the purpose of calculation of radiocaesium intake due to forest gifts consumption in the time of accidental situation.

The object of this study is to provide an appreciation of the role of consumption of forest products in the internal dose formation for people, who are living at the territories, contaminated after the Chernobyl accident.

For this the following questions were investigated:

• the transfer of radiocaesium to the forest gifts from the contaminated forests, taking into account types of forest soil and time after the accident,
• the modification of the activity in forest gifts during processing and culinary preparation and characterisation this transformation with the help of the processing factors values;
• dietary habits of population (determination of the frequency of usage of different
types of culinary preparation and the quantities of forest gifts consumed by citizens of
Belarus and Russia);

In this study we intend to attribute a transfer factor to the principal edible
mushrooms and berries species, and one transfer factor for all game in the dynamics.

More than 4000 samples for 18 species of mushrooms were examined.

On the basis of samples of most consumed species of mushrooms it were obtained
main parameters which characterise the data distribution of transfer factor for
mushrooms as a whole (Fig. 1).

![Figure 1: The distribution of the transfer factor for mushrooms.](image)

Analysis of the distribution of transfer factors for all mushrooms shows a
lognormal character with bimodal component within the distribution.

It is known that different species of mushrooms have a great distinction in the
ability for radionuclides accumulation. Rantavaara (1), Randa et al. (2) and Mascanzoni
(3) note a strong difference between some types of species. The first one including
Cantharellus cibarius, Boletus edulis among others, for which the transfer factor is about 5
to 10 Bq.kg\(^{-1}\)/kBq.m\(^{-2}\) and the second one including Boletus badius, Lactarius, Suillus
variegatus for which it is about 80 to 400 Bq.kg\(^{-1}\)/kBq.m\(^{-2}\). The reason given for this
differentiation is often the depth of layer at which mycelium sources its nutrients. For
example Boletus edulis has deeper mycelium development compared to others and
remains less contaminated.

Results of our investigation clearly demonstrates the possibility of identifying
types of mushrooms in accordance with their ability for accumulation of radiocaesium.
The comparison between the values of transfer factor shows that the border between
high and low levels of transfer factor in our study is near 40 Bq.kg\(^{-1}\)/kBq.m\(^{-2}\). The
parameters of transfer factor for Leccinum scabrum have an intermediate character. This
fact is the next confirmation of the bimodal component in the lognormal distribution of
all mushrooms. The first peak is formed by transfer factor of those species of
mushrooms without an ability for radionuclides accumulation and the second one
represents transfer factors for species with a strong accumulation capacity.

According to our results and literature data first type of mushrooms includes
Agaricus arvensis, Agaricus augustus, Armillaria mellea, Armillaria mellea, Boletus
edulis, Cantharellus cibarius, Hygrophorus species, Leccinum aurantiacum, Lepista nuda,
Macrolepiota procera, Macrolepiota Rhacodes, others Boletus species. The second one is formed by the following species: Hydnum repandum, Hydnum rufescens, Leccinum scabrum, Russula species, Rosites caperata, Suillus luteus, Suillus variegatus, Suillus Bovinus, Xerocomus Badius and others Xerocomus species.

The investigation of the transfer factors for different species separately shows the following (Table 1).

### Table 1. Main statistical parameters of the transfer factor distribution for different species of mushrooms, Bq.kg⁻¹ / kBq.m⁻².

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Boletus edulis</td>
<td>A 7.3 M 4.6 SD 7.2</td>
<td>A 7.8 M 6.4 SD 6.0</td>
<td>A 13.9 M 9.9 SD 11.0</td>
</tr>
<tr>
<td>Cantharellus cibarius</td>
<td>6.2 4.6 5.8</td>
<td>8.6 5.2 10.4</td>
<td>11.7 6.8 14.6</td>
</tr>
<tr>
<td>Xerocomus badius</td>
<td>- - -</td>
<td>110.6 99.1</td>
<td>83.6 81.2 74.4</td>
</tr>
<tr>
<td>Russula</td>
<td>10.0 6.3 10.0</td>
<td>28.3 17.0</td>
<td>42.7 50.3 25.6</td>
</tr>
<tr>
<td>Tricholoma flavovirens</td>
<td>11.0 5.7 11.0</td>
<td>8.4 5.9 7.3</td>
<td>43.7 44.0 25.0</td>
</tr>
<tr>
<td>Suillus luteus</td>
<td>32.0 23.0 26.0</td>
<td>98.3 90.1</td>
<td>68.3 41.7 32.9</td>
</tr>
<tr>
<td>Armillaria mellea</td>
<td>1.6 1.2 1.5</td>
<td>7.4 7.9 4.2</td>
<td>4.8 3.4 4.6</td>
</tr>
<tr>
<td>Leccinum scabrum</td>
<td>15.0 10.0 17.0</td>
<td>46.4 40.0</td>
<td>57.2 48.9 35.0</td>
</tr>
</tbody>
</table>

A - average,  M - median, SD - standard deviation,  R - range.

We obtained the high values of transfer factor for Xerocomus badius, Suillus luteus. The average levels of transfer factor for Boletus edulis, Cantharellus cibarius, Armillaria mellea, Tricholoma flavovirens are between 7.4 and 8.6 Bq.kg⁻¹ / kBq.m⁻². The transfer factor for Russula and Leccinum scabrum are also at these low levels. According to the data of Randa, the levels of transfer factor for Boletus edulis after the Chernobyl accident are lower than for other species of mushrooms (4). The mean values of transfer factor reported by Rantavaara are 0.8-20.0 Bq.kg⁻¹ / kBq.m⁻² for Boletus edulis, 6.1-13.0 Bq.kg⁻¹ / kBq.m⁻² for Cantharellus cibarius (1). The results of the factor investigation of Mascanzoni are as follows: the average value of transfer factor for Boletus edulis is 5.0 Bq.kg⁻¹ / kBq.m⁻², for Cantharellus cibarius - 14.0 Bq.kg⁻¹ / kBq.m⁻² (3).

From the data on the transfer factor for different species of mushrooms it is clear that there are no significant differences between values obtained during different years after the Chernobyl accident. Figure 2, completed on the basis of Russian data, confirm this observation.

We did not find statistically significant decrease of radioactive contamination of mushrooms during 8 years after the Chernobyl accident, or their decontamination was very slow. Relatively high rate of caesium-137 specific activity decrease in mushrooms was noted for Cantharellus cibarius - the half-period of decontamination (T) is equal to approximately 5 years and for Suillus luteus - T = 7-8 years. However, all these decrease are not statistically significant.
Figure 2. Cs-137 transfer factor from soil into Boletus edulis (a), Armillaria mellea (b) and Russula cyanoxantha (c). The inner pair of dashed line defines the domain of the 95% confidence limits of the mean values; the outer pair of dashed line bounds 95% of individual data points.
Furthermore, for almost all mushrooms species, gathered in Russia, were found an increase of caesium-137 specific activity in the first 2-3 years after the Chernobyl accident. A similar effect was noted by other investigators (5,6). The explanation is, on one hand, the penetration of the radionuclide from the upper forest fall to the layer of mushroom mycelium, and on the other hand, an increase in the Cs-137 content of soil due to its additional ingress with fallen leaves in autumn 1986 and with needles of coniferous trees over several years after the accident. This effect is most obvious in the case of Boletus edulis, whose mycelium is relatively deep.

It is important to emphasise, that the transfer factor for different types of mushrooms depends on the type of forest soil. The investigation of the transfer factor for Boletus edulis, Cantharellus cibarius, Tricholoma flavovirens and Xerocomus badius, gathered at the different types of forest soil Belarus during 1989-1994 years shows the following (table 2).

### Table 2.

<table>
<thead>
<tr>
<th>Species of mushrooms</th>
<th>Automorphic soil</th>
<th>Hydromorphic soil</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Number of samples</td>
<td>Average</td>
</tr>
<tr>
<td>Boletus edulis</td>
<td>279</td>
<td>14.8</td>
</tr>
<tr>
<td>Cantharellus cibarius</td>
<td>311</td>
<td>7.7</td>
</tr>
<tr>
<td>Tricholoma flavovirens</td>
<td>208</td>
<td>8.4</td>
</tr>
<tr>
<td>Xerocomus badius</td>
<td>221</td>
<td>56.2</td>
</tr>
</tbody>
</table>

According to our data, it is possible to conclude, that there is dependence of the transfer factor values on the type of soil. The transfer factor for different species, gathered on hydromorphic soil higher than those, gathered on automorphic soil. This fact is more obvious for Boletus edulis, Tricholoma flavovirens and Xerocomus badius. In general, variation of transfer factor for uptake of Cs-137 by all mushrooms in automorphic and hydromorphic soil are 10 - 100 Bq.kg⁻¹ / kBq.m⁻² and 20-1700 Bq.kg⁻¹ / kBq.m⁻² correspondingly.

Investigation of the transfer factor of berries were carried out on the basis of examination of more than 2000 samples for 8 species. The main parameters of the transfer factor for all berries which were obtained are the following (Fig. 3).

The investigation of the transfer factors for species of berries separately shows that there are clearly distinction in the transfer factor of different species (Table 3).
Figure 3: Distribution of the transfer factor for berries.

Table 3.  
Main statistical parameters of the transfer factor distribution for different species of berries, Bq.kg⁻¹/kBq.m⁻².

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>A</td>
<td>M</td>
</tr>
<tr>
<td>Vaccinium myrtillus</td>
<td>7.7</td>
<td>5.4</td>
</tr>
<tr>
<td>Vaccinium oxycoccus</td>
<td>8.9</td>
<td>8.5</td>
</tr>
<tr>
<td>Vaccinium vitis-idaea</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Fragaria vesca</td>
<td>2.0</td>
<td>1.6</td>
</tr>
<tr>
<td>Rubus idaeus</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

A - average, M - median, SD - standard deviation, R - range.

By the data of Rantavaara (1) and Balonov (7), the average values of transfer factor for different species of berries are between 0.9-13.4 Bq.kg⁻¹/kBq.m⁻². For Vaccinium myrtillus this values are 2.8 - 5.8 Bq.kg⁻¹/kBq.m⁻², 7.9 Bq.kg⁻¹/kBq.m⁻².

It is known that there are great differences in transfer factor of berries which connect with the peculiarities of forest soil. We investigated the transfer factor for Fragaria vesca, gathered at the hydromorphic and automorphic soils of Belarus during 1989-1994 years. Transfer factor for Fragaria vesca, gathered at the hydromorphic soils is 3.9 times higher than those for automorphic soils. Variation of transfer factor for uptake of Cs-137 by all berries in automorphic and hydromorphic soil are 10 - 15 Bq.kg⁻¹/kBq.m⁻² and 80-130 Bq.kg⁻¹/kBq.m⁻² correspondingly.

The level of contamination of game varies widely. This is connected with the large home range of wild animals and different levels of radiocaesium density contamination within this territory. In this connection, the examination of the transfer factor for game is an extremely complicated process. We prepared the distribution of the transfer factor for game, without differentiation between types of wild animals on the basis of investigation about 100 samples (Fig. 4).
Figure 4: Distribution of the transfer factor for game.

As can be seen, the distribution is lognormal, the average value of the transfer factor is 36.2 Bq.kg\(^{-1}\) / kBq.m\(^{-2}\), median - 11.0 Bq.kg\(^{-1}\) / kBq.m\(^{-2}\), standard deviation - 72.7 Bq.kg\(^{-1}\) / kBq.m\(^{-2}\). According to data, which were obtained in Russia the average values of this parameter are 0.5 - 28.0 Bq.kg\(^{-1}\) / kBq.m\(^{-2}\).

It is necessary to emphasise the importance of the investigation of the radioactivity modification during culinary preparation of forest gifts and dietary habits of the rural citizens in consumption of natural products.

The results of such investigation about values of processing factors for different culinary practices and the frequencies of its usage are the same (Table 5).

**Table 5.**

<table>
<thead>
<tr>
<th>Type of culinary preparation</th>
<th>Processing factor</th>
<th>Normalised frequency of usage, %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Preparations of mushrooms</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cleaning and washing</td>
<td>0.8</td>
<td>100</td>
</tr>
<tr>
<td>Cooking with pouring out of the first water</td>
<td>0.6</td>
<td>20</td>
</tr>
<tr>
<td>Cooking with pouring out of the second water</td>
<td>0.2</td>
<td>13</td>
</tr>
<tr>
<td>Cooking with the pouring out of the third water</td>
<td>0.2</td>
<td>9</td>
</tr>
<tr>
<td>Drying</td>
<td>10.5</td>
<td>22</td>
</tr>
<tr>
<td>Frying</td>
<td>0.3</td>
<td>19</td>
</tr>
<tr>
<td>Pickling</td>
<td>0.3</td>
<td>18</td>
</tr>
<tr>
<td>Preparations of berries</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Washing</td>
<td>0.9</td>
<td>100</td>
</tr>
<tr>
<td>Cooking of jam</td>
<td>0.5</td>
<td>49</td>
</tr>
<tr>
<td>Beating up with sugar</td>
<td>0.65</td>
<td>45</td>
</tr>
<tr>
<td>Drying</td>
<td>9.0</td>
<td>6</td>
</tr>
<tr>
<td>Preparations of game</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Steeping and salting</td>
<td>0.3</td>
<td>100</td>
</tr>
<tr>
<td>Cooking</td>
<td>0.25</td>
<td>32</td>
</tr>
<tr>
<td>Frying</td>
<td>1.3</td>
<td>56</td>
</tr>
<tr>
<td>Smoking</td>
<td>1.3</td>
<td>12</td>
</tr>
</tbody>
</table>
Therefore, the types of processing and culinary preparation provide for a considerable decrease of the initial contamination of a product.

For the purpose of calculation of radiocaesium intake due to forest gifts consumption and on the base of the data obtained the approaches to setting up a deterministic model were investigated. During this study different parameters, which are important to take into account in the principal structure of the model were discussed. According to this, the following parameters are included in the model (Fig. 5).

Calculations have been made with the help of the following equations:

\[
INTK_{m,b,g} = DC \cdot TF \cdot Q \cdot \sum_{i} F_{li} \cdot PF_{i}
\]

with:
- \(INTK_{m,b,g}\) - daily intake due to mushrooms, berries or game ingestion
- \(DC\) - density of contamination \(\text{Bq} \cdot \text{day}^{-1}\)
- \(TF\) - transfer factor to mushrooms, berries or game \(\text{m}^2 \cdot \text{kg}^{-1}\)
- \(Q\) - quantity consumed per day \(\text{kg} \cdot \text{day}^{-1}\)
- \(F_{li}\) - frequency of culinary practice \(i\) \((-)\)
- \(PF_{i}\) - processing factor of the culinary practice \(i\) \((-)\)

\[
INTK_{fg} = INTK_{m} + INTK_{b} + INTK_{g}
\]

with:
- \(INTK_{fg}\) - daily intake due to consumption of forest gifts \(\text{Bq} \cdot \text{day}^{-1}\)
- \(INTK_{m}\) - daily intake due to consumption of mushroom \(\text{Bq} \cdot \text{day}^{-1}\)
- \(INTK_{b}\) - daily intake due to consumption of berries \(\text{Bq} \cdot \text{day}^{-1}\)
- \(INTK_{g}\) - daily intake due to consumption of game \(\text{Bq} \cdot \text{day}^{-1}\)

\[
365 \int_{0}^{\text{INTK}_{fg}} dt = [\text{INTK}_{fg}]_a
\]

with:
- \([\text{INTK}_{fg}]_a\) - annual intake due to the consumption of forest gifts \(\text{Bq} \cdot \text{year}^{-1}\)
Figure 5. Principal scheme of the model for radiocaesium intake calculation due to forest gifts consumption.
The estimation of different foodstuffs contribution in radiocaesium intake among the rural population of the contaminated area of Belarus revealed the following (Figure 6).

![Comparison between contributions of different products in daily ration and radiocaesium intake for rural forest population of Belarus](image)

This figure shows the great disproportion between daily consumption rate of forest gifts and their contribution to the intake due to their high level of contamination in relation to others foodstuffs of the same region. In Belarus, mushrooms which make 0.09% of the total ration volume, contribute 10.5% into the daily radiocaesium intake. Therefore, foodstuffs from forest will make 39% of daily alimentary radiocaesium intake and will form a dose of internal exposure equal to 0.34 mSv/year vs. 0.86 mSv/year, formed by the whole ration. This data confirm the important contribution of forest gifts in the internal exposure.

Data obtained during the investigation about the transfer factors of forest gifts for different types of soil and different species of mushrooms and berries, data about processing factors and frequency of usage of some types of culinary practices are the background for model of calculation the internal exposure due to forest gifts consumption.

**References**


