Content and distribution of long-life nuclear-fission products in Upper Volga reservoirs

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Content and distribution of long-life fission products in Upper Volga reservoirs

The content of radioactive products of nuclear explosions in a water reservoir is determined to a considerable degree by the hydrological conditions of the water body, and first of all by the role of atmospheric sediments in the feeding of the river. As known, the main source of water of the Volga River is snow-melt water equal to 65-70% of the yearly runoff. After the winter draw-off, the Volga River reservoirs are filled with spring waters of the surface runoff, containing an increased quantity of radioactive matter. The comparatively high level of radioactivity of melt water depends on accumulation of radioactive fall-out in the snow cover on the expanse of the river's drainage basin.

The further fate of radioactive products which have entered the reservoirs with surface waters, depends on the coefficient of flow regulation which determines the duration of...
retention of flood waters in the reservoir and the participation of fission products in the exchange processes. Simultaneously with chemical transformations, depending on the properties of the radioactive isotope and the form in which it is present, biological processes are an important factor in the distribution. The absorption of radioactive isotopes by water organisms not only causes a reduction in the level of water radioactivity, but also promotes their accumulation in the bottom sediments of the reservoirs.

Some fission products possessing a high sorption ability enter reservoirs with suspended substances. When these radioactive isotopes are absorbed intensively by water organisms, their content and distribution in bottom sediments will in part characterize the intensity of participation of allochthonous suspensions in the biochemical processes of the water body. In this connection, the study of such distribution of fission products is of great interest.

Method of collection and processing of samples and measurement of the activity

The results of analyses of samples of water and bottom sediments collected in the Ivankovskoe, Uglishskoe, Rybinskoe and Gor'kovskoe reservoirs in summer 1965 were used as material for the present report.

Collection of water samples was made with a Rušner water bottle, 0.6 m from the water line. The bottom sediments were sampled by means of a Perfil'ev silt pump, which made it possible to collect the upper, finely dispersed layer of the

* 0.6 m below the surface?
The collected sample of the surface layer of sediments was left standing for 8 hrs in a glass beaker of a volume of 0.5 l; later, the upper 10 cm layer of liquid mud was separated from the residue by siphoning-off. After such length of settling the part of the sample siphoned-off contained particles smaller than 0.01 mm in diameter. Both, the original sample and the siphoned-off, finely dispersed fraction of the silt were analysed.

The preliminary treatment of water samples consisted in evaporation of 1 liter and transfer of the dry residue to a standard aluminum plate. Samples of the bottom sediments were dried at a temperature of 105°C to constant weight and heated to 500°C. From the heated residue, quantities weighing 300-400 mg were prepared.

The radiometric analysis consisted in determination of the total $\beta$-activity of the prepared samples. The measurements were conducted with the radiometer "Volna" by means of an end-window counter T-25-BFL.

In calculating the "absolute" activity of the samples, the relative method of comparison with potassium standards was applied, taking into account the auto-absorption of $\beta$-emissions with a maximum energy of the $\beta$-spectrum equal 1.32 Mev. The result of the measurements are expressed in picocuries (pc). The mean quadratic error of the measurement was 8-27% for water samples and did not exceed 12% for the silt samples.

*Translator's note: in Russian "nailek" a term not shown in dictionaries, meaning "top of silt"
To determine the natural radioactive background of the water and bottom sediments, the content of potassium was determined in all samples. The determinations performed by N.A. Kobyakova were conducted using the method of flame photometry. The activity of 1 mg of potassium connected with the presence of the natural radioactive isotope K\textsuperscript{40} equals 0.8 pc. The potassium activity was calculated for each prepared sample and deducted from the total activity of the sample.

During observations, the content of potassium in the water of the Volga River varied from 1.5 to 3.1 mg/l. In the finely dispersed fraction of the silt, the content of potassium was from 17.3 to 26.0 mg/g of the heated residue; in silt samples not separated into fractions this content was 12.0 to 23.0 mg/g of the heated residue.

A correction for activity caused by the content of uranium was not introduced, since according to literature data (Baranov and Tseitlin, 1941; Starik et al., 1958), the content of the latter in surface waters and earth layers equals values of an order of $10^{-5}$ and $10^{-4} \%$. When measuring the activity of the dry residue of 1 liter of water, and suspensions of 300-400 mg of silt such quantities of uranium would produce a $\beta$-activity because of UX\textsubscript{2} of less than 1 pc, a value below the range of sensitivity of our measuring method.

**Composition of radioactive fall-out during observations**

To determine the composition of radioactive products, the penetration of which into the reservoirs is possible during the period of snow melt, samples of snow in the area of the drainage basin were collected. Measurements of the activity of the samples and observations of its gradual decrease were
conducted. A graphical elaboration of the data was obtained, following the formula\(^1\) by Way and Wigner (cited according to Gedeonov, 1957) expressing the regularity of a decrease of the total activity of a mixture of fission fragments of uranium; this made possible a determination of the age of fission products contained in the snow samples. The term "age of the fission products" means the time which has elapsed since the beginning of the fission or the date of the explosion. In summer 1965, the age of the fission products contained in the snows samples was measured as being approximately three years. With the help of the nomogram of Cantor and Ballou (cited acc. to Gedeonov, 1957) the chemical composition of the radioactive products at the age of three years was determined, as well as the activity percent in relation to the total, pertaining to each of the isotopes present (Table 1).

Table 1

<table>
<thead>
<tr>
<th>Isotope</th>
<th>Period of half-life</th>
<th>Daughter isotope</th>
<th>Period of half-life</th>
<th>% of activity of parent and daughter isotopes in relation to the total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ce(^{144})</td>
<td>282 days</td>
<td>Pr(^{144})</td>
<td>17 min.</td>
<td>42</td>
</tr>
<tr>
<td>Sr(^{90})</td>
<td>28 years</td>
<td>Y(^{90})</td>
<td>91 hrs</td>
<td>18</td>
</tr>
<tr>
<td>Pm(^{147})</td>
<td>2.6 years</td>
<td>-</td>
<td>-</td>
<td>19</td>
</tr>
<tr>
<td>Cs(^{137})</td>
<td>30 years</td>
<td>Ba(^{137})</td>
<td>2.6 min.</td>
<td>14</td>
</tr>
<tr>
<td>Ru(^{106})</td>
<td>1 year</td>
<td>Rh(^{106})</td>
<td>20 sec.</td>
<td>6</td>
</tr>
</tbody>
</table>

1. Way and Wigner equation: \(A_t = A_1 t^{-1/2}\), where \(A_t\) is the activity of the sum of the fission fragments during time \(t\) after the moment of fission; \(A_1\) is the activity of the sum of fission fragments at the beginning of fission.
Thus, the radioactive fall-out contained in the snow cover in winter 1965 comprised five long-life radioactive isotopes with a half-life period from 282 days to 30 years. During the decay of those fission products, excluding promethium, radioactive daughter isotopes are formed, possessing a short period of half-life and hard $\beta$-radiation (Table 1,2). Due to the relatively low level of activity of the samples and measurement taking place not earlier than a month after collection, the existence of daughter isotopes is possible only in the presence of the parent isotope in a quantity equal to the latter in radioactivity.

<table>
<thead>
<tr>
<th>Isotope</th>
<th>Radiation energy, Mev</th>
<th>Daughter isotope</th>
<th>Radiation energy, Mev</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ce$^{144}$</td>
<td>0.31(76%) 0.19(20%)</td>
<td>Pr$^{144}$</td>
<td>2.97(99%) 0.69</td>
</tr>
<tr>
<td>Sr$^{90}$</td>
<td>0.13, 0.03</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pm$^{147}$</td>
<td>0.22</td>
<td>Y$^{90}$</td>
<td>2.2</td>
</tr>
<tr>
<td>Cs$^{137}$</td>
<td>0.52(92%) 0.66</td>
<td>Ba$^{137}$</td>
<td>- 0.66</td>
</tr>
<tr>
<td>Ru$^{106}$</td>
<td>0.04</td>
<td>Rh$^{106}$</td>
<td>3.53 0.51,0.62</td>
</tr>
</tbody>
</table>

Using this method of measurement, Ce$^{144}$ and Sr$^{90}$ are registered as having the greatest effectiveness of all the long-life fission products.

The percent ratio of the activities of long-life fission in fragments in water and bottom sediments differs from those observed in snow samples and depends on the intensity of the washoff from the area of the drainage basin. This in turn depends on the chemical properties of the radioactive isotope.
Movement of the fission products from the area of the drainage basin

The migration ability of the radioactive isotopes depends to a great extent on their physical and chemical state. With respect to the degree of dispersion, two groups of fission products are distinguished. In the first group, including radioactive isotopes present in ionic or soluble form, are Sr\(^{90}\) and Cs\(^{137}\). Rare earths (Ce\(^{144}\), Pm\(^{147}\)) and Ru\(^{106}\) belong to the second group which contains fission products in colloidal state. In conditions of an explosion, the fission products, mostly of the second group, form insoluble oxides and, in transition from gaseous into solid state, form particles fused with iron of poor solubility. Strontium and cesium can also enter into the composition of these particles and become insoluble (Reissig, 1959). Investigation of the fall-out fission products has shown that the soluble fraction of Sr\(^{90}\), Cs\(^{137}\) and Ce\(^{144}\) amounted to 95.6, 70.0 and 42.0% respectively (Wellford and Collins, 1960). Falling on the earth surface, the radioactive products are absorbed by the soil and the vegetation cover. According to data by V.M. Klechkovskii and I.V. Gulyakin (1958), soils possess a high sorption ability with regard to most fission products. However, the durability of absorption is different for various isotopes. Strontium and ruthenium have the greatest mobility. Under the influence of surface waters, part of the radioactive strontium can be displaced from the soil as the result of ion exchange. The degree of displacement depends on the exchange capacity of the soil, the pH of the soil solution and the content of calcium, the chemical analog of strontium. Rare earths and cesium become securely fixed to
soils and almost do not desorb under the influence of surface waters (Polyakov, 1956; Spitsin and Gromov, 1959; Titlyanova and Timofeeva, 1959).

Observations conducted by us in 1959 on the Volga River have shown that during the spring flood the inflow of fission products 6-7 months old amounted to 4.5% of the total amount in the snow cover of the area of the river drainage basin. During this period, 13% $^{90}\text{Sr}$ entered the Volga River. The relatively high percent of the $^{90}\text{Sr}$ wash-off from the area has been established also by other authors (Straub and al., 1960; Morgan and Stanbury, 1961). It should be noted that in April 1959 the mean value of radioactivity of the Volga River water in a non-regulated sector, where the influence of the surface run-off of such waters is most distinct, was approximately 20 times smaller than the activity of snow water. In June, after the Volga River reservoirs were filled, the ratio of the specific radioactivity of snow water, with a correction for decay, to the waters of the Ivanovskoe, Ugличskoe and Rybinskoe reservoirs was equal, on the average, to 27:1.

In June and July 1965, in the period of more complete mixing of flood waters with less active winter waters, the average level of radioactivity of the Upper Volga reservoirs was found to be only 5 times lower than the activity of snow waters. Consequently, on the basis of the ratio of the radioactivity of snow water to the river waters during the period of observations, we can conclude with certainty that the inflow of old products from the area of the drainage basin is considerably higher than of fission fragments, the age of which is counted as 6-7 months.
The increased flow of long-life fission products can in part be explained by a rise of the corresponding content of Sr\textsuperscript{90}, the radioactive isotope possessing the greatest migration ability.

In a study of the pollution with radioactive fall-out of three small rivers in England it has been established that the content of the long-life Sr\textsuperscript{90} and the short-life Sr\textsuperscript{89} in the river water was observed to be 20 and 60 times, respectively, lower than in rain water (Morgan and Stanbury, 1961). The higher concentration of Sr\textsuperscript{90} in river water is explained by the authors by additional inflow from the drainage basin resulting from desorption from the soil.

Factors of distribution of fission products in the water reservoir

As known, during the period of spring flood large quantities of suspended matter enter the Volga river as the result of erosion by the melt waters of the soil in the area of the drainage basin. Radioactive products contained in the flood waters in ionic and colloidal form (part of the non-absorbed activity) enter a new stage of interaction with the suspended substances; this is characterized by other relationships between the liquid and solid phases. In comparison with where the soil solution in conditions of the reservoir, the concentration of the suspended matter decreases sharply, the relative sorption ability of the suspension rises and the coefficients of distribution of radioisotopes increase. However, the absolute quantities of the fission products extracted as the result of...
sorption processes depend obviously on the level of radioactivity of the water.

In a study of the sorption of long-life fission products from a suspension of clay in river- and distilled water, at a concentration of the clay particles from 16 to 256 mg/l, high coefficients of distribution of radioactive cerium and cesium (8900-3900), medium for ruthenium (1600-690) and comparatively low for strontium (950-660) were obtained (Garder and Skulberg, 1964). The same authors note a suppression of sorption of ruthenium from clay suspension in river water. Despite the fact that the sorption process depends on a series of factors (such as the nature and exchange capacity of the suspended substances, the chemical composition of the water, particularly important for Sr\textsuperscript{90}, micro-quantities of which participate in the ion exchange together with Ca\textsuperscript{2+}, Mg\textsuperscript{2+}, K\textsuperscript{+}, Na\textsuperscript{+} etc.), cerium in water bodies and cesium are predominantly absorbed by suspended substances.

At the end of the flood, after the reservoirs are filled and the flow velocity reduced, continuous settling of the suspended matter, and the radioactive isotopes bound with them, occurs most intensively.

Observations and calculations conducted in 1959 have shown that as the result of settling 40% of fission products, 6-7 month old, which entered the Volga river during the period of the spring flood, are retained in the Volga River reservoirs. The percentage of retention has been determined by the comparison of the actually observed level of the water radioactivity to the activity of l\textsuperscript{lm}of suspension to 2. The coefficient of distribution represents the ratio of the activity of l\textsuperscript{ml} of water after establishing a dynamic equilibrium of activity between the liquid and the solid phases; it characterizes the mobility of the radioisotope.
in a point below the system of reservoirs with data on the specific activity of water at this point; this is calculated by taking into account the reduction of activity because of radioactive decay and dilution.

After filling of the reservoirs in 1965, a decrease in the water radioactivity level was not observed. This allows us to assume that settling without participation of organisms is not a decisive factor in the accumulation of long-life fragments of uranium in the bottom sediments of the water body.

Apparently an important role is played by biochemical processes in the transformation of long-life fission products, where the water organisms appear not only as accumulators of radioactive substances but also as transformers promoting both the transformation of the fission products from a dissolved or colloidal state into an insoluble form and the settling of these products.

During the period of observations in 1965, a statistically reliable decrease in the radioactivity of the water in the reservoirs was noted only during the peak of the growing period. Thus, during the summer months, the distribution of radioactive products contained in the water of the reservoir depends on their participation in biological processes and on the intensity of these processes. In this connection the data by N.V. and E.A. Timofeev-Resovskii (1955) on the absorption of long-life fission products by water organisms are interesting. In particular, attention is drawn by the high coefficients of accumulation of Ce$^{144}$ by fresh water organisms of various groups, including bacteria, advanced water flora, plankton and benthos. As the
result of a study of absorption and elimination of radioactive cerium by the mollusk *Dreissena polymorpha*, Glaser (1962b) established that Ce\(^{144}\) accumulates mostly in the shell of the mollusk. The highest concentrations were detected in the growing part of the shell which is an indication of the active participation of Ce\(^{144}\) in its formation. By observing the accumulation of radioactive fall-out by higher water plants in Lake Stechlinsee, the same author proved (1962a) that their activity is almost entirely caused by Ce\(^{144}\). He also (1966) established that, after water plants die off, radioactive cerium does not enter the water and that the vegetation remnants and detritus continue to sorb cerium from the water. Similar results were obtained by G.G. Polikarpov (1961) with the alga *Cystoseira barbata*. At the same time, after the death of this alga, almost all of Sr\(^{90}\) returns to the water. Cs\(^{137}\) is partially drawn into the sea sediments with rather low coefficients of accumulation. In experimental bodies of fresh water, a high accumulation of Cs\(^{137}\) in the sediment was noted; this can be explained by the capacity of this element to penetrate into the crystal lattice of silicates (Agafonov et al., 1960).

In water reservoirs, the direct contact of the water mass with the bottom of the reservoir, is also a factor in the absorption of long-life fission products from the water. However, with a lowering of the activity level of the water, a reverse movement of radioactive products from the bottom sediments is not excluded. According to data of B.A. Stepanov (1957) fragmentary radioelements sorbed by the
silt are washed out by water only with great difficulty. Under experimental conditions, over a period of 2 months approximately 4% of the silt activity was desorbed; it was mainly radioactive strontium which transferred into the solution.

Content of long-life fission products in bottom sediments of reservoirs

As has been mentioned earlier, measurement of the total β-activity was conducted on samples containing a finely dispersed fraction of the silt with particles measuring less than 0.01 mm, and on original samples of liquid mud which were left unseparated. Table 3 shows the results of activity measurements of samples of bottom sediments collected in June and July 1965.

The determination of activity were made in the last decade of October i.e. 3-4 months after the samples were taken.

At all the observation points, the highest values of activity were obtained for the finely dispersed fraction of the silt. Judging from the loss during heating, these samples also differed by their higher content of organic matter. The chemical composition of the finely dispersed fraction of the bottom deposits is characterized by data shown in Table 4 (analysis conducted by V.M. Smelova).

The results of the activity measurement of the bottom deposits in the Gorkovskoe reservoir are presented in Table 5. The activity was measured five months after collection of the samples. In the Gorkovskoe reservoir, the activity of the samples of the bottom deposits, which were not divided into fractions, was expressed by values similar to the total...
activity of samples of the finely dispersed silt fraction in the Gorkovskoe reservoir can be explained by the fact that the measurements were conducted after a great interval from the time when the samples were taken. During this period a reduction of activity took place because of decay of the fission products with a half-life period of about one year. The presence of fission products with a medium half-life period was discovered in samples by observation of the decrease of their activity with time. In some samples of the bottom deposit the course of the decrease of activity almost completely corresponded

Table 3
Radioactivity of bottom deposits of the Upper-Volga reservoirs in 1965

<table>
<thead>
<tr>
<th>Point of taking samples</th>
<th>11-12. VI</th>
<th>7-8. VII</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Loss by heating of heated residue</td>
<td>Loss by heating of heated residue</td>
</tr>
<tr>
<td></td>
<td>% of dry substance</td>
<td>pc/g</td>
</tr>
<tr>
<td>Finely dispersed fraction of silt</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ivankovskoe reservoir above dam</td>
<td>16.60</td>
<td>59.2</td>
</tr>
<tr>
<td>Uglishskoe reservoir:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Kimry</td>
<td>18.20</td>
<td>48.4</td>
</tr>
<tr>
<td>Kalyazin</td>
<td>17.59</td>
<td>62.8</td>
</tr>
<tr>
<td>above dam</td>
<td>11.51</td>
<td>41.6</td>
</tr>
<tr>
<td>Rybinskoe reservoir:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Koprino</td>
<td>14.97</td>
<td>66.4</td>
</tr>
<tr>
<td>Not settled silt</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ivankovskoe reservoir above dam</td>
<td>11.10</td>
<td>45.9</td>
</tr>
<tr>
<td>Uglishskoe reservoir:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Kimry</td>
<td>7.59</td>
<td>30.2</td>
</tr>
<tr>
<td>Kalyazin</td>
<td>14.47</td>
<td>48.7</td>
</tr>
<tr>
<td>above dam</td>
<td>8.77</td>
<td>32.3</td>
</tr>
<tr>
<td>Rybinskoe reservoir:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Koprino</td>
<td>14.13</td>
<td>37.1</td>
</tr>
</tbody>
</table>
### Table 4

Chemical composition of the finely dispersed fraction of the sediments of Upper-Volga water reservoirs, June 1965 (% of heated residue)

<table>
<thead>
<tr>
<th>Point of sample taking</th>
<th>SiO₂</th>
<th>Al₂O₃</th>
<th>Fe₂O₃</th>
<th>MnO</th>
<th>TiO₂</th>
<th>CaO</th>
<th>MgO</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ivankovskoe reservoir above dam</td>
<td>56.80</td>
<td>20.73</td>
<td>7.52</td>
<td>0.30</td>
<td>0.96</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Uglikhskoe reservoir at Kalyazin</td>
<td>63.21</td>
<td>15.86</td>
<td>8.07</td>
<td>0.32</td>
<td>0.52</td>
<td>3.08</td>
<td>2.28</td>
</tr>
<tr>
<td>Rybinskoe reservoir at Koprino</td>
<td>63.43</td>
<td>13.95</td>
<td>8.02</td>
<td>0.28</td>
<td>0.47</td>
<td>2.97</td>
<td>2.78</td>
</tr>
</tbody>
</table>

To the speed of decay of Ce₁⁴⁴; the period of half-life of the radioisotope present in the sample, determined graphically, amounted to 280 days (see graph). In the majority of samples, however, the activity dropped off much slower which indicated the presence in them of long-life products of fission.

The period of observations of the decrease of activity did not exceed one year. During such an interval, Sr⁹⁰ and Cs¹³⁷ virtually does not change. If we assume that the activity of the
Radioactivity of bottom deposits of the Gorkovskoe reservoir (11 - 23. VIII 1965)

<table>
<thead>
<tr>
<th>Point of sample collection</th>
<th>Loss by heating</th>
<th>$\beta$-activity of heated residue</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>% of dry matter</td>
<td>pc/gm</td>
</tr>
</tbody>
</table>

Finely dispersed fraction of silt

Below Yaroslavl
5 km
13.00
34.2

50 km, bed of Volga River
17.00
64.4*

50 km, at right bank
11.70
27.2

Below Kineshma
17.80
40.5

Above dam
20.70
46.3
21.00
55.7

Not settled silt

Below Yaroslavl
5 km
12.20
35.6

10 km
9.96
20.3

50 km, bed of Volga River
9.02
28.9*

50 km, at right bank
9.80
37.5

Below Kineshma
11.40
42.8

Above dam
11.00
35.5
12.40
41.5

silt samples was caused by a binary mixture of $\beta$-emitters, (including a long-life isotope the activity of which does not change in this time interval) and a radioisotope with a medium half-life period ($T=282$ days), the content of the long-life component can be determined from the equation $a_1 - x = k (a_t - x)$

![Decrease of activity of a silt sample. Uglishskoe reservoir below Kalyazin 7. VII. 1965](image)

* Measurement of the activity was conducted three months after collection of samples
where \( a_1 \) is the initial activity of the sample; \( a_t \) is the activity of the sample after time \( t \); \( k \) is the correction for the decay of Ce\(^{144}\) during the time \( t \) \( (k = e^{0.6933t}) \); \( x \) is the activity caused by the long-life isotope.

The amounts of long-life products of fission with a long and medium half-life in the samples of silt and water were determined by calculations (Tables 6 and 7).

The data shown prove that Ce\(^{144}\) concentrates in large quantities in the upper, finely dispersed layer of bottom deposits. The content of fission products with a long period of half-life was higher in the silt samples which were not submitted to separation. This indicates that strontium is probably adsorbed both by the fine fraction of the silt and by larger particles, and penetrates into the lower layers of the silt deposits.
### Table 6

#### Content of long-life fission products in the bottom deposits of reservoirs in 1965

<table>
<thead>
<tr>
<th>Point of collection of samples</th>
<th>Date</th>
<th>$\text{Sr}^{90}$ of the heated residue pc/g</th>
<th>$\text{Ce}^{144}$ of the heated residue pc/g</th>
</tr>
</thead>
<tbody>
<tr>
<td>Finely dispersed fraction of silt</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Uglichskoe reservoir at Kalyazin</td>
<td>7.VII</td>
<td>5.1</td>
<td>61.1</td>
</tr>
<tr>
<td>Rybinskoe reservoir at Koprino</td>
<td>12.VI</td>
<td>10.1</td>
<td>56.3</td>
</tr>
<tr>
<td>Silt not subjected to settling</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Uglichskoe reservoir at Kalyazin</td>
<td>7.VII</td>
<td>19.4</td>
<td>31.6</td>
</tr>
<tr>
<td>Rybinskoe reservoir 12.VII</td>
<td>26.4</td>
<td>10.7</td>
<td></td>
</tr>
</tbody>
</table>

### Table 7

#### Content of long-life fission products in bottom deposits of the Gorkovskoe reservoir (August 1965)

<table>
<thead>
<tr>
<th>Point of collection of samples</th>
<th>$\text{Sr}^{90}$ in heated residue pc/g</th>
<th>$\text{Ce}^{144}$ in heated residue pc/g</th>
</tr>
</thead>
<tbody>
<tr>
<td>Finely dispersed fraction of silt</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Below Yaroslavl:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5 km</td>
<td>8.4</td>
<td>25.8</td>
</tr>
<tr>
<td>50 km, bed of Volga River</td>
<td>1.5</td>
<td>62.9</td>
</tr>
<tr>
<td>Below Kineshma</td>
<td>1.6</td>
<td>38.9</td>
</tr>
<tr>
<td>Above dam</td>
<td>37.0</td>
<td>18.7</td>
</tr>
<tr>
<td>Silt not subjected to settling</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Below Yaroslavl:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5 km</td>
<td>15.7</td>
<td>19.9</td>
</tr>
<tr>
<td>50 km, bed of Volga River</td>
<td>2.6</td>
<td>34.9</td>
</tr>
<tr>
<td>Below Kineshma</td>
<td>17.0</td>
<td>25.7</td>
</tr>
<tr>
<td>Above dam</td>
<td>31.0</td>
<td>10.6</td>
</tr>
</tbody>
</table>
In the upper and middle sections of the water reservoirs, the bottom deposits contain more Ce\(^{144}\) than strontium, whereas in the sections above the dam the activity of the silt is mainly caused by the presence of long-life fission products. Apparently cerium carried in detritus, does not reach the section of the Gorkovskoe reservoir above the dam in large quantities because of absorption by water organisms and permanent sorption of this radioisotope by their decay products.

The results of a comparison of the content of fission products in water and bottom deposits are shown in Table 8.

The high coefficient of accumulation of fission products can be explained first of all by the fact that the uppermost, finely dispersed layer of silt deposits was subjected to analysis. The influence of the degree of dispersion and the character of the ground on the sorption of long-life fission products has been demonstrated very well in the work of I.O. Bogatyrev (1962). According to data of this author, the coefficients of accumulation of Sr\(^{90}\) in sand and silt were on the average 1 and 240 and for Cs\(^{137}\) 20 and 5300 respectively. On the basis of literature data, lower accumulation coefficients would have been expected for Sr\(^{90}\).
Table 8

Coefficients of accumulation of long-life fission products by bottom deposits of reservoirs

<table>
<thead>
<tr>
<th>Points of collection of samples</th>
<th>Character of deposits</th>
<th>$K_{Sr^{90}}$</th>
<th>$K_{Ce^{144}}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Uglichskoe at Kalyazin reservoir</td>
<td>Finely dispersed fraction</td>
<td>2100</td>
<td>7100</td>
</tr>
<tr>
<td>Uglichskoe at Kimry reservoir</td>
<td>Silt not subjected to settling</td>
<td>1100</td>
<td>3400</td>
</tr>
<tr>
<td>Gorkovskoe at Kineshma reservoir</td>
<td>Finely dispersed fraction</td>
<td>1100</td>
<td>4100</td>
</tr>
</tbody>
</table>

Note: The accumulation coefficient ($K$) is the ratio of activity of 1 g of silt (dry weight) to the activity of 1 ml of water.

The values obtained apparently are conditioned also by the presence in the samples of Cs$^{137}$ intensely absorbed by the sediment, although in the method applied for measuring the activity, strontium was mainly taken into account. The values of accumulation coefficients obtained for Ce$^{144}$ agree fully with data as to the high sorption of this radioisotope by suspended substances of organic and mineral origin.

Conclusion

The purpose of this work was a study of the distribution in a reservoir of radioactive fall-out which enters mainly with waters of the surface run-off during the period of the spring flood. To determine the composition of the radioactive fall-out at the source of the reservoirs, i.e. snow melt waters, snow samples were collected, their total activity...
measured and the decrease of this activity with the progress of time observed. As a result it was established that during the period of observations the activity of the fall-out is caused basically by four long-life fission products: Ce\textsuperscript{144}, Sr\textsuperscript{90}, Cs\textsuperscript{137} and Ru\textsuperscript{106}. A comparison of the specific activities of snow melt waters and the water from the reservoirs allows us to conclude that the surface run-off of old fission products (3 years old) is considerably higher than that of fission fragments whose measured age is 6-7 months. After the water reservoirs are filled in spring and the flow velocity is reduced, virtually no drop in specific $\beta$-activity of the water has been noted. This indicates that settling of the suspended substances is not an important factor for the transfer of long-life fission products from the water into the bottom deposits in contrast to fission fragments 6-7 months old.

In analysing the bottom deposits, the highest values of $\beta$-activity were obtained for the finely dispersed fraction of silt. Observation of the drop in activity of the samples over a period of time have shown that in some samples the reduction of activity corresponded to the rate of decay of Ce\textsuperscript{144}. The rate of decay in the majority of samples was slower, which indicated the presence of a long-life component. The content in silt samples of a binary mixture of $\beta$-emitters which included a long-life isotope, the activity of which virtually does not change during the given time interval, and a radioisotope of a medium half-life period, made possible use of the calculation method for determination of the composition of the isotopes.

As the result of the determinations, relatively small
quantities of Sr$^{90}$ and Cs$^{137}$ were detected in the finely dis-
dispersed fractions of the silts, whereas the content of cerium
in them was considerable. In silt samples which were not sub-
jected to separation, a large share of the activity is caused
by long-life isotopes. In bottom deposits of upstream and,
in particular, middle sections of the reservoirs, cerium
predominates over strontium and cesium; in sections above the
dam, the content of cerium decreases and in the Gorkovskoe
reservoir, above the dam, the quantities of long-life fission
products increase. Consequently, cerium as a component of the
detritus carried in, virtually does not reach as far as the
section of the Gorkovskoe reservoir above the dam be-
cause of intensive absorption by water organisms.

The presented interpretation of the results obtained
is of a preliminary character and requires ample material for
its confirmation.

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