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AT THE SURVEYOR V, VI, AND VII LANDING SITES

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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 dis. $sec.^{-1}$ cm^{-2}. The presence of Po^{210} in close-to-equilibrium amounts indicates a continuous turnover rate of lunar material at this site of less than 0.1 micron 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, arising from 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 using data from the Explorer 35 satellite orbiting the moon. The alpha-scattering experiment performed at three locations on the moon in 1967-1968 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 of the crater Tycho.

The active deposit from radon (Rn^{222}, $t_{1/2}$ = 3.825d) should contain, at equilibrium, daughter products emitting alpha particles of energies 6.00, 7.69 and 5.31 MeV. The deposit from thoron (Rn^{220}, $t_{1/2}$ = 54.5s) 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 (Rn^{219}), should be on the very top of the undisturbed lunar surface. The Po^{218} and Po^{214} daughters of Rn^{222} and the Po^{216}, Bi^{212} and Po^{212} daughters of Rn^{220}, 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 Po^{210} however, is held up by the 22y half-life of its grandparent, Pb^{210}.

Although not designed for this purpose, the Surveyor alpha-scattering experiment (3,4,5) 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 Es^{254} (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 (e.g. Po^{210}, T_{α}= 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 Rn^{222} through the amounts of the short-lived progeny, i.e. Po^{218} (6.00 MeV) and Po^{214} (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 that to be expected on an open lunar surface. The proton detectors of the instrument should have been sensitive only to the 7.69 MeV (Po^{214}) alpha particles because of the gold absorbers over the detectors. The degraded alpha spectrum in this mode, however, is expected to be too smeared to be identifiable.

In this stage of operation, the Surveyor V experiment at Mare Tranquillitatis, gave moderately convincing evidence for alpha particles of energy 5.31 and 6.00 MeV (see figure 1). The presence of the former 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 instrument was suspended over the lunar surface as compared with that observed after the instrument was lowered.

After the instrument was placed on the lunar surface, any Rn^{222} emitted from the moon into the instrument cavity could be expected (on a 3.8 day time scale) to escape and so the short-lived daughters to disappear. On the Surveyor V mission there was the expected decrease in the number of events in the overflow channel in this stage of operation, and also no evidence for the 6.00 MeV alpha group, nor for the 5.31 MeV Po^{210} alpha particles. The latter disappeared presumably because either 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 of reference (6) 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 that the process of deploying the instrument onto the surface disturbed it enough to bury the Po^{210} deposit in the small area being examined.

The three items of information obtained on the Surveyor V mission about the equilibrium alpha activity of Rn^{222} daughters on the unshadowed lunar surface are:

Po^{210}: $(3.3 \pm 1.1) \times 10^{-3}$ dis sec^{-1} cm^{-2} ster^{-1}

Po^{214}: $(1.5 \pm 1.1) \times 10^{-3}$ dis sec^{-1} cm^{-2} ster^{-1}

Po^{218}: $(1.8 \pm 1.4) \times 10^{-3}$ dis sec^{-1} cm^{-2} ster^{-1}

where the errors quoted here and elsewhere in this paper are statistical at the 1σ-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 Rn^{222} daughters at Mare Tranquillitatis is calculated to be $(2.3 \pm 0.7) \times 10^{-3}$ dis sec^{-1} cm^{-2} ster^{-1}. On the assumption of isotropic emission, this is equivalent to a total alpha activity on the lunar surface due to Rn^{222} progeny of 0.087 ± 0.026 dis sec^{-1} cm^{-2}.

In the case of the thoron (Rn^{220}) deposit, the 6.78 MeV alpha particles of Po^{216} fall in a region of very low background of the instrument, above the Es^{254} 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 min of measurement with the instrument suspended, at about the right energy for Po^{216}, with no events in the 4 channels below or 6 channels above, is consistent with an activity of a Rn^{220} deposit about ten percent of the activity of the Rn^{222} deposit.

With the instrument on the lunar surface, the Rn^{220}, with its 54.5 sec half life, is much less likely to escape from the instrument cavity before decaying than is the Rn^{222}. The resulting active deposit should be spread more or less uniformly over the inside of the instrument. The 3506 min 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 min. The evidence for a Rn^{220} deposit is thus less conclusive, since it is based on only one alpha group. This data would correspond to an emission rate of $(8 \pm 5) \times 10^{-3}$ Rn^{220} atoms sec^{-1} cm^{-2}, to be compared with the Rn^{222} emission rate calculated from the data above of $(58 \pm 17) \times 10^{-3}$ atoms sec^{-1} cm^{-2}.

On the basis of a Th/U ratio of 3, as observed on the returned Apollo 11 samples (7) and the assumption that the two radon isotopes have the same probability of escaping their matrices, simple diffusion theory indicates a ratio of emissivity of Rn^{222} to Rn^{220} of 75 to 1. Three possible explanations for the lower observed ratio of about 7 to 1 are: 1. If the emissivity of radon in Mare Tranquillitatis is larger than in surrounding areas of the moon, the Rn^{222} deposit will be lowered by the escape of the noble gas from the region before decaying, with no compensating influx. Rn^{220}, with its shorter half-life, will decay much closer to its point of emission. 2. The effective diffusion constant in the lunar material may be smaller for Rn^{222} than for Rn^{220} due 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 Rn^{222} diffuses. 3. Because of its longer residence time, Rn^{222} may be removed preferentially from the lunar "atmosphere", for example, by the solar wind, before decaying.

The absolute amount of Rn^{222} deposit observed at Mare Tranquillitatis is a factor of seven lower than the upper limits deduced by Yeh and Van Allen (2) for an average for the moon. It is a factor of 25 lower than the value calculated from diffusion theory using a concentration of uranium of 0.5 ppm (7), a density of 3.0 gm 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 Rn^{222} emission on the earth (8), its applicability to the vacuum conditions on the moon is questionable. The absolute value of the Rn^{222} deposit, moreover, will depend on the variation in uranium content on the moon on a scale of approximately 1000 km.

Data from Surveyor VI (Sinus Medii) and Surveyor VII (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 Po^{210} activity observed at Mare Tranquillitatis, and less than one-third the amount of Po^{218}. 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 Po^{210} alpha group, with an intensity comparable to those from Po^{214} and Po^{218}, in the data from the suspended-instrument-phase of the Surveyor V operations, provides evidence on the time scale of turnover or "gardening" effects on the lunar surface. Po^{210} has a 22 yr Pb^{210} grandparent. Burial of the Po^{210} into as much as 1 micron of material would have smeared out the alpha energy over 8 channels of figure 1. The intensity of Po^{210} alpha particles in the "peak" is, however, comparable to that 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 one micron in tens of years.

The pertinence of this limit to various possible mechanisms of disturbing 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 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. Experiments designed to measure this effect more quantitatively by the same technique appear very promising.

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Figure Caption

Figure 1. Top: Data Recorded in the Alpha Mode by the Alpha Scattering Instrument While Suspended Over the Lunar Surface in Mare Tranquillitatis. The abscissae are the channel numbers (energy) of the pulse height analyzer. The ordinates are events per channel per 10^3 min. Statistical (1σ) errors are indicated. The peak at around channel 110 is due to Es^{254} (T_α = 6.44 MeV) used as an energy marker on the detectors. 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 Es^{254} Contribution as Measured on Earth Before Launch. The expected locations of Po^{210} and Po^{218} alpha particles are 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.

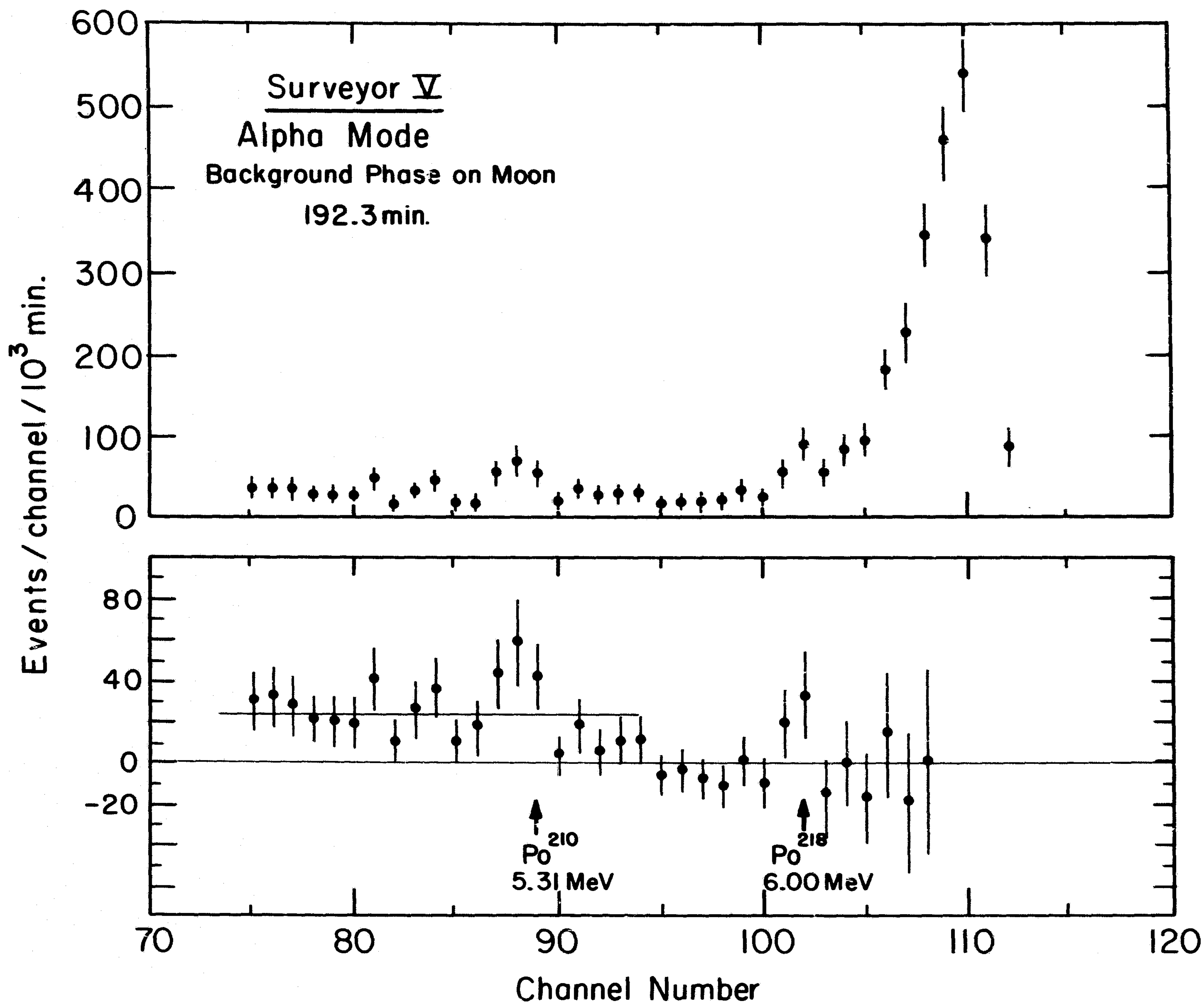
Surveyor V
Alpha Mode
Background Phase on Moon
192.3 min.
Events / channel / 10^3 min.
600
500
400
300
200
100
0
80
40
0
-20
Po 210
5.31 MeV
Po 218
6.00 MeV
70
80
90
100
110
120
Channel Number

Fig. 1