when added in concentrations of approximately 1 percent by weight, will transform a beaker of water into a thixotropic paste which exhibits many external physical properties similar to those of polywater.

We conclude that our anomalous water specimen is a two-phase system, that is, a hydrosol, consisting of finely divided particulate matter suspended in ordinary water. This conclusion is consistent with the reported properties of anomalous water. As previously noted, thoroughgoing analyses of all kinds will be required before sufficient data is amassed to unequivocally establish the nature of anomalous water. There is presently little evidence to suggest that the anomalous water studied by others (*1, 2*) is not a hydrosol. We therefore suggest that proposed "polywater" specimens be examined for the presence of particulate matter. The presence of such matter offers an alternative explanation for the unusual properties of anomalous water. This alternative does not require the postulation of a polymeric form of H_2O.

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6. The authors are indebted to A. Chodos, Department of Geology, California Institute of Technology, for performing electron microprobe analysis.
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Alpha Radioactivity of the Lunar Surface at the Landing Sites of Surveyors 5, 6, and 7

Abstract. *Evidence has been obtained for a radioactive deposit on the lunar surface at Mare Tranquillitatis with a total intensity of 0.09 ± 0.03 alpha disintegration per second per square centimeter. The presence of polonium-210 in amounts that are close to equilibrium indicates a continuous turnover rate of lunar material at this site of less than 0.1 micrometer per year. The lack of such a deposit at two other lunar sites suggests lower local concentrations of uranium there.*

The possibility of an alpha-emitting radioactive deposit on the lunar surface, caused by the decay in space of radon isotopes diffusing out of lunar surface material, was suggested by Kraner *et al.* (*1*). Recently Yeh and Van Allen (*2*) have set upper limits on the amount of such alpha radioactivity by the use of data from the Explorer 35 satellite orbiting the moon. The alpha-scattering experiment performed at three locations on the moon in 1967–68 by Surveyor spacecraft has provided evidence for such an alpha-active deposit in Mare Tranquillitatis. No such evidence was found at Sinus Medii or outside the crater Tycho.

The active deposit from radon (^{222}Rn, $t_{1/2} = 3.825$ days) should contain, at equilibrium, daughter products that emit alpha particles of energies 6.00, 7.69, and 5.31 Mev. The deposit from thoron (^{220}Rn, $t_{1/2} = 54.5$ seconds) should be less intense if the source rock has a Th/U concentration ratio in the usual range and should emit alpha particles of energies 6.78 (1), 6.05 (0.33), and 8.78 (0.67) Mev, where the numbers in parentheses refer to the relative intensities within the series. The deposit from both of these radon isotopes, as well as from the even less abundant actinon ^{219}Rn, should be on the very top of the undisturbed lunar surface. The ^{218}Po and ^{214}Po daughters of ^{222}Rn and the ^{216}Po, ^{212}Bi, and ^{212}Po daughters of ^{220}Rn, because of their relatively short half-lives and those of their precursors, should come to equilibrium with their noble gas ancestors within a day or less. The formation of ^{210}Po is held up, however, by the 22-year half-life of its grandparent ^{210}Pb.

Although not designed for this purpose, the Surveyor alpha-scattering experiment (*3, 4*) provided information on this question of an active deposit on the lunar surface. Its sensitivity was limited by the short operating time in certain stages of the experiment, by the presence of a small amount of ^{254}Es ($T = 6.44$ Mev) placed close to the alpha detectors to provide a check of the energy scale of the instrument, and by the presence of a small "background" produced by the scattering of uncollimated alpha particles from the gold-lined interior of the instrument. The cosmic-ray-produced background in the alpha detectors was very low.

In the second stage of operation of the experiment (*3*), data were recorded while the instrument was suspended about 56 cm above the lunar surface. In this position the alpha detectors should have measured any long-lived (for instance, ^{210}Po, $T_\alpha = 5.31$ Mev) alpha activity on approximately 7000 cm^2 of lunar surface underneath the instrument. They should also have measured the rate of the deposition of active products of ^{222}Rn through the amounts of the short-lived progeny—that is, ^{218}Po (6.00 Mev) and ^{214}Po (7.69 Mev). Because of shadowing by the spacecraft and by the overhanging instrument (30 cm diameter), the observed rate of deposition is estimated to be only about 0.74 of the rate expected on an open lunar surface. The proton detectors of the instrument should have been sensitive only to the 7.69-Mev (^{214}Po) alpha particles because of the gold absorbers over the detectors. The degraded alpha spectrum in this mode is expected, however, to be too smeared to be identifiable.

In this stage of operation, the Surveyor 5 experiment at Mare Tranquillitatis gave moderately convincing evidence for alpha particles of energy 5.31 and 6.00 Mev (see Fig. 1). The presence of 5.31-Mev alpha particles indicates that at least part of the surface near the spacecraft had not been disturbed by the landing. In addition to the evidence in the alpha spectrum, the overflow channel of the pulse-height analyzer, which recorded events of energy greater than 7.3 Mev and therefore should have recorded the 7.69-Mev alpha particles also, showed an excess number of events when the in-

strument was suspended over the lunar surface as compared with the number of events observed after the instrument was lowered.

After the instrument was placed on the lunar surface, any ^{222}Rn emitted from the moon into the instrument cavity could be expected (on a 3.8-day time scale) to escape and the short-lived daughters to disappear. On the Surveyor 5 mission there was the expected decrease in the number of events in the overflow channel in this stage of operation, and there was no evidence of the 6.00-Mev alpha group or of the 5.31-Mev ^{210}Po alpha particles. The latter disappeared presumably either because the particular 80 cm^2 being examined by the instrument on the lunar surface had been disturbed during the landing of the Surveyor [television pictures (*5*) show that, upon landing, the footpads of the spacecraft ejected loose material, which cascaded down the 20° slope of the small crater in which the Surveyor came to rest] or because the process of deploying the instrument onto the surface disturbed it enough to bury the ^{210}Po deposit in the small area being examined.

The three items of information obtained on the Surveyor 5 mission about the equilibrium alpha activity of ^{222}Rn daughters on the unshadowed lunar surface are (in disintegration per second per square centimeter per steradian)

$$^{210}\text{Po}: \quad (3.3 \pm 1.1) \times 10^{-3}$$
$$^{214}\text{Po}: \quad (1.5 \pm 1.1) \times 10^{-3}$$
$$^{218}\text{Po}: \quad (1.8 \pm 1.4) \times 10^{-3}$$

where the errors quoted here and elsewhere in this paper are statistical at the 1-σ level.

Although the individual values are only marginally significant, they are consistent with equilibrium within their respective errors. The average activity at equilibrium of each of the ^{222}Rn daughters at Mare Tranquillitatis is calculated to be $(2.3 \pm 0.7) \times 10^{-3}$ disintegration sec^{-1} cm^{-2} sr^{-1}. On the assumption of isotropic emission, this value is equivalent to a total alpha activity on the lunar surface due to ^{222}Rn progeny of 0.087 ± 0.026 disintegration sec^{-1} cm^{-2}.

In the case of the thoron (^{220}Rn) deposit, the 6.78-Mev alpha particles of ^{216}Po fall in a region of very low background of the instrument, above the ^{254}Es peak. The other two possible alpha groups fall in regions of the spectrum where the background was relatively high. The one event observed in the 192 minutes of measurement with the instrument suspended, at about the right energy for ^{216}Po and with no events in the four channels below or six channels above, is consistent with an activity of a ^{220}Rn deposit about 10 percent of the activity of the ^{222}Rn deposit.

With the instrument on the lunar surface, the ^{220}Rn, with its 54.5-second half-life, is much less likely to escape from the instrument cavity before decaying than is the ^{222}Rn. The resulting active deposit should be spread more or less uniformly over the inside of the instrument. The 3506 minutes of measurement on the lunar surface at Mare Tranquillitatis yielded an excess in the region of 6.78 Mev of 1.7 ± 1.0 events per 10^3 minutes. The evidence for a ^{220}Rn deposit is thus less conclusive, since it is based on only one alpha group. These data would correspond to an emission rate of $(8 \pm 5) \times 10^{-3}$ ^{220}Rn atom sec^{-1} cm^{-2}, to be compared with the ^{222}Rn emission rate calculated from the data above of $(58 \pm 17) \times 10^{-3}$ atom sec^{-1} cm^{-2}.

On the basis of a Th/U ratio of 3 observed on the returned Apollo 11 samples (*6*) and on the assumption that the two radon isotopes have the same probability of escaping their matrices, simple diffusion theory indicates a ratio of emissivity of ^{222}Rn to ^{220}Rn of 75 to 1. Three possible explanations for the lower observed ratio of about 7 to 1 are: (i) If the emissivity of radon in Mare Tranquillitatis is larger than in surrounding areas of the moon, the ^{222}Rn deposit will be lowered by the escape of the noble gas from the region before ^{222}Rn decay, with no compensating influx. With its shorter half-life, ^{220}Rn will decay much closer to its point of emission. (ii) The effective diffusion constant in the lunar material may be smaller for ^{222}Rn than for ^{220}Rn, owing either to location of the parent uranium and thorium in different minerals or to the lower effective temperature of the deeper lunar material from which the ^{222}Rn diffuses. (iii) Because of its longer

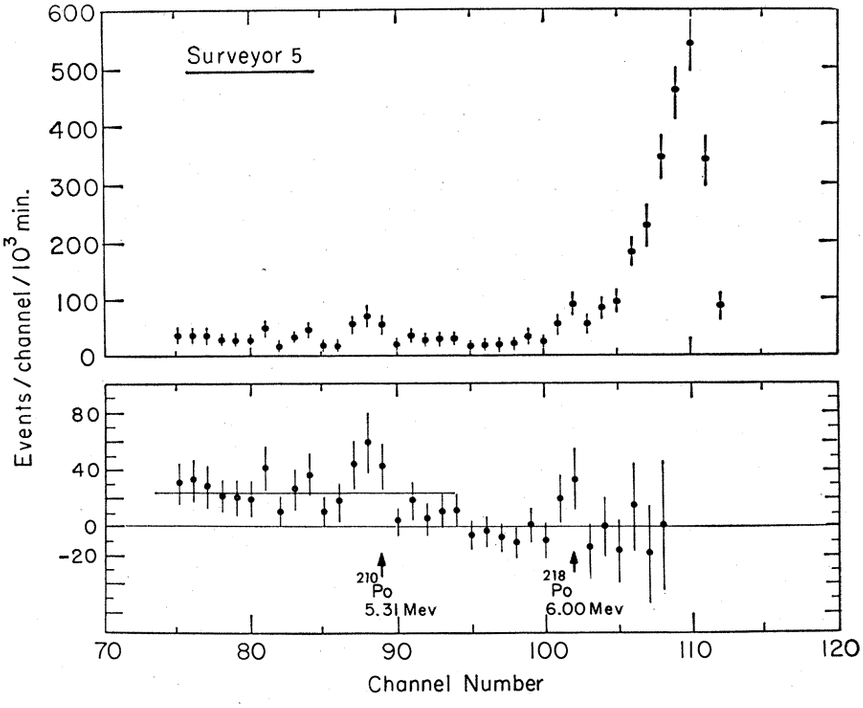

Fig. 1. (Top) Data recorded in the alpha mode by the alpha-scattering instrument while suspended (background phase) over the lunar surface in Mare Tranquillitatis; the instrument operated in this position for 192.3 minutes. The abscissae are the channel numbers (energy) of the pulse-height analyzer. The peak at around channel 110 is due to ^{254}Es ($T\alpha = 6.44$ Mev), which was used as an energy marker on the detectors. Statistical (1σ) errors are indicated. The average efficiency of the alpha detectors for registering particles originating on a sample at nominal distance was 4.1×10^{-4}. (Bottom) The data of the top part of the figure after subtracting the ^{254}Es contribution as measured on earth before launch. The expected location of ^{210}Po and ^{218}Po alpha particles is indicated. The horizontal line at the left of the figure indicates the level of scattering of uncollimated alpha particles from the gold-lined interior of the instrument.

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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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 $[^{14}C]Na_2CO_3$