TOTAL ^{137}Cs AND ^{90}Sr CONTAMINATION AND EXTERNAL-RADIATION DOSES IN THE TERRITORY OF THE USSR

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Data on radiation background are basic to the establishment and application of criteria for the safe use of atomic energy for peaceful purposes. The radiation background is determined by the radioactive contamination of a locality, the natural radioactivity of the environment, and cosmic rays.

In this article we consider the components of the radiation background for the territory of the USSR. The actual data concerning the total ^{137}Cs contamination and the natural radioactivity were obtained from airborne γ-spectral surveys [1, 2]. The errors of the airborne measurements do not, for the most part, exceed 15-20%.

^{137}Cs Contamination of the Soil and Vegetation Cover. The distribution of the surface density (the concentration) of ^{137}Cs for 1974 over the territory of the USSR is shown in Fig. 1. As is shown by the estimates of [2], the concentration of ^{137}Cs varies only slightly with time and will remain practically the same for the next few years. The average concentration of ^{137}Cs in the territory of the USSR amounts to 92 μCi/km² (excluding the regions of high mountains where no investigations have been conducted). The observed values of the concentration amount in practice to 15-20 μCi/km². The frequency distribution of the concentration values can be satisfactorily approximated by the normal law. The mean-square deviation is 33 μCi/km².

The distribution of ^{137}Cs is characterized by marked differences between latitude zones. Against the background of this overall rule, there is considerable spottiness in the distribution of contamination levels, due to the local peculiarities of individual regions. The maximum contamination levels are concentrated chiefly in the latitude belt from 50 to 60° north. Here the ^{137}Cs concentrations amount to 100-175 μCi/km². North and south of this belt the contamination levels decrease. The minimum value (25-50 μCi/km²) is found north of 70° and south of 45° north latitude.

In addition to varying with latitude, the contamination levels are higher for areas close to the mountain systems: the Carpathians, the Crimean and Ural mountains, the Caucasian ridge, the Tien-Shan, the Altai, and the Eastern Siberian and Transbaikal systems. East of the Yenisei River, owing to the complex orography — the presence of many mountain systems occupying a large part of the territory — the latitude-zone differentiation is less marked. The latitude-zone distribution and the local deviations from it are closely related to the observed patterns of precipitation distribution [2].

The distribution of the ^{137}Cs concentration according to geographic and climatic zones is shown in Table 1. These data indicate the connection between the contamination level and the annual amount of atmospheric precipitation. A more detailed analysis has shown that the relation between the ^{137}Cs concentration and the annual average precipitation (P, mm) is expressed, for individual zones of the nonmountain areas of the country shown in Table 1, by the following formulas:

Tundra and forest—tundra	$Q = 0.25 + 0.14P$
Forest zone	$Q = 0.3 + 0.14P$
Forest—steppe and steppe	$Q = 0.45 + 0.12P$
Semidesert and desert	$Q = 0.55 + 0.35P$

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TABLE 1. Surface Density (concentration) of ^{137}Cs in Various Geographic Zones

Zone	Soil, vegetation	Participation, mm/yr	Concen., $\mu Ci/km^2$
Tundra and forest–tundra	Tundra gley and swampy soils (mosses, lichens, bushes, low trees)	150-600	64
Coniferous forest (taiga)	Podzol and swampy soils (coniferous forests, swamps, meadows)	300-900	110
Mixed forest	Sod-podzol and gray forest soils (coniferous and broadleaf forests, meadows)	450-900	107
Forest–steppe zone	Chernozem, gray forest soils (alternation of steppe massifs and forest areas)	300-550	91
Steppe zone	Chernozem and chestnut-colored soils (steppe vegetation)	300-400	87
Semidesert	Light chestnut and brown soils (wormwood-type and halophytic vegetation)	100-200	70
Desert	Gray-brown soils, serozems (haloxylon)	75-150	59

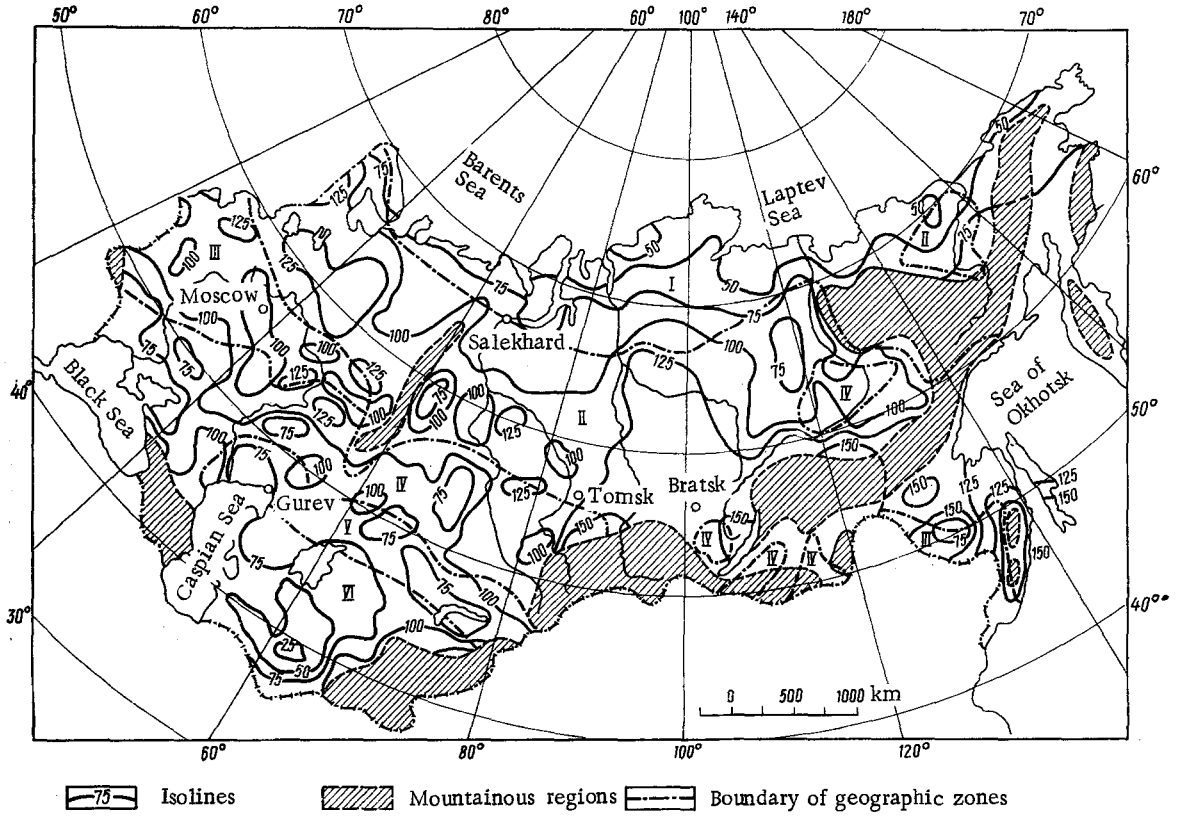

Fig. 1. Distribution of the concentration of ^{137}Cs over the territory of the USSR, $\mu Ci/km^2$: I) tundra and forest–tundra; II) coniferous forest; III) mixed forest; IV) forest–steppe and steppe; V) semidesert; VI) desert.

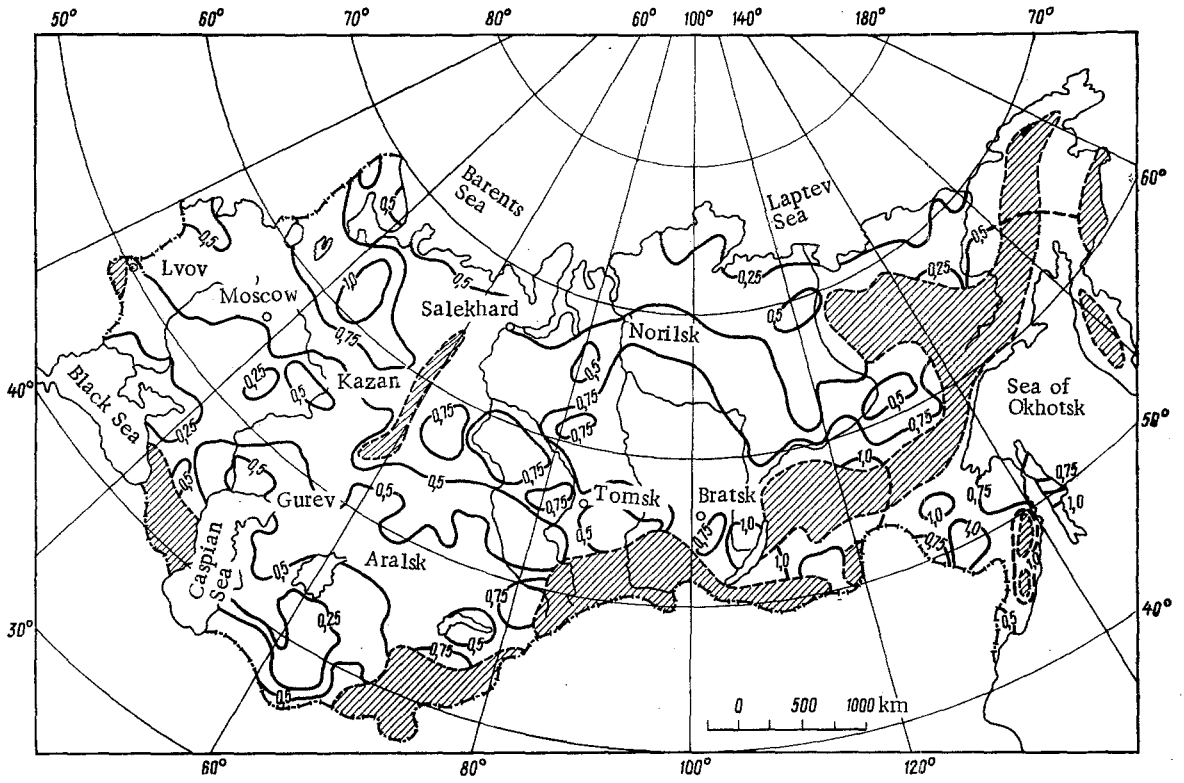

Fig. 2. ^{137}Cs γ-ray dose rate at a height of 1 m above the ground, μR/h (same legend as in Fig. 1).

(here $Q = q(P)/\bar{q}$ is the ratio of the ^{137}Cs concentration in a region with precipitation P to the average concentration in the entire zone).

In the equations given above, the constant term is equal to the fraction of the concentration due to dry fallout, and the regression coefficient characterizes the specific intensity of washing out of radioactive aerosols by the atmospheric precipitation. The dry-fallout fraction increases from the northern to the southern regions (from 25 to 55%). In the semidesert and desert zone the specific intensity of washing out of aerosols by the precipitation increases sharply.

^{90}Sr Contamination of the Soil and Vegetation Cover. An analysis of the ratio of ^{90}Sr to ^{137}Cs in the fallout [2] showed that the ^{90}Sr concentration can be found from the equation $q_{Sr} = 0.54\ q_{Cs}$ with an error of no more than 10%.

We investigated specimens of different types of USSR soils. The ratio of ^{90}Sr to ^{137}Cs for gray forest soils, chernozems, and chestnut soils was 0.55 ± 0.12. For gray-brown soils, serozems, and fixed sands it was 0.62 ± 0.15. The fairly large observed variations in the ratio (∿25%) are due to the fact that the ^{90}Sr can be reliably determined in soil samples to a depth of about 10 cm but is not taken into account when it migrates into deeper horizons. The ratio in the soils is practically equal to the ratio in the fallout. Therefore the ^{90}Sr concentration should be assumed to conform to the relation given for the fallout. The average ^{90}Sr concentration calculated in this way for the territory of the USSR is equal to 50 μCi/km^2.

^{137}Cs γ-Ray Dose Rate. The distribution of the ^{137}Cs γ-ray dose rate at a height of 1 m for the territory of the USSR is shown in Fig. 2. In calculating the dose rate it was assumed that in the virgin lands the penetration of ^{137}Cs into the soil follows an exponential law. The penetration coefficient for 1972 was 0.6 ± 0.2 cm^2/yr. For this value of penetration coefficient the dose rate at a height of 1 m is related to the ^{137}Cs concentration by the equation P (in μR/h) = $6.5 \cdot 10^{-3} \cdot$q (in μCi/km^2). The variations in dose rate as a result of oscillations in the value of the penetration coefficient amount to 15%.

Between the ^{137}Cs concentration map (see Fig. 1) and the dose-rate map (see Fig. 2) there are certain differences, due essentially to the fact that in cultivated fields the ^{137}Cs has penetrated the topsoil. As a result, the dose rate drops by a factor of as much

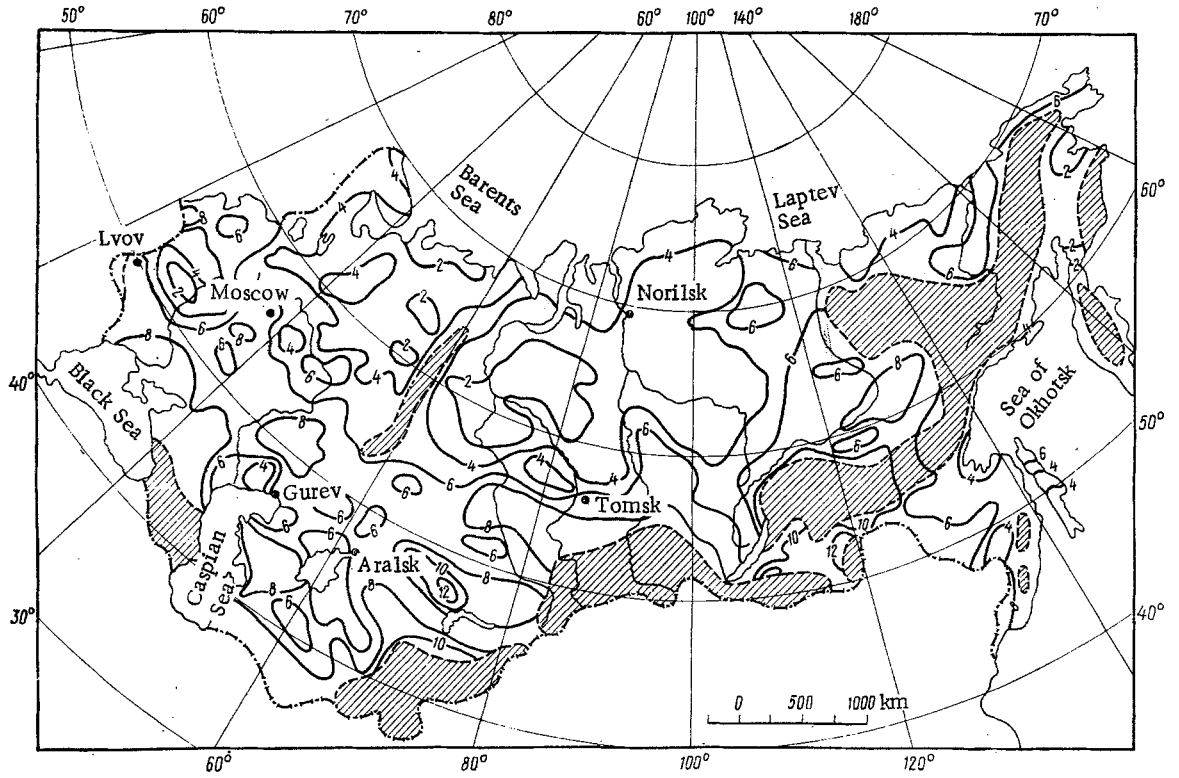

Fig. 3. Dose rate of γ rays from natural radioactive elements at a height of 1 m above the soil, μR/h (same legend as in Fig. 1).

TABLE 2. Average γ-Ray Dose Rate at a Height of 1 m above the Soil

Soils	Dose rate, μR/h	Coeff. of variation, %	Characteristic range of variation, μR/h
Tundra	3,5	43	2,0—5,0
Podzol	2,9	48	1,5—4,3
Sod-podzol	4,5	45	2,5—6,5
Gray forest soils	6,5	23	5,0—8,0
Chernozems	7,1	21	5,5—8,6
Chestnut soils	7,6	20	6,1—9,1
Brown desert—steppe soils	7,2	28	5,9—9,2
Gray-brown desert soils	7,7	18	6,4—9,2
Serozems	8,6	18	7,0—10,2

as 2.5. Therefore, where there is intensive agriculture, owing to the large areas taken up by plowed fields, the average dose rate is found to be considerably lower. The range of variation of the dose rate is between 0.10 and 1.25 μR/h. The average value of the dose rate when the plowed fields are taken into consideration is about 0.5 μR/h. As in the case of the concentration, there is a distribution into latitude zones.

The frequencies of the dose-rate values have a logarithmic-normal distribution. The marked asymmetry of the dose-rate distribution when there is a normal distribution of the concentration is due to the large number of low dose-rate values for plowed areas.

Dose Rate of γ-Rays from Natural Radioactive Elements. Natural radioactive elements constitute a constantly present source of γ rays. On the global and regional scales, the external irradiation is affected, as a rule, by the radioactivity of the soils. Except for mountainous regions, rock outcrops are limited in area, and therefore their γ radiation is local in character. The relative concentration of natural radioactive elements in soils is

TABLE 3. Numerical Values of the Shielding Coefficient

Geographic zone	^{137}Cs	Natural radioisotopes
Tundra and forest–tundra	0,40—0,80	0,60—0,90
Coniferous forest	0,50—0,85	0,70—0,95
Mixed forest	0,75—0,95	0,90—1,0
Forest–steppe and steppe	0,75—0,95	0,90—1,0
Semidesert	0,85—0,95	0,95—1,0
Desert	0,90—1,0	0,95—1,0

TABLE 4. Distribution of Cosmic-Ray Dose over the Terriotry of the USSR

Dose, Mrd/yr	Exposure dose rate, μR/h	Territorial extent, %
28—30	3,65—3,9	60
30—40	3,9—5,2	33
40—50	5,2—6,5	5,5
50—100	6,5—13	2,0
100—150	13—19,5	0,5

found to lie mainly within the following limits: $(0.5\text{-}3.5)\cdot10^{-4}$% for uranium, $(1\text{-}14)\cdot10^{-4}$% for thorium, 0.3-3.0% for potassium. A characteristic of the spatial distribution of natural radioactive elements in the soil is that on the regional level the relative concentrations increase from north to south. The relative concentrations in rocks do not, for the most part, exceed the maximum values of the relative concentrations in the soils. However, in some varieties of rocks the uranium and thorium content may be greater by as much as one order of magnitude than in the soils [1].

A map of the dose rate of γ rays from natural radioactive elements in the territory of the USSR, calculated on the basis of the uranium, thorium, and potassium content values determined by the aerial survey method [2], is shown in Fig. 3. The dose rate has a clearly marked latitude-zone distribution. Genetic types of soils closely related to the geographic and climatic zonality determine the spatial distribution of the dose field over the territory of the USSR (Table 2).

The frequency distribution of the dose rate within each genetic type of soil is satisfactorily approximated by the normal law. The amount associated with the range of dose-rate values (see Table 2) is 68%. This range was calculated on the basis of the normal distribution. There is a great deal of overlapping between the dose-rate values of different genetic types of soils; this corresponds to the gradual transition from one type of soil to another and is due to the effect of local factors, primarily the radioactivity of the parent rocks and the mechanical composition of the soils.

Table 2 does not take account of soil radioactivity data for the regions east of the Yenisei River. Here most of the territory is occupied by high plateaus and ridges which have a high proportion of outcrops (∿40%), so that it is difficult to distinguish the soil and rock radioactivity values. The isoline contours in this region often correspond to the boundaries of individual rock complexes. The lowest radioactivity is found in intrusive rocks of basic composition — basalts, andesites, and their tuffs (1.5-2.5 μR/h). The maximum value (9-14 μR/h) is found in areas of acid intrusive rocks (granites, granodiorites, quartz diorites) and metamorphic rocks.

Attenuation of External γ Radiation by Snow Cover. The snow cover can substantially reduce the external-radiation dose of field personnel and the general population. From the data of 550 weather stations concerning the moisture content in the snow cover in the territory of the USSR, averaged over many years [3], maps have been prepared to show the attenuation of the annual γ-ray dose rate from ^{137}Cs and natural radioactive elements [4].

The attenuation of the γ rays is characterized by the dose-rate shielding coefficient of the snow cover, $K(x) = P(I, x)/P(I)$, where x is the moisture content of the snow cover; $P(I, x)$ and $P(I)$ are the dose rates at a height of 1 m above the snow and above the soil, respectively. In calculating the shielding coefficient, the nature of radioisotope penetration into the soil was taken into account. The limits of variation of $K(x)$ over a 1-yr period for the main geographic zones of the country are shown in Table 3. These changes characterize the climatic nonuniformity of the zones considered. The greatest attenuation of the annual dose values is found in the tundra and the forest—tundra. The annual dose value decreases by a factor of 1.5 for natural radioactive elements and 2.5 for ^{137}Cs. In the southern regions of the country the γ-ray attenuation may be disregarded in practice.

Cosmic-Ray Dose. The cosmic-ray dose is caused mainly by the ionizing part of cosmic radiation. The contribution made by neutrons for geomagnetic latitudes of 40-50° in the 0-4-km altitude range is only 2-8% and is disregarded here.

TABLE 5. External Annual Radiation in the Territory of the USSR

Geographic zone	Natural radioactivity of soils and rocks	^{137}Cs	Cosmic rays	Atmospheric radon	Total dose
Tundra and forest–tundra	26,9*	3,3	28,3	1,5	50,0
	20,5	2,2	28,3	1,5	52,5
	39	4	54	3	100
Coniferous forest	27,7	5,5	28,5	1,2	62,9
	22,8	4,0	28,5	1,2	56,5
	40	7	51	2	100
Mixed forest	41,6	4,2	28,6	2,3	76,7
	37,4	3,4	28,6	2,3	71,7
	52	5	40	3	100
Forest–steppe and steppe	56,2	3,7	29,1	3,0	92,0
	50,5	3,0	29,1	3,0	85,6
	60	3	34	3	100
Semidesert	56,2	4,0	29,3	4,5	94,0
	53,3	3,6	29,3	4,5	90,7
	59	4	31	5	100
Desert	57,7	2,7	29,1	4,5	94,0
	57,7	2,7	29,1	4,5	94,0
	61	3	31	5	100

*The first line gives the average dose value in Mrd/yr; the second, the dose value taking account of the snow-cover shielding, Mrd/yr; the third line, the contribution to the total dose (taking account of the snow-cover effect), %

The annual doses for points which have a geomagnetic latitude of φ and an altitude of H above sea level can be calculated by the approximate formula [5]

$$D(\varphi, H) = a(\varphi) + b \exp [H/c(\varphi)].$$

If $D(\varphi, H)$ is expressed in megarads per year and H in kilometers, then b = 11,

$$a(\varphi) \begin{cases} 15 \text{ for } \varphi < 25°; \\ 15 + 0.118(\varphi - 25°) \text{ for } 25 < \varphi < 42°; \\ 17 \text{ for } \varphi > 42°; \end{cases}$$

$$c(\varphi) \begin{cases} 1.96 \text{ for } \varphi < 10°; \\ 1.96 \exp [-0.0028(\varphi - 10°)] \\ \qquad \text{for } 10 < \varphi < 50°; \\ 1.75 \text{ for } \varphi > 50°. \end{cases}$$

The formula given above enables us to estimate the annual doses with an error of no more than 5% in the 0-5-km altitude range.

The distribution of the cosmic-ray dose over the territory is characterized by the data of Table 4. An isodose map for the territory of the USSR is given in [5]. For about 60% of the territory of the USSR, including the European part of the country (except for the Carpathians and the Caucasus) and the Western Siberian plain, the dose is 28-30 Mrd/yr, while the eastern mountainous part of the country has a dose of 30-50 Mrd/yr. The highest dose values are found in the area of the Pamir–Tien-Shan mountain system and the Caucasus, where the dose exceeds 100-150 Mrd/yr, with a maximum value of 200-350 Mrd/yr (∿700 Mrd/yr on Lenin Peak, Victory Peak, and Communism Peak). The dose rate may differ from the average by 3-10% because of variations in cosmic radiation.

Contribution Made by Various Sources to External Radiation in the Territory of the USSR. The maps shown above enable us to estimate the contribution made by γ-radiation from ^{137}Cs, natural radioactive elements, and cosmic rays to the external-radiation dose in the territory of the USSR.

In addition, γ rays are also emitted by radon decay products found in the atmosphere. In order to take this factor into account, we may assume that the average emanation coefficient is 10% and that the concentration of decay products in the air decreases exponentially with altitude and decreases by a factor of 2 at an altitude of 1 km [1].

The annual doses of external radiation for the geographic zones of the USSR are indicated in Table 5, from which it can be seen that the total dose of external radiation increases from the tundra to the desert zone by a factor of almost 2: from 52 to 94 Mrd/yr. The contribution made by the different components varies regularly for the different zones. Thus, in the first two zones most of the annual dose is due to cosmic rays. In the other zones the contribution of natural radioactivity is predominant. In the desert zone it is one and a half times as high as in the tundra and the coniferous forests. This difference is additional proof of the fact that the peaceful use of atomic energy has only a slight effect on the annual dose.

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COMPLEX OF DEVICES FOR SAMPLING AND MEASURING TRITIUM IN ENVIRONMENTAL OBJECTS

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Among the contaminants of technical origin in water systems are many which remain in the dissolved (ionic) state for a long time. Tritium may serve as an analog of their dispersal with bodies of water. At present, the tritium content in waters is sufficient for studying migration. Such research makes it possible to predict the behavior of industrial effluents in regions where new facilities are planned.

The use of nuclear energy has resulted in a marked global increase in the concentration of tritium over the past decades in almost all water systems, in rainfall, and in surface water. Thus, the mean monthly concentration of tritium reached 130 tritium units (t.u.) in U.S. river basins in 1966 [1], from 60 to 360 t.u. in various U.S. rivers in the winter of 1971-1972 [2], an average of 150 t.u. in the rivers of the prefectures of Japan in 1971 [3], and about 100 t.u. in the northern rivers of the USSR in 1972 [4].

Owing to dilution, the tritium concentration in large bodies of water is appreciably lower. Highly sensitive techniques must be employed to determine it. The highest sensitivity is ensured by methods employing scintillation and proportional counters. Analysis of work on tritium determination in natural bodies of water shows that when enrichment is employed the reproducibility of results is not good since there are no reliable methods of determining the degree to which the sample has been enriched with tritium if the initial concentration was low. An advantage of gas-filled proportional counters is that they ensure high sensitivity (without enrichment) and make absolute measurements.

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