Reports

Lead-210 in Natural Waters

Abstract. The distribution of lead-210 which enters the oceans subsequent to its production in the atmosphere by radon-222 decay, shows an increase with depth in sea water. By use of a simplified two-layer model of the ocean, a residence time of lead in the upper mixed layer of less than 2 years is derived. It is suggested that the marine biosphere is responsible for the conveyance of lead from surface to deeper waters. The distribution of lead-210 in the Colorado River indicated a rapid removal along the path from its origin in the feed waters to the reservoir at Lake Mead.

A recent series of papers (*1, 2*) illustrating the use of lead-210 as a tracer of natural processes in the atmosphere and on the earth's surface prompted us to investigate the distribution of this isotope in natural waters. The present picture of the behaviors of lead-210 and its precursor radon-222, in the uranium-238 decay series, can be summarized in the following way. Radon-222 escapes from the surface rocks at an average rate of 42 atoms per minute per square centimeter of land surface (*3*) into the atmosphere, where it decays with its half-life of 3.8 days. The average standing crop of radon in the atmosphere therefore should be about 42 disintegrations per minute per square centimeter (or 3.3×10^5 atoms/cm^2) of land area.

The radon nuclei transform through a series of short-lived daughters to lead-210 with a half-life of 21.4 years (*4*). This long half-life would permit a uniform distribution of lead-210 to be approached in the atmosphere. However, this condition is never realized since the removal of lead-210 by natural precipitation effectively limits its residence in the atmosphere to a few weeks (*1*). This period, though short, is nevertheless long enough to allow a considerable amount of lead-210 to be transported in the atmosphere over the oceans where it is removed by rains. Since the land area represents but one-third of the total surface area of the earth, the average production rate of lead-210 should be 42/3 or 14 atoms per minute per square centimeter of earth's surface. The observed fall-out rate of lead-210 agrees well with this value. The concentrations in rains over continents and oceanic islands vary about 5 disintegrations per minute per liter or 8×10^7 atoms/lit. (*1, 5*). This is equivalent to a fallout of 15 atoms per minute per square centimeter of earth's surface, if one assumes an annual rainfall of 1 m.

It was initially felt that this unsupported lead might be a useful tracer for studying the mixing between the upper mixed layer and the deeper waters of the ocean, a process that is presumed to take place in a time of the order of or less than the half-life of lead-210. A rainfall of 1 m per year into a mixed layer of 100-m depth should result in an input of lead-210 of 0.5 disintegration per minute per square centimeter per year (0.05 disintegration per minute per liter of water in the mixed layer per year). The production of lead-210 in the mixed layer from the dissolved radium-226 is comparatively small. A concentration of 4 to 5×10^{-14} grams of radium per liter produces lead-210 at a rate of 0.003 disintegration per minute per liter per year. If no transfer of lead-210 takes place between the mixed layer and the water below the thermocline, the equilibrium value of lead-210 should be $(0.05 + 0.003) \times 21.4/0.693 = 1.6$ disintegrations per minute per liter.

It may be noted that the input of lead-210 from the atmosphere is 17 times the amount resulting from radium decay in the mixed layer but is only about 10 percent of the amount that results from the decay of radium in the entire ocean.

A simple and effective technique for the separation with known yield of lead-210 from bismuth-210 and other radionuclides in natural waters was devised. To a membrane-filtered water sample of about 20 liters, 30 mg of lead carrier, as lead nitrate free of any lead-210, was added. The lead was then precipitated as lead chromate by the addition of sodium chromate. The chromate precipitate was dissolved in 1.5*N* HCl and passed through an anion-exchange column (AGI-X8, 100 to 200 mesh, analytical grade, from Bio-Rad Laboratories, Richmond, Calif.). The lead was eluted from the column with distilled water and reprecipitated as the chromate. The precipitate was dried to constant weight, which gave the chemical yield of the extraction process, and then deposited on planchets for radioactive assay under a low-level beta counter (background 0.07 count per minute and an efficiency for counting the bismuth-210 betas of about 34 percent). The lead-210 activity was determined and identified by measuring the growth of bismuth-210 in the sample.

The organic material from the biological tows and water filters was destroyed in a mixture of nitric and per-

Table 1. Distribution of lead-210, in disintegrations per minute per liter, in natural waters.

Sample	Lead-210
Ocean waters	
La Jolla Pier, 3 Nov. 1960	0.12
31°10′N, 120°54.5′W, 4200-m depth	
Surface water	0.10
600-m water	0.12
2000-m water	0.28
Biological material from tow No. 1	1.5×10^{-7}
Biological material from tow No. 2	7.5×10^{-7}
Rainwater	
Friday Harbor, Wash., 6 May 1960	0.8
La Jolla, Calif., 3 Nov. 1960	7.1
San Diego, Calif., 7 to 8 Dec. 1960	1.9
Snow	
Echo Lake, Colo., 13 Dec. 1960	
Feed water to Colorado River	3.8
Colorado River water	
Fruita, Colo., 14 Dec. 1960	14.7
Green River, Utah, 14 Dec. 1960	1.0
Hoover Dam, Lake Mead, 15 Dec. 1960	0.29
Miscellaneous	
Tap water, La Jolla, Calif.	0.12
Distilled water (blank run)	< 0.01

Instructions for preparing reports. Begin the report with an abstract of from 45 to 55 words. The abstract should *not* repeat phrases employed in the title. It should work with the title to give the reader a summary of the results presented in the report proper.

Type manuscripts double-spaced and submit one ribbon copy and one carbon copy.

Limit the report proper to the equivalent of 1200 words. This space includes that occupied by illustrative material as well as by the references and notes.

Limit illustrative material to *one* 2-column figure (that is, a figure whose width equals two columns of text) or to *one* 2-column table or to *two* 1-column illustrations, which may consist of two figures or two tables or one of each.

For further details see "Suggestions to contributors" [*Science* **125**, 16 (1957)].

chloric acids. The residue from this treatment was taken up in 1.5*N* HCl and treated in the same manner as the water samples for the isolation of the lead-210. There was no lead-210 activity on the filters, within experimental error. The activity in the biological tows, comprised of zooplankton, was easily measurable, but was insignificant when considered on a per-liter-of-sea-water basis.

The results of our work are given in Table 1. The over-all experimental errors in the tabulated values are less than 10 percent.

The activity in the oceanic mixed layer proved to be less than it was in deeper waters—a result contrary to expectations. This strongly suggests a removal of lead-210 from the surface waters to deeper water by biochemical or inorganic processes. This can be seen more clearly by setting up the steady-state equations for a simple two-layer model of the oceans (*6*):

$$dN_m/dt = 0 = P - BN_m - K_{m-d}N_m + K_{d-m}\,N_d - \lambda\,N_m$$

where N_m and N_d are the amounts of lead-210 in the surface and deep waters, K_{m-d} and K_{d-m} are the rate constants for the mixing of mixed to deep waters and deep to mixed waters, B is the rate constant for the biological or inorganic removal of lead, λ is the decay constant of lead-210, and P is the total input of lead-210 into the mixed layer both from atmospheric radon-decay and from radium-decay in the sea water. Rearranging, we find

$$P = (B + \lambda)\,N_m + (K_{m-d}\,N_m - K_{d-m}\,N_d)$$

Taking the volumes of the mixed and deep layers as 10 and 500 lit./cm^2 (that is, an average oceanic depth of 5000 m) respectively, and the concentration of lead-210 in the mixed and deep layers as 0.1 and 0.3 disintegration per minute per liter, we find

$$0.53\,\frac{\text{disintegrations/min}}{\text{cm}^2}\ \text{year}$$

$$= (B + 0.03)\,1 + (K_{m-d} \times 1 - K_{d-m} \times 150)$$

$$\text{or } 0.50 = B + (K_{m-d} \times 1 - 150\,K_{d-m})$$

Although order of magnitude values of K_{m-d} and K_{d-m} exist (*6*), we first consider the extreme case where no mixing occurs between the mixed and deep layers, that is, $K_{m-d} = K_{d-m} = 0$. Here, B is 0.5, or the biological removal time of lead-210 is 2 years. The second term in the last equation must be negative for the cases where the K's have positive values, inasmuch as any physical mixing can result only in a net transfer of lead-210 from the deep to the mixed layer. This would make values of the biological removal period even smaller. However, the period may be longer, if the oceanic rains are, on the average, poorer in lead-210 than we have indicated. Nonetheless, the order of magnitude is of primary significance.

The residence time of lead in the deep oceans before precipitation to the sediments is of the order of 10,000 years (*7*). The markedly shorter residence time in surface waters emphasizes the distinction between the mechanisms of transport of lead from the mixed to the deep waters and from the deep waters to the sea floor. The well-known enrichment of heavy metals in the marine biosphere, coupled with the biological activity in the mixed layer, suggests biological transport in the first case, while inorganic processes are undoubtedly responsible for the accumulation of lead in sediments. The observations on the distribution of barium in the oceans (*8*) have already indicated the importance of biological activity in the conveyance of heavy metals from the mixed to deeper waters.

The very long residence time of lead in the deep oceans indicates that only an insignificant fraction of the oceanic lead-210 will be deposited in the sediments. This seems to be borne out by our observations also. The concentrations of lead-210 in deep-sea waters are found to be essentially in secular equilibrium with the radium-226 values reported for such waters (*9*).

The behavior of lead-210 in terrestrial surface waters was sought in order to evaluate its use as a tracer of the movements of these waters. It is quite clear from Table 1 that there is a rapid depletion of lead-210 in the Colorado River during its journey from the area of its feed waters to the man-made reservoir Lake Mead. These results clearly direct one to the conclusion that the composition of river waters reflects not only the geology of the drainage basins and the accompanying weathering processes therein but also, and possibly of equal significance, the chemical reactions, either inorganic or biochemical, that occur within these waters (*10*).

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Discharge Patterns of Neurons in Cochlear Nucleus

Abstract. Patterns of discharge in slowly adapting, spontaneously discharging neurons of the cochlear nucleus were studied. A technique for analyzing the distribution of intervals between discharges of neurons is described. The response to a steady tone generally was an irregularly spaced train of impulses. In the majority of cells examined, the intervals between discharges were distributed exponentially. The mean interval and standard deviation of the distributions decreased as the level of afferent excitation was increased, but the modal value of the distribution was unchanged.

Many neurons of the mammalian central nervous system have highly irregular patterns of discharge. Measurement of the average frequency of discharge of these neurons does not sufficiently characterize their behavior. A useful method of analyzing the behavior of these neurons is to determine the frequency of occurrence of the various intervals at which they discharge. These intervals can be plotted in the form of a histogram. Histograms of this type have been constructed by various authors for muscle spindle receptors (*1*), retinal ganglion cells (*2*), and neurons of the auditory cortex (*3*). Analysis of these histograms may provide information about fundamental properties of the neuron (*1, 2, 4*). The present report is concerned with describing some examples of histograms of discharge intervals in units in a sensory nucleus in the cat.

Tungsten microelectrodes with tip diameters of 1 μ were used for the extra cellular recording of discharges of single neurons. Light pentobarbital anesthesia or awake chronic preparations with implanted microelectrode