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RADIOACTIVE CONTAMINATION OF LAND AREAS BY INSECTS

EMERGING FROM CONTAMINATED WATER BODIES

by A. A. Peredel'skiy and I. O. Bogatyrev

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Formulation of the Problem

Many studies from different aspects and quite a little practical effort have been devoted to problems of deactivation and burial of radioactive wastes of atomic industry. However, to the present time the conditions of a technical-economic nature do not yet permit ideal burial, in which contamination of nature by long-lived radioactive isotopes would be entirely eliminated. The same is observed in the burial of radioactive isotopes which contaminate the sewage systems of cities and irrigation fields.

In connection with this, the tendency still persists toward utilizing fresh water bodies for the dilution and burial of radioactive wastes, which has been quite neatly attested to by the literature of recent years (Browden, 1951; Ruchhoft, 1951, 1953; Foster and Davis, 1955; Parker, 1955, 1956; Coopey, 1956a, b; Rostenbach, 1956; Garner and Kochtitsky, 1956; Clukey, 1957; Marey, 1956a, b, c, 1957a; Lebedeva, 1957; Telushkina, 1957, and many others). It should also be kept in mind that certain progress made in the technic of utilization of nuclear reactors, which in principle do not need the presence or circulation of large masses of water, does not eliminate the problem of contamination already effected, although it does reduce the danger of future contamination of nature. In the literature, problems of degrees of contamination of fresh water bodies with radioactive products of different types by atomic bomb and hydrogen bomb explosions have been described also (see, for example, Lacy, 1954).

Therefore, it is clear that at the present time problems of radioactive contamination of fresh water bodies, burial and the fate of radioactive waste in them have not only maintained their current im-

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Therefore, it is clear that at the present time problems of radioactive contamination of fresh water bodies, burial and the fate of radioactive waste in them have not only maintained their current im-

importance but in some respects have even become more acute.

A number of direct and indirect studies has been made for working out ideas about processes which put radioisotopes contaminating water bodies in a state which provides for burial of them. Here, we shall dwell on references from B. M. Agafonov's (1957) and Ye. A. Timofeyeva-Resovskaya's (1957) works, who showed that in a series of connected running-water ponds the plankton organisms, water weeds, ooze, bottom and sand rapidly and quite completely extract various radioisotopes entering the first pond as waste requiring burial from the water and retain them firmly.

Processes leading to complete burial of radioisotopes were, to a considerable degree, represented as the result of the dying and sinking into the ooze of progressively newer bodies of animals and plants which during their lifetimes had cleared the water of isotopes dissolved in it. Actually, in the comparatively brief periods of the experiments, after which the investigators took samples of the main components of the water body for radioactivity tests, the total balance of radioactivity constituted evidence of a process of this kind.

Nevertheless, from the logic of radioecological concepts (Poredel'skiy, 1957a, b) the burying role of water bodies has not appeared to us to be adequately reliable, since at times tremendous quantities of bottom fauna, living and feeding in the ooze and on the bottom but leaving the water bodies en masse when they become winged (insects) or after metamorphosis (amphibians), in addition to fish, mollusks and worms, cannot help but interfere with dependable burial of radioisotopes in the bottom and ooze of normal water bodies.

Naturally, in such an important matter, where, simultaneously with functions of burial in water bodies sources of radioactive contamination of adjacent areas might be created, our doubts had to be resolved in special studies.

In a very preliminary form we were able to begin such studies in the summer of 1956, taking advantage of the invitation of the Ural Affiliate of the Academy of Sciences USSR, which offered us part of the necessary equipment and radioactive isotopes. (We should like to mention the active assistance given to us by L. Z. Redionova and G. A. Sokolova. Considerable aid in our work was given by N. V. Timofeyev-Resovskiy, N. V. Kulikov, Ye. A. Timofeyeva-Resovskaya and B. M. Agafonov).

Material and Method

Ten identical aquaria (height 30 centimeters, area of the bottom 340 square centimeters) were placed in a row. Into each of them dry sand (in a quantity of two kilograms) covered with a layer of ooze (50 grams when recalculated for dry weight) was poured in an even layer; then, 20 ramules of Elodea and four ramules of Myriophyllum (dry weights of the plants, three-four grams each) were transplanted into each of the aquaria. Eight liters of lake water were poured into each aquarium, and a few score living bottom insect larvae were put into the aquaria (only those which became winged during the experiment are mentioned): caddis flies (chiefly, *Polycentropus flavomaculatus*), mayflies (*Cocoon dipterum*, *Ephemerella ignita*), and mosquitoes (chiefly, *Tendipes*).

Therefore, to a certain extent natural water bodies were imitated.

For the purpose of subsequent catching of the winged insects and those which left the water bodies a cap-like covering made of wire screen was set tightly on each aquarium.

After two days, solutions of different radioactive isotopes were added to the aquaria. An undiluted mixture of beta- and gamma-emitters -- fission products of a nuclear reactor -- were put into four aquaria. This mixture was three years old, that is, at the time of the experiment it had no short-lived radioisotopes.

A mixture was added to two of these aquaria in a quantity which created a total activity of 400 microcuries in each or 50 microcuries per liter. In the other two aquaria the mixture created a total activity of 80 microcuries, or 10 microcuries per liter. Cs^{137} was put into two other aquaria, calculating a total activity in the aquaria of 93.6 microcuries, or 11.7 microcuries per liter in each. Sr^{90} which formed 80 microcuries total activity and 10 microcuries per liter, was added to the next two aquaria. Co^{60} , creating 80 microcuries and 10 microcuries per liter, was put into the last two aquaria. (A comparison with some data in the literature (Browden, 1951; Lacy, 1954; Ruchhoft and Setter, 1953) shows that the activities used in our experiments correspond to usual contamination levels of water bodies with radioactive wastes of atomic enterprises).

As we see, every experiment was performed twice, and in treating the results of the studies the average figures were derived from them.

The experiments lasted from 23 July through 26 August. In this time the water temperature in the aquaria varied from 12 to 19°, that is, it was less than optimum for development of insects.

Each winged insect was dried, weighed, put into a standard aluminum cup, and its activity was determined on a B-2 apparatus with a Geiger type counter of the BFL-25 type.

The results of activity measurements, expressed in pulses per minute, were then, according to the usual method, converted into absolute activity figures. These latter figures are shown for every experiment in Table 1 as the average values in millimicrocuries per insect of the given group.

Results

Of the numerous results of our studies here we are interested only in the magnitude of the activity brought out by winged insects which had gone through part of the larval and pupal stages of development on the bottom of the radioactively contaminated water body. Some other results have been presented in the article by I. O. Bogatyrev (1959, in publication).

Table 1

Average Accumulation of Radioactivity per Insect at the Time of Emergence from Aquaria containing Different Isotopes

① Isotope	② Activity of the water body		③ Average activity per insect		
	④ Total activity, microcuries	⑤ Specific activity, microcuries per liter	⑥ Mosquitoes	⑦ Mayflies	⑧ Caddis flies
⑨ Cesium β- and γ-emitters	400	30	0.26 ± 0.04	0.24 ± 0.03	11.45 ± 1.04
⑩ To 200 Cist. Sp. Cist.	20	10	0.11 ± 0.01	0.08 ± 0.01	1.15 ± 0.05
	20.6	11.7	0.08 ± 0.004	1.05 ± 0.04	2.15 ± 0.05
	20	10	0.12 ± 0.01	0.15 ± 0.01	2.15 ± 0.05
	20	10	<0.05	0.15 ± 0.01	2.15 ± 0.05

1. Isotope; 2. Activity of the water body; 3. Average activity per insect, millimicrocuries; 4. Total activity, microcuries; 5. Specific activity, microcuries per liter; 6. Mosquitoes; 7. Mayflies; 8. Caddis flies; 9. Mixture of beta- and gamma-emitters; 10. The same.

First of all, we should like to emphasize that the activity brought out of the water body by imagoes and subimagoes (in the may-

flies) is the result only of radioactive isotopes incorporated into their organs. Adsorption of radioisotopes on the surface of the imago's body could not occur, since the winged forms hatch out outside of the water, leaving their molts, which adsorb the isotopes, in the water or on objects projecting from it. The results of the experiments are shown in Table 1.

We should like to point out that in four groups of experiments both the specific and total radioactivities of the "water bodies" were equal, respectively, in the eight aquaria (a slight difference in the group containing the Cs¹³⁷ was not determinative in the results), and only in the fifth group of experiments were the activities increased by five times.

The results presented in Table 1 require a clarification of the statistical significance of differences in the activity magnitudes in different experiments and in different insects. The criteria of significance in such comparisons are given in Table 2, according to the ratio values (the ratio of the difference of the averages of the values being compared to the square root of the sum of the squares of their mean errors). We assume that with a ratio of more than or equal to three the differences are significant.

Table 2

Significance (By Ratio) from Comparisons of Average Activities Brought
 our of Water Bodies Insect in Different Experiments

① Исотопы	② Активность водной среды		③ Общая активность, микрокюри		④ Специфическая активность, микрокюри на литр		⑤	
	1	2	3	4	5	6		
⑪ Смесь β- и γ-излучателей	60	50	5.4	5.0	6.0	6.1	6.0	2.2
⑫ Тс 132	80	10	7.7	7.7	8.0	18.3	18.3	2.5
Cs ¹³⁷	93.6	11.7	6.1	7.0	9.0	4.8	10.2	7.8
Sr ⁹⁰	80	10	2.8	2.8	—	7.3	7.5	0.7
Co ⁶⁰	80	10	—	—	—	2.9	—	—

1. Isotope; 2. Activity of the water body; 3. Total activity, microcuries;
 4. Specific activity, microcuries per liter;
 5. Caddis flies; 6. Mayflies; 7. Mosquitoes; 8. Caddis flies and mayflies;
 9. Caddis flies and mosquitoes; 10. Mayflies and mosquitoes; 11. Mixture of beta- and gamma-emitters; 12. The same.

First of all, we should like to note that the average activity brought out by caddis flies was significant in the majority of cases and was far greater than in the case of mayflies and mosquitoes. However, Cs^{137} was brought out to the greatest extent by mayflies, and differences in the amounts of other isotopes brought out by the latter by comparison with mosquitoes were not statistically significant. As for differences in the amount of activity brought out by some species of insect in the case of the different isotopes, in the majority of cases (there was an exception only in the comparisons of amounts of Sr^{90} and Co^{60} brought out) these differences were mathematically significant.

Therefore, caddis flies brought the greatest activity out of aquaria with a quintuple mixture of beta- and gamma-emitters; then came the aquaria with Sr^{90} and Co^{60} ; the lowest activity was brought out of aquaria containing a unitary mixture of beta- and gamma-emitters and those with Cs^{137} . Mayflies brought most activity out of the aquaria with Cs^{137} and less, from the unitary mixture of beta- and gamma-emitters.

It goes without saying that under different conditions of the medium and with different specific activities all these relations might be expressed differently, both in comparisons of the capacity of species for bringing out the same isotopes and in comparisons of the activities of different isotopes taken out by insects of the same species. Undoubtedly, in this sense there is still considerable room here for study.

Discussion of Results

In our work generalizing on problems of radioecology, one of us (Peredel'skiy, 1957a, b) expressed the hypothesis of the comparatively rapid and complete bioecological self-purification of radioactively contaminated water bodies by different animals (particularly insects) and corresponding contamination of the land areas in the vicinity.

We should like to analyze both parts of this hypothesis. A defect in its first part in some special cases may be the absence of a reservation concerning the limnological rules and regulations which interfere with the complete renewal of the water body biomass and contribute to the conservation of considerable quantities of it in the form of peats and sapropels. Therefore, radioactive isotopes bound in one way or another to this portion of the organic matter of the water body will be reliably buried in its bottom and will not be exposed to

absorption by migrating organisms in ecological feeding chains. Further, the results of our studies described above showed that an individual insect, belonging to any of the groups which were in the experiment, is capable of bringing a very small fraction of the total activity out of a radioactively contaminated water body. The excellent work of Ye. V. Borutskiy (1939a, b) dealing with the dynamics of the biomass in fresh water bodies permitted us to make a number of recalculations. The latter show that for those insects, which are able to save themselves from enemies in the water body itself until they reach the winged state, to bring out all of the radioactivity from the water body would require an exceedingly large number of generations and time, which would be greater than the half-life of even such isotopes as Sr^{90} . Incidentally, it should be kept in mind that in the studies of Ye. V. Borutskiy consideration was not given to the migration of the biomass beyond the limits of the water body by many, including such large forms of insects as caddis flies, dragonflies, etc., as well as amphibia undergoing metamorphosis, and consideration was not given to the role of divers, the washing-up of biomass by the surf, and a number of other factors of appropriate significance.

We should like to analyse now the significance of the second hypothesis concerning the danger of radioactive contamination of land areas adjacent to the contaminated water bodies. For this, first of all, we should like to bring to mind that the quite typical water bodies of the central Russian zone, which the water bodies studied by Ye. V. Borutskiy are, had an insect-breeding bottom area equal to approximately 0.5 square kilometer. The number of imagoes of just one species of mosquito, *Chironomus plumosus*, emerging during the warm season reached 50,000,000. Another species, *Cerethra*, emerged in a quantity of 103,000,000 individuals; and there were 25,000,000 *Tanyti* mosquitoes which emerged. Many millions of representatives of other species of insects emerging from such water bodies, including such large ones as dragonflies, could be added to these numbers. In any case, the total number of emerging insects undoubtedly reaches 200,000,000 or more per year. However, Ye. V. Borutskiy has found that up to 90 percent of the emerging insects is eaten by birds and bats (we should like to add also, by predatory insects, spiders, and amphibians), while the natural death rate with dropping of the bodies to the ground amounts to 10 percent.

From this it follows, I daresay, that in a radius of up to 1.5 kilometers around such a lake the average fall-out density of bodies of insects can amount to two bodies per square meter of ground surface.

Let us not forget that the spray and pieces of the droppings of all those enemies which have destroyed the other 90 percent of the insects which emerged will fall to the ground near the lake. The bulk of the droppings will accumulate at places remote from the water body, in the neighborhood of nesting and breeding places, including among places inhabited by people.

Let us now gain an idea of the quantity of radioactivity which must occur on a square meter of ground around the water body of this size as a result of its bioecological self-purification from contamination with industrial radioactive waste. From just two insect bodies the activity per square meter of ground can increase by 0.2-two millimicrocuries or more for the season. In order to have an idea of the significance of this figure it should be kept in mind that the global contamination of the land with radioactive fallout after the explosion of just one hydrogen bomb comes to 5.4 millimicrocuries per square meter (see, for example, Nuclear Explosions, etc., 1956; Kurchatov, Chul'kov and Shvedov, 1956). Therefore, very little time (from two to 10 years) is needed for the radioactive contamination of the ground around contaminated water bodies (from the bodies of insects) to come to twice the level of the global contamination occurring from the explosion of a single hydrogen bomb.

There is a radioecological basis for supposing (Peredel'skiy, 1957) that the increased activity of the ground will in time advance progressively further from this original zone near the water body. The quantity of radioactivity in the vicinity of contaminated places near the nesting places of radioactively contaminated birds, places where their bodies fall, as well as from the bodies of amphibians which have come from radioactively contaminated water bodies cannot yet be calculated, but probably it at times exceeds the total radioactivity transported by the insects whose bodies are strewn on the area around the water body.

The problem of the danger of such contamination can be considered, probably, only from a genetic aspect.

Conclusion

Adult winged insects, whose larvae have lived on the bottoms of water bodies contaminated with radioactive isotopes contain small quantities of radioactivity in their bodies.

A species specificity of a quantitative nature is observed in the carrying out of the various isotopes (Cs^{137} , Sr^{90} , Co^{60} , undiluted)

[mixture of beta- and gamma-emitters -- fission products of a nuclear reactor) by the bodies of adult insects (mosquitoes, mayflies, caddis flies). When the specific activity of the water was increased the adult insects contained more activity. A greater total activity is characteristic of the larger forms of insects.

The total activity brought out of a water body by winged insects can reach high figures over a number of generations, of which each one consists of tens and hundreds of millions of individuals.

Therefore, experimental verification of the hypothesis of the biocological self-purification of water bodies from radioactive contamination with subsequent contamination of the land areas in the environs with radioactivity (Peredel'skiy, 1957a, b) has been confirmed in a general form. However, in the presence of processes of peat- and sapropel-formation obstacles will arise to the complete self-purification of water bodies, particularly since the insects which leave the water bodies when they become winged cannot by themselves rapidly purify them of radioactive isotopes. On the other hand, the accumulation of radioactive bodies of insects in the zones of the land areas nearest the water body can in a comparatively short time increase their radioactive background to a figure similar to the increase in the background coming from global contamination with products of a routine hydrogen bomb explosion.

The true rates of bioradioecological purification of water bodies and increase in the background of the adjacent land area are probably even greater because of the fallout of radioactive droppings of insectivorous birds, the emergence of amphibians which have undergone metamorphosis from the contaminated water bodies and their deaths on the dry land, etc.

Only water bodies which have artificially been cleared of organisms which come out on the dry land will be better suited to burial of radioactive wastes.

The present study shows once again that in the problem of burial of radioactive wastes, as in problems of contamination of nature with radioactive isotopes, such a trend in science as radioecology must introduce essential additions and corrections of theoretical and sanitary-hygienic significance.

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