TRANS-217

OPREDELENIYE KOEFFITSENTOV TURBULENTNOY DIFFUZII V MORE S POMOSHCH'YU RADIOAKTIVNYKH INDIKATOROV

(Determination of the Coefficients of Turbulent Diffusion in the Sea with the Aid of Radioactive Indicators)

by

B. A. Nelepo

VESTNIK MOSKOVSKOGO UNIVERSITETA
SERIYA III. FIZIKA, ASTRONOMIYA

Vol. 4, Pp. 64-70

MOSCOW 1960

Translator: M. Slessers
P.O.: 33081
J.O.: PU6671

U. S. NAVAL OCEANOGRAPHIC OFFICE
WASHINGTON, D. C.

1964

TRANS-217

ABSTRACT

A method based on the application of the iodine-131 isotope was used for investigation of turbulent diffusion in the sea. A special apparatus constructed for the purpose in 1956 was utilized for measurements conducted in the Black Sea on the basis of which the numerical values of turbulent diffusion factors were determined. The tracers were observed with the aid of recorders consisting of Geiger-Müller counters which made it possible to determine the concentration of radioactive element in a definite solid angle. The operation of the apparatus is illustrated by graphs and the methods of recording; calculation and verification of the results are elucidated by mathematical formulae based on tests.

The Translator

Author: B. A. Nelepo

Title: OPREDELENIYE KOEFFITSENTOV TURBULENTNOY DIFFUZII V MORE S POMOSHCH'YU RADIOAKTIVNYKH INDIKATOROV (Determination of the Coefficients of Turbulent Diffusion in the Sea with the Aid of Radioactive Indicators)

Source: VESTNIK MOSKOVSKOGO UNIVERSITETA. SERIYA III. FIZIKA, ASTRONOMIYA. Vol. 4, Pp. 64-70. MOSCOW 1960.

Language: Russian

Translator: M. Slessers

Library

U. S. NAVAL OCEANOGRAPHIC OFFICE
WASHINGTON, D. C.

1964

DETERMINATION OF THE COEFFICIENTS OF TURBULENT DIFFUSION IN THE SEA WITH THE AID OF RADIOACTIVE INDICATORS

Radioactive isotopes of some elements find an increasingly wide application in various investigations conducted at the present time. Their typical properties, depending upon the type of investigations and tasks faced by investigators, are taken into consideration. On the basis of their properties, the radioactive isotopes are divided into three basic groups. Depending upon the character of investigation peculiar to the given element, they are called α-, β-, and γ-radiators. The first two groups of radiators emit corpuscular radiation and, in connection with it, they appear to be intensely ionizing elements. Because of great energy losses per unit travel distance (mean free path), β- and especially α-particles are weakly penetrating particles; whereas the γ-rays emitted by the various elements are considerably more penetrating particles because of which they make possible the studies of relatively greater layers of matter. This difference appears to be one of the main properties on the basis of which the elements designed for the solution of experimental problems are selected. A large section of investigations is devoted to the utilization of dependence of radiation absorption upon the properties of the matter to be investigated. This type of investigation makes it possible to measure the "statistical" properties of matter. The method of utilizing radioactive elements as property indicators has found a wide application when solving the problems in which the dynamics of various processes are investigated. Indeed, the use of indicators having the size of molecules opens wide vistas for the study of most complex processes. Because the α- and β-particles are readily absorbed by matters and have short travel routes, the greatest prospects for practical application are associated with γ-indicators. The possibility of observing an indicator at a relatively great distance from the /65 place where the indicator is located, without disturbing the medium to be investigated, presented a basis for the application of γ-active isotopes to studies in the turbulent diffusion occurring in the sea. This paper is devoted to the description of the investigation method, apparatus, and the measurement data.

The Choice of Radioactive Indicator

The need for safety when working with radioactive isotopes lends a specific character to the work. In this instance the investigator must take into consideration not only the requirements for optimum physical conditions during experiments but also the safety regulations. In some instances the former aspect must be sacrificed in favor of the latter. The main properties of radioactive isotopes are as follows: the character of radiation (β or γ), radiation energy, and the period of half-life of the isotope. In our case, the choice of γ-radiator was necessary for the purpose of observing the indicator at considerable distances from the recorder. On the basis of the same concepts, it appeared necessary to use the isotope having a maximum of radiation energy; however, the selection of extremely great energy was impeded by safety requirements. In addition, the curve characterizing the attenuation of γ-radiation in water demonstrates that with energies exceeding 100 kev the dependence of the attenuation factor upon the energy is considerably less pronounced. This makes it possible to select isotopes having a moderate radiation energy. In the given case, it is desirable to select an indicator characterized by monochromatic radiation, which may facilitate the interpretation of the resultant picture. Because the area where the investigations of turbulent diffusion are conducted cannot be isolated, it is necessary to select an isotope having the smallest possible period of half-life. Experience has demonstrated that an isotope whose period of half-life equals about 10 days is well suited for investigations. The radioactive iodine-131 isotope satisfactorily fulfills all these conditions, although it does not appear to be a monochromatic radiator ($E_\gamma = 0.7$, Mev $T_{12} = 8.1$ days).

Also the question of the quantity of the emitted isotope at each experiment is important. Preliminary calculations, which have been verified in practice, demonstrate that 0.1 to 1.0 millicuries is an entirely satisfactory magnitude for the conduction of measurements. At the same time, the concentration of isotope created by the emittance of such a quantity of radioactive matter will in a few hours become safe in open sea, because the process of intermixing diminishes to a certain degree the magnitude of concentration.

The Scheme of Measurements

In 1956, Professor A. G. Kolesnikov at the Department of Physics of the Sea and Continental Waters of the Faculty of Physics led the construction of an apparatus making it possible to determine the intensity of turbulent diffusion along the vertical in the sea. In the summer of 1956, the apparatus was used for investigations conducted in the Black Sea (The Black Sea Branch of Marine Hydrophysics Institute of the Academy of Sciences of USSR).

The diffusion of the "cloud" of radioactive liquid in the sea was subjected to concrete investigations. If a drop of radioactive liquid is introduced into the medium to be investigated (sea, in this case) and the diffusion of radioactive matter is observed, it is possible to determine, on the basis of these observations, the diffusion factor in all directions by using the method of mathematical analysis.

The tracers were observed by recorders consisting of Geiger-Müller counters. The structure of the recorders made it possible to determine the concentration of radioactive element in a definite solid angle.

Figure 1 explains the test. The B and C recorders, as well as the source of radioactive isotopes A, were submerged into the sea so that they assumed a strictly definite position with respect to one another. In addition, the structure of the instrument guaranteed such a positioning of the instrument in the current that the direction of the current coincided with the plane containing the recorders and the source of the isotopes. At a definite time moment, the source emitted a definite quantity of iodine-131 solution. After some time (t_1) the concentration of radioactive isotope in area G_1 began to exceed the level of the background and the data unit B recorded the change in the concentration. As a result of diffusion, a considerable quantity of radioactive molecules entered the area G_2 in time interval t_2. Consequently, the data unit C also recorded the increase in radioactivity and rise above the level of background. Subsequently, the radioactive solution continued to become diffused in the surrounding medium. Thus, in the beginning, each of the data units recorded the increase of radioactivity in the corresponding area, but later each of the units recorded the fall of the level of this area to that of the background. At the corresponding time moments, t_3 and t_4, the data units C and B ceased correspondingly to record the excess of radioactivity. The graphical distribution of radioactivity during the measurements is presented in figure 2.

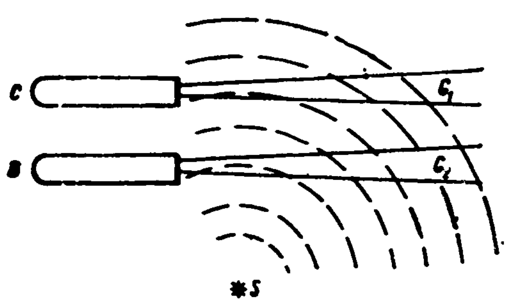

Fig. 1

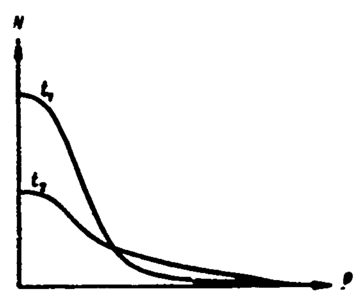

Fig. 2

The operation pattern of the instrument is such that the appearance of radioactivity can be recorded only when its value in comparison with the level of the instrument background is exceeded two to three times.

The Recording Apparatus

Data Units. In order to obtain dependable results, the recorder must have a small "aperture" (G). This requirement appeared to be one of the main conditions that had to be observed when constructing the apparatus. The recording units (Geiger-Müller counters) were placed in a steel container with thick walls (30 mm). The cover was made of aluminum plate 5 mm thick. Such a structure made it possible to /67 isolate the recording units from the water. At the same time, the sensitivity of the apparatus in the direction of the aluminum "window" was considerably greater than the sensitivity in any other direction due to considerable differences in the absorption values of γ-rays in the walls made of iron and aluminum. A still greater anisotropy as regards the sensitivity would be gained in this case by the generally known scheme of concurrences. Regrettably, the use of Geiger-Müller counters in these conditions did not make it possible to utilize the scheme. Indeed, it is known that the sensitivity of the counter when recording the γ-rays does not exceed 1 % . Consequently, the sensitivity of the scheme of double concurrence is of the order E = 0.01 %. Such a small E-value requires the emittance of 100 times greater quantity of isotopes, which is not recommended with respect to safety conditions in the work. Therefore, the counters had to be shielded by a thick layer of iron and they had to be switched on simultaneously in order to increase the sensitivity of counting. Eight counters of the type MC-7* were placed into the body of each recorder. The recorders, which contained in addition to the counters one cathode repeater for each channel, were connected by means of a multicore cable with a control desk where the impulses obtained from counters were transformed in a definite manner. The transformed signal was further transmitted to a loop oscillograph ЯО-4* which recorded variations in the concentration of the radioactive element in area G. The use of the cathode repeater appeared to be necessary because of a great capacity of the cable and a small power of impulses coming from the counters.

The Unit of Impulse Transformation. The impulses coming from the cathode repeaters of recorders were arranged according to duration and amplitude with the aid of cascades of locked multivibrators. Further, the impulses, having been intensified, were transmitted to the integrating nucleus. A loop oscillograph had been placed at the exit of the integrating nucleus. According to the operation principle of the integrating nucleus, the current passing through the loop is in the given case proportional to the frequency of the impulses arriving at

*The Russian letter symbols have not been transliterated in order to facilitate the identification of the symbols.

the entrance. Because each impulse coming from the data unit corresponds to the impulse formed in the course of the integrating nucleus, the current passing through the loop is proportional to the frequency of the impulses arriving by the cable from the data unit, i. e. to the concentration of γ-active element that is measured in the G areas. Thus, the change of current when leaving the integrating chain attests to the variation in the concentration of radioactivity in the sea. The processing of such records enabled us to determine the coefficient of turbulent diffusion by a method which is discussed below. The structure of the detector is presented in figure 3.

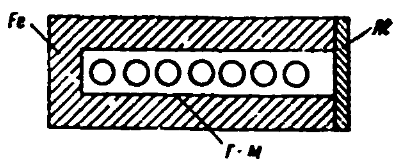

Fig. 3

The Source of the Gamma-Indicator. When constructing the apparatus, which emitted at a definite moment the needed amount of iodine-131 isotope, the following conditions were taken into consideration: 1) it had to be compact, 2) convenient for operation, and 3) safe in handling. The following device was constructed with a view to satisfying these requirements. The source consisted of a rotating drum in which ampoules containing the solution of radioactive isotope were set on the basis of radii. The axis of the drum was firmly fastened to the data units. The drum could be set in motion at any required time /68 moment. When the drum was rotating, the ampoules successively passed near a blade that would break them open. Thus it was possible to conduct 16 successive measurements without any additional charging of the apparatus. The preliminary examination of the operation of the source was verified in the laboratory with the use of dyes. The result was completely satisfactory, which made it possible to apply the method at the time when the radioactive isotope was emitted.

The Theory of the Method

When processing the data, it is necessary to obtain a mathematical definition which in a satisfactory measure reflects correctly the true physical pattern of the isotope diffusion in the sea. The mathematical physics includes a problem on the diffusion of clouds formed as a result of explosion of charges. The difference in the given case is characterized only by two peculiarities. The cloud itself is a source of "luminescence," whereas in the problem that is discussed the cloud absorbs the light coming from infinity. The second peculiarity is that, when solving the problem, it is necessary to account for the absorption of light in the medium between the cloud and the observer or the instrument that records the intensity of its luminescence in a given direction. Evidently, these peculiarities are not essential and therefore the conclusions can be drawn in a quite analogous way.

This process can be presented in the form of the diffusion of a cloud, ignoring the gravitational force of the earth and inequalities in the initial scattering. In addition, it is assumed that the dependence of the intensity of the process upon the decomposition during the measurement can be neglected. In these conditions, the concentration of radioactivity in a cloud is expressed by the following formula

$$U(x, y, z, t) = Q\left[\frac{1}{2\sqrt{\pi D t}}\right]^3 e^{-\frac{x^2+y^2+z^2}{4Dt}},$$

where Q denotes the quantity of radioactive isotope emitted during a single test, D is the coefficient of turbulent diffusion. Thus, the problem of diffusion from a momentary source of current with power Q in unlimited space arises.

Let us direct axis z along the axis of vision and assume that the observer is found in infinity. In this case the cloud will be as if projected on plane x,y. Let us appraise the visibility of various areas of the cloud. It is known that the intensity of radiation at a distance z from the source in an absorbing medium is expressed by formula $D = D_0 e^{-\mu z}$, where D_0 is the intensity of radiation at point $z = 0$, and μ is the attenuation factor of the current of gamma-rays in water. If the distribution of concentration of radioactive molecules is given by formula U(x,y,z,t), the total intensity along the axis of vision is determined by

$$A = \int_{-\infty}^{+\infty} U(x, y, z, t) e^{-\mu z} dz = \frac{Q}{(2\sqrt{\pi D t})^3} e^{-\frac{\rho^2}{4Dt}} \int_{-\infty}^{+\infty} e^{-\frac{z^2}{4Dt} - \mu z} dz.$$

The integral $D_1 = \int_{-\infty}^{\infty} e^{-\frac{z^2+4Dt\mu z}{4Dt}} dz$ is reduced to the Gauss integral by introducing $v = \frac{z + 2Dt\mu}{2\sqrt{Dt}}$.

Finally we have

$$A = \frac{Q}{(2\sqrt{\pi Dt})^2} e^{-\frac{\rho^2}{4Dt}} i_1 = \frac{Q}{(2\sqrt{\pi Dt})^2} e^{-\frac{\rho^2}{4Dt}} e^{Dt\mu^2} 2\sqrt{Dt} \int_{-\infty}^{\infty} e^{-v^2} dv =$$

$$= \frac{Q}{4\pi Dt} e^{-\frac{\rho^2}{4Dt}} e^{Dt\mu^2}.$$

Thus

$$A = \frac{Q}{4\pi Dt} e^{Dt\mu^2} e^{-\frac{\rho^2}{4Dt}}.$$

where $\rho = x^2 + y^2$.

In the calculations we did not account for the current speed because in the area where the investigations were conducted, the phenomenon could be ignored.

The "visibility" of the cloud of radioactive particles is determined by the value of the threshold of sensitivity of the recording instrument, and thus the resultant formula is reduced to a form making it possible to apply the formula to the processing of the data that are obtained. Thus, taking into consideration the threshold of sensitivity of the instrument, the observed cloud has finite sizes at each time moment and its radius is determined by the given formula. Finally, the equation relative to the coefficient of turbulent diffusion assumes the following form:

$$4D^2t^2\mu^2 - 4Dt\left(\ln \frac{Dt}{a}\right) = \rho^2,$$

where $a = \frac{Q}{4\pi\delta}$.

An analysis of the Gauss integral demonstrates that if the error is limited to 10% it can be assumed that the observer is in infinity at $v > 1.17$. If a greater accuracy is needed and if the magnitude of argument is smaller than the given value, the method of solution remains the same; however, in lieu of integral $\sqrt{\pi}$, it is necessary to use tables in order to arrive at the correction formula for the solution of this problem.

As is seen, the final formula includes a magnitude that characterizes the ratio of sensitivity of the instrument to the quantity of the isotope that is emitted. In order to eliminate this magnitude from the final solution, corresponding measurements have to be carried out.

Indeed, let us solve the problem with the presence of two radii along which the recording instruments extend. Suppose the time moments are t_1 and t_2 between the emittance of isotope and the beginning of recording of radioactivity that exceeds the threshold for each of the distances ρ_1 and ρ_2, respectively. In this case we have the following system of equations:

$$4D^2t_1^2\mu^2 - 4Dt_1 \ln \frac{Dt_1}{a} = \rho_1^2,$$

$$4D^2t_2^2\mu^2 - 4Dt_2 \ln \frac{Dt_2}{a} = \rho_2^2.$$

The second equation is transformed and we have

$$4D^2t_2^2\mu^2 - 4Dt_2 \ln \frac{Dt_1}{a} - 4Dt_2 \ln \frac{t_2}{t_1} = \rho_2^2$$

by changing /70

$$\ln \frac{Dt_2}{a} = \ln \frac{Dt_1}{a} \frac{t_2}{t_1} = \ln \frac{Dt_1}{a} + \ln \frac{t_2}{t_1}.$$

Solving the system jointly, we find that

$$4\mu^2D^2(t_2^2 - t_1t_2) - 4Dt_2 \ln \frac{t^2}{t_1} + \left(\frac{t_2}{t_1}\rho_1^2 - \rho_2^2\right) = 0.$$

Hence

$$D = \frac{bt_2 \ln \frac{t_2}{t_1} + \sqrt{16t_2^2 \ln^2 \frac{t_2}{t_1} - 4\mu^2(t_2^2 - t_1t_2)\left(\frac{t_2}{t_1}\rho_1^2 - \rho_2^2\right)}}{8\mu^2(t_2^2 - t_1t)_2},$$

$$D = \frac{B + \sqrt{B^2 - AC}}{A} \quad \begin{cases} A = 4\mu^2(t_2^2 - t_1t_2), \\ B = -2t_2 \ln \frac{t_2}{t_1}, \\ C = \left(\frac{t_2}{t_1}\rho_1^2 - \rho_2^2\right). \end{cases}$$

The Results and Conclusions

On the basis of the derived formula we processed the records obtained as a result of experiment. Because a series of measurements was carried out with a view to verifying the correctness of results during small time intervals, it was possible to compare the results of the entire series. This enabled us to eliminate to a degree the effect of the introduction of the isotope into the given medium. The results differed very little throughout the series of measurements. The coefficient of turbulent diffusion fluctuated from one measurement to the other, the values lying between 5 cm^2/sec and 7 cm^2/ sec.

The work demonstrated that it is possible to measure the coefficient of turbulent diffusion with the aid of radioactive isotopes. In conjunction with other methods, this method makes it possible to visualize better the pattern occurring in the sea at turbulent intermixing. At the same time one asserts that the apparatus and means needed for safe work are sufficiently simple. All this makes it possible to utilize the apparatus in expeditionary conditions. At the same time, the use of scintillation counters in recorders in conjunction with the schemes of concurrence will enable us to make the instrument lighter and to increase its accuracy and, consequently, the accuracy of data. In conclusion, the author expresses his gratitude to Professor A. G. Kolesnikov for the assistance rendered in the operation of the instrument and advice that greatly aided the processing of resultant data.

ooOoo