residence time, ^{222}Rn may be removed preferentially from the lunar "atmosphere"—for example, by the solar wind—before decaying.

The absolute amount of ^{222}Rn deposit observed at Mare Tranquillitatis is a factor of 7 lower than the upper limits deduced by Yeh and Van Allen (*2*) as an average for the moon. It is a factor of 25 lower than the value calculated from diffusion theory by using a concentration of uranium of 0.5 part per million (*6*), a density of 3.0 g cm^{-3} and an effective diffusion constant of $D = 10^{-2}$ cm^2 sec^{-1}. Although this value of the diffusion constant is in the range used in discussions of ^{222}Rn emission on the earth (*7*), its applicability to the vacuum conditions on the moon is questionable. The absolute value of the ^{222}Rn deposit will depend, moreover, on the variation in uranium content on the moon on a scale of approximately 1000 km.

Data from Surveyor 6 (Sinus Medii) and Surveyor 7 (rim of highland crater Tycho) give no evidence of alpha radioactive deposits. For these sites a limit can be set of less than half of the ^{210}Po activity observed at Mare Tranquillitatis and of less than one-third the amount of ^{218}Po. Thus, the concentration of uranium and thorium at these two sites must be lower than in Mare Tranquillitatis, or the effective diffusion constant for radon isotopes must be much lower.

The presence of a distinguishable ^{210}Po alpha group, with an intensity comparable to intensities of alpha groups of ^{214}Po and ^{218}Po, in the data from the suspended instrument phase of the Surveyor 5 operations provides evidence on the time scale of turnover or "gardening" effects on the lunar surface. Polonium-210 has a ^{210}Pb grandparent with a 22-year half-life. Burial of the ^{210}Po into as much as 1 μm of material would have smeared out the alpha energy over eight channels of Fig. 1. The intensity of ^{210}Po alpha particles in the "peak" is, however, comparable to the intensity value expected from the rate of deposition. Thus, even the present crude data indicate a rate of disturbance of the topmost lunar surface of less than 1 μm in tens of years.

The pertinence of this limit to various possible mechanisms that disturb the lunar surface differs with the mechanism. Thus it can say nothing about the average rate due to processes of low frequency (less than one event in tens of years) but high efficiency, such as comets or moderately large meteorites. On the other hand, it should be applicable to the rate of relatively continuous processes, such as hopping or turnover of surface particles, and to the rate of erosion of the surface by micrometeorites, radiation, or solar wind.

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References and Notes

1. H. W. Kraner, G. L. Schroeder, G. Davidson, J. W. Carpenter, *Science* **152**, 1235 (1966).
2. R. S. Yeh and J. A. Van Allen, *ibid.* **166**, 370 (1969).
3. A. L. Turkevich, E. J. Franzgrote, J. H. Patterson, *ibid.* **165**, 277 (1969); *ibid.* **158**, 635 (1967); A. L. Turkevich, J. H. Patterson, E. J. Franzgrote, *Amer. Scientist* **56**, 312 (1968).
4. A. L. Turkevich, J. H. Patterson, E. J. Franzgrote, *Science* **160**, 1108 (1968); A. L. Turkevich, E. J. Franzgrote, J. H. Patterson, *ibid.* **162**, 117 (1968).
5. E. M. Shoemaker, R. M. Batson, H. E. Holt, E. C. Morris, J. J. Rennilson, E. A. Whitaker, *Surveyor V Mission Report*, part 2, *Science Results*, Technical Report 32-1246 (Jet Propulsion Laboratory, Pasadena, Calif., 1967), p. 7.
6. Lunar Sample Preliminary Examination Team, *Science* **165**, 1211 (1969).
7. H. W. Kraner, G. L. Schroeder, R. D. Evans, in *Natural Radiation Environment* (Univ. of Chicago Press, Chicago, 1964), chap. 10, p. 191.
8. Work at the University of Chicago aided by NASA grant NGR-14-001-128; at the Jet Propulsion Lab., by NASA contract 7-1000; and at the Argonne National Lab., by the AEC. Discussions with Profs. N. Sugarman and E. Anders of the University of Chicago are appreciated.
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Marine Phytoplankton Vary in Their Response to Chlorinated Hydrocarbons

Abstract. *Photosynthesis and growth in cultures of four marine phytoplankton species, isolated from different oceanic environments, were affected by three chlorinated hydrocarbons (DDT, dieldrin, and endrin) to varying extents. This ranged from complete insensitivity in* Dunaliella *to toxicity at concentrations of 0.1 to 1.0 part per billion of the pesticides in* Cyclotella. *Other forms were intermediate in their response.*

Inhibition of photosynthesis by DDT in four species of marine phytoplankton, and in a natural phytoplankton community, has been documented (*1*). The photosynthesis curves were typical of dose-response reactions (*2*) although, in general, pronounced toxicity occurred at concentrations well in excess of 1.2 parts per billion (ppb), the solubility of DDT in water (*3*). It is not clear how chlorinated hydrocarbons effect photosynthesis in unicellular algae, though it may be inferred from previous data (*1*, *4*) that some possess a marked capacity to concentrate these compounds from the aquatic media.

Tests were made to determine whether organisms isolated from markedly different oceanic environments vary in their response to three chlorinated insecticides. Four species in culture were assayed for their response to dieldrin, endrin, and DDT (*5*) which are identified in that order as the most widely distributed chlorinated hydrocarbons in major U.S. river basins (*6*). The species assayed included *Skeletonema costatum* (WHOI clone "Skel."), a coastal centric diatom isolated from Long Island Sound; the naked green flagellate *Dunaliella tertiolecta* (WHOI clone "Dun") typical of tide pools and estuaries; the coccolithophorid *Coccolithus huxleyi* (WHOI clone BT-6) and the centric diatom, *Cyclotella nana* (WHOI clone 13-1), both from the Sargasso Sea.

In all experiments the cultures were illuminated by fluorescent lights (6000 lux) and were grown in half-strength medium "f" (*7*). Cell carbon concentrations were adjusted to 100, 250, and 500 μg of carbon per liter, considered within the range of naturally occurring carbon concentrations in surface oceanic waters (*8*). Within these limits no effect of cell concentration on toxicity was noted. For short-term dose-response experiments, cultures, in duplicate, were added to 33-ml screw cap pyrex tubes to which were also added varying concentrations (0.01 to 1000 ppb) of the insecticide dissolved in 5 μl of either acetone or ethanol. The same amount of solvent, previously shown not to affect ^{14}C uptake, was added to the control tubes. To each tube 1 μc of $[^{14}C]Na_2CO_3$

was also added. After 24 hours' exposure to light the plants were filtered and counted in a Geiger-Müller end-window counter.

Long-term effects of DDT and endrin on cell division were studied by counting cells each day for 7 days. Cultures were inoculated into 125-ml Erlenmeyer flasks that contained 50-ml portions of media to yield cell concentrations of approximately 10^4 cell/ml (about 200 μg of carbon per liter). To each flask 100 ppb of insecticide was added daily, and an equal volume of solvent was added to each of the controls. Counts were based on the average of four flasks.

None of the insecticides tested at any concentration up to 1000 ppb affected cultures of *Dunaliella*. Although there is considerable scatter in the data in the dose-response experiments, trends indicating toxicity were not evident. Furthermore, no effect on the rate of cell division was measured over a 7-day period (Fig. 1). This species is apparently insensitive to the compounds tested, up to 1000 ppb.

The rate of ^{14}C uptake in *Skeletonema* and *Coccolithus*, on the other hand, was reduced significantly (*1*) at concentrations above 10 ppb by all three insecticides. The DDT at 100 ppb (added each day) blocked cell division after 2 to 3 divisions in *Skeletonema* but had no apparent effect on *Coccolithus*. Endrin, contrarily, had little effect on the final concentration of *Skeletonema* cells, although the rate of growth over the first 5 days was considerably slower than that of the controls. Reduced growth rates occurred throughout the experiment in *Coccolithus* (Fig. 1).

In contrast to the above species, ^{14}C uptake in *Cyclotella* (Fig. 1) was inhibited by all three insecticides at concentrations above 1 ppb. The slopes of the dose-response curves for dieldrin and endrin suggest that these may have been inhibitory as concentrations down to 0.01 ppb. Cell division was completely inhibited by dieldrin and endrin, whereas cells exposed to DDT divided, but more slowly than the controls.

To interpret the ecological significance of observations concerning the toxicity of these insecticides it is important to recall that all have very low water solubilities. For example, water can carry 1.2 ppb of DDT (*3*) and 100 ppb of dieldrin (*9*) in solution. Concentrations above these must be accommodated by precipitation or adsorption to surfaces. Some species responded to concentrations above solubility limits, which indicates that they are capable of incorporating the compounds as small particles or that saturation is maintained while they concentrate the pesticide from solution. These possibilities were tested by adding 0, 3, 10, 100, and 1000 ppb of DDT to seawater, filtering the solution, and adding *Coccolithus* (200 μg of carbon per liter) to each filtrate. No dose-response reactions characteristic of the above-described experiments were detected; all gave the same ^{14}C uptake in 24 hours as did the controls. Since *Coccolithus* was inhibited at 10 ppb (Fig. 1) the concentration of DDT in all cases must have been reduced to less than that.

Sensitivity and response to environ-

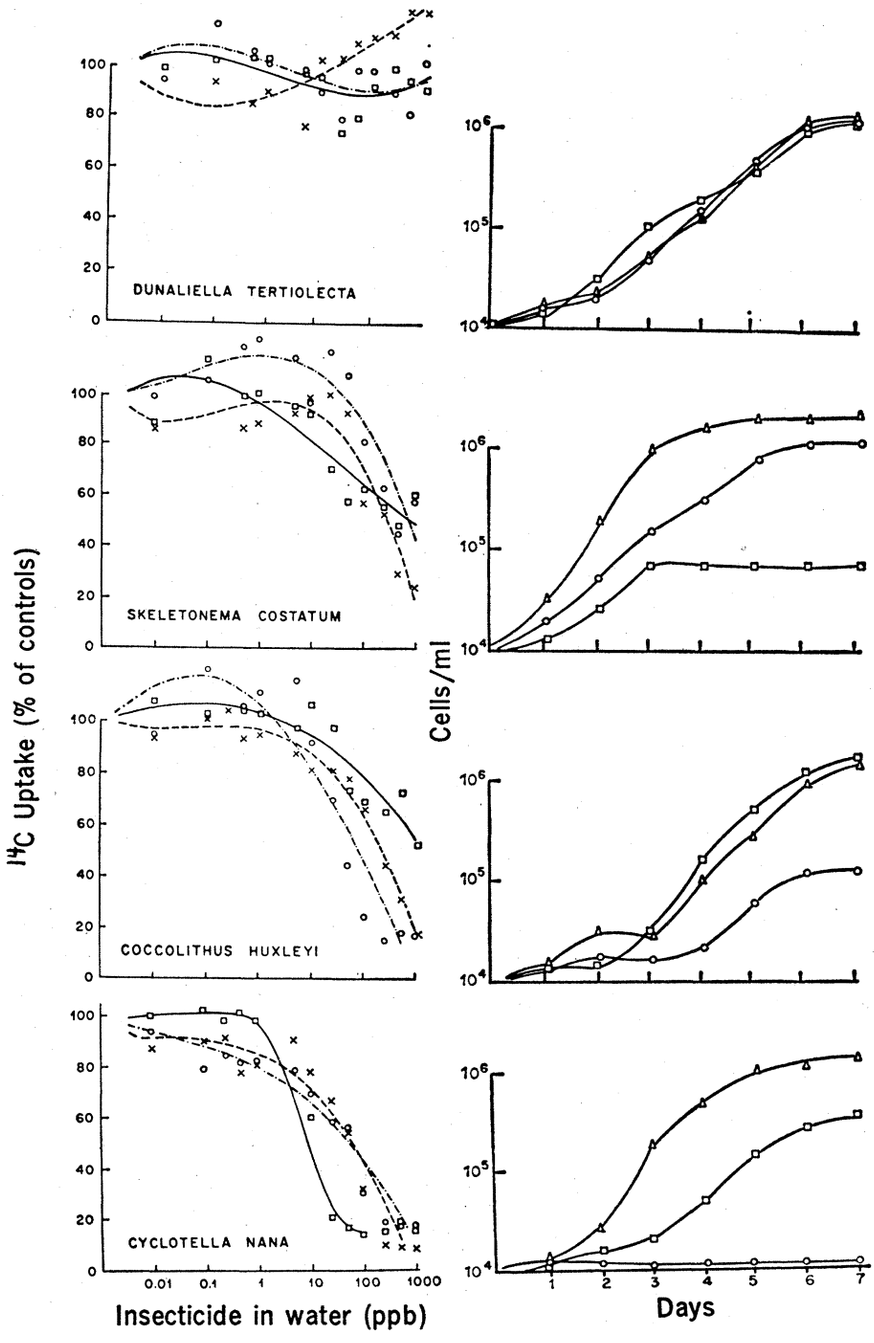

Fig. 1. Left side of figure shows ^{14}C uptake by phytoplankton at various concentrations of DDT (squares and solid lines), dieldrin (crosses and dashed lines), and endrin (open circles and dash-dot lines) relative to uptake by controls (percentages) over 24 hours. The curves were fitted to third-order polynomials by the method of least squares. Right side of the figure shows growth rates of the same species (cells per milliliter) as a function of time when 100 ppb of DDT (squares) and endrin (circles) were added each day for 7 days and solvent was added in equal volume to the controls (triangles).

mental pollutants may vary considerably among species of marine planktonic algae. The greater resistance of the one estuarine species, *Dunaliella*, in comparison with the susceptibility of coastal and open-ocean forms like *Skeletonema* and *Coccolithus* and the extreme sensitivity of *Cyclotella*, may reflect the need for adaptability in the face of more unstable conditions close to hand. Although chlorinated hydrocarbons may not be universally toxic to all species, they may exert a dramatic influence on the succession and dominance of individual forms (*10*).

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References and Notes

1. C. F. Wurster, Jr., *Science* **159**, 1474 (1968).
2. W. W. Westerfeld, *ibid.* **123**, 1071 (1956).
3. M. C. Bowman, F. Acree, M. K. Corbett, *J. Agr. Food Chem.* **8**, 406 (1960).
4. A. Södergren, *Oikos* **19**, 126 (1968).
5. The DDT is 1,1,1-trichloro-2,2-*bis*(*p*-chlorophenyl) ethane. Dieldrin is 1,2,3,4,10,10-hexachloro-6,7-epoxy-1,4,4a,5,6,7,8,8a-octohydro-1,4-endo-exo-5,8-dimethanonaphthalene. Endrin is 1,2,3,4,10,10-hexachloro-6,7-epoxy-1,4,4a,5,6,7,8,8a-octohydro-1,4-endoendo-5,8-dimethanonaphthalene.
6. L. Weaver, C. G. Gunnerson, A. W. Breidenbach, J. J. Lichtenberg, *Publ. Health Rep. (U.S.)* **80**, 481 (1965).
7. R. R. L. Guillard and J. H. Ryther, *Can. J. Microbiol.* **8**, 229 (1962).
8. D. W. Menzel, *Deep-Sea Res.* **14**, 229 (1967).
9. C. A. Edwards, *Residue Rev.* **13**, 83 (1966).
10. N. Lazaroff, R. B. Moore, *J. Phycol. Suppl.* **2**, 7 (1966).
11. Supported in part by NSF grant GB 15103 and AEC contract AT(30-1)-3862 (Ref. NYO-3862-25). Contribution No. 2424 from the Woods Hole Oceanographic Institution, Woods Hole, Mass. 02543.

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Response of Olfactory Bulb Neurons to X-rays as a Function of Nasal Oxygen Concentration

Abstract. *Responses of single olfactory bulb neurons in rats to x-irradiation of the head were examined during the perfusion through the nasal cavities of gas containing various concentrations of oxygen. Response to x-ray was unchanged with oxygen concentrations of from 100 percent down to about 5 percent. Progressively larger response decrements were observed with oxygen concentrations of 2 percent and less.*

The olfactory systems of a variety of animal species, including rats, cats, dogs, rabbits, pigeons, and monkeys, are responsive to ionizing radiation (*1*). Several lines of evidence indicate that the effects of radiation are exerted on olfactory receptors rather than on the olfactory nerves or bulb. For example, in tracheotomized rats breathing room air, responses of olfactory bulb neurons are eliminated or depressed by the nasal perfusion of argon or nitrogen (*2*). Secondly, transection of the olfactory nerves eliminates behavioral responses of pigeons to x-rays (*3*). Finally, localized beta-irradiation of the olfactory mucosa in rabbits produces responses of olfactory bulb neurons (*4*). We have proposed that the effect of ionizing radiation on the olfactory system is an indirect one involving the production of some chemical intermediate such as ozone or hydrogen peroxide (*2*, *4*). Some support for this hypothesis was provided by behavioral experiments with rats. In one (*5*) it was shown that ambient ozone selectively masks the ability of rats to detect x-rays. In another (*6*) conditional responses established with ozone as the conditional stimulus readily transferred to an x-ray conditional stimulus, whereas conditional responses established initially to an odor other than ozone (ethyl butyrate) did not transfer to the x-ray stimulus. The data of this experiment show that the concentration of oxygen within the nasal cavities is an important determinant of the olfactory response to ionizing radiation.

The activity of single olfactory bulb neurons was recorded in adult Wistar rats anesthetized with ethyl carbamate (urethan). The trachea of each rat was severed and both ends were cannulated. The animal breathed room air through the caudal cannula. The rostral cannula was connected to a gas perfusion system which permitted the nasal perfusion of either odorized or unodorized gas containing any concentration of oxygen. Pressurized tanks of nitrogen and oxygen were used, with the desired percentages of the two gases obtained through a system of flowmeters and needle valves. An oxygen meter was included in the perfusion line. The flow rate of gas was 250 to 300 ml/min. The x-ray dose rate was 90 roentgen/min measured in air at the skin surface. All exposures were 3 seconds long and were made with a Westinghouse x-ray machine operated at 250 kv peak and 15 ma, with filtration through 1 mm of aluminum and ½ mm of copper. In most experiments maxi-

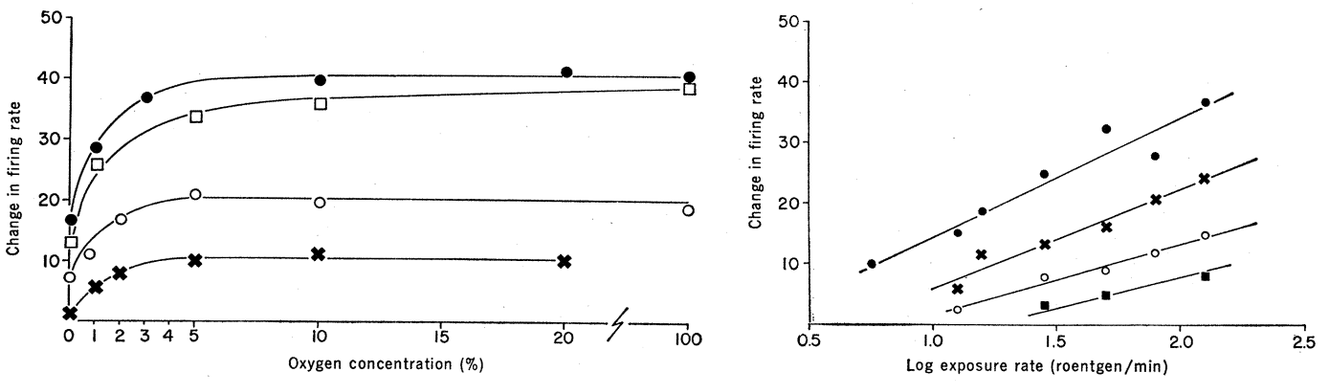

Fig. 1 (left). Change in firing rate of four different olfactory bulb neurons in response to x-ray as a function of nasal oxygen concentration. Change in firing rate is the number of action potentials per second during 3 seconds of irradiation minus the number of action potentials per second for the 3-second period preceding the irradiation. Each point is the mean of two observations. Fig. 2 (right). Change in firing rate of one olfactory bulb neuron as a function of x-ray exposure rate and nasal oxygen concentration. Each point is the mean of two observations. Oxygen concentrations were: 10 percent (filled circles); 2 percent (X's); 1 percent (open circles); 0.5 percent (squares).