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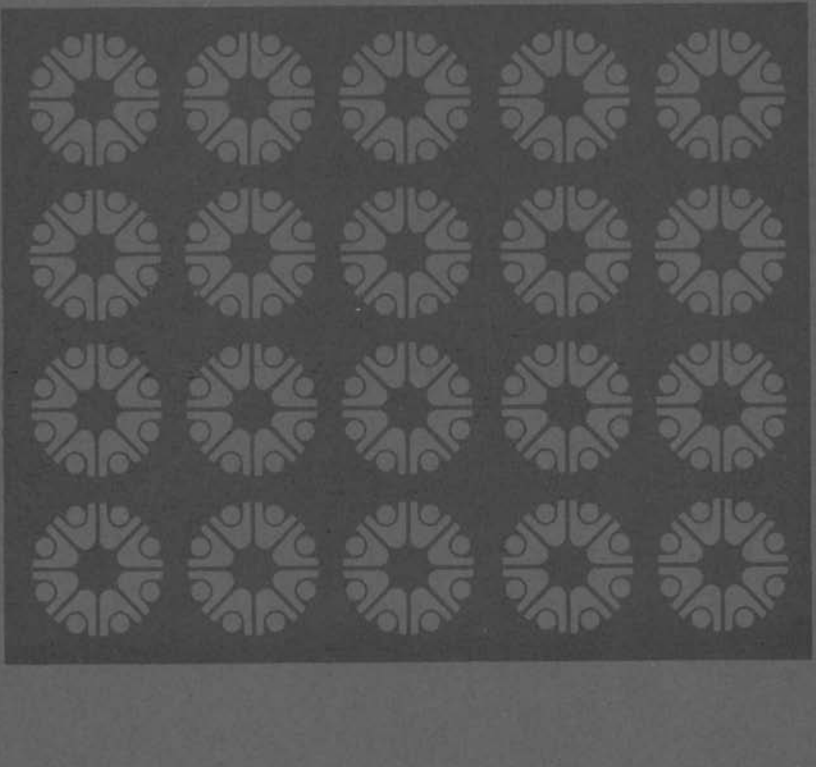
AEC Research and Development Report

QUARTERLY RESEARCH REPORT TO THE NASA MANNED SPACECRAFT CENTER

THE MEASUREMENT OF RADIATION EXPOSURE OF ASTRONAUTS BY RADIOCHEMICAL TECHNIQUES

JANUARY 3, 1972 THROUGH APRIL 2, 1972

APRIL 15, 1972



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QUARTERLY RESEARCH REPORT TO THE NASA MANNED SPACECRAFT CENTER

THE MEASUREMENT OF RADIATION EXPOSURE OF ASTRONAUTS BY RADIOCHEMICAL TECHNIQUES

January 3, 1972 Through April 2, 1972

by

R. L. Brodzinski

April 15, 1972

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THE MEASUREMENT OF RADIATION EXPOSURE OF ASTRONAUTS BY RADIOCHEMICAL TECHNIQUES

January 3, 1972 Through April 2, 1972

R. L. Brodzinski

ABSTRACT

Only two of the fecal specimens collected inflight during the Apollo 15 mission were returned for analysis. Difficulty in obtaining reasonably accurate radiation dose estimates based on the cosmogenic radionuclide content of the specimens was encountered due to the limited sampling. The concentrations of ^{22}Na, ^{40}K, ^{51}Cr, ^{59}Fe, and ^{137}Cs are reported.

The concentrations of 24 major, minor, and trace elements in these two specimens were determined. Most concentrations are typical of those observed previously. Major exceptions are extremely low values for selenium and extraordinarily high values for rare earth elements.

The net ^{210}Po activities in the Apollo 11 and 12 Solar Wind Composition foils and in the Apollo 8 and 12 spacecraft reflective coatings due to lunar exposure have been determined. Equilibrium concentrations of 0.082 ± 0.012 disintegrations cm^{-2} sec^{-1} of ^{222}Rn in the lunar atmosphere and 0.0238 ± 0.0035 disintegrations cm^{-2} sec^{-1} of ^{210}Po on the lunar surface have been calculated for Oceanus Procellarum.

A summary of a paper entitled, "Radon-222 Activity at Oceanus Procellarum," and the text of a manuscript entitled, "Radon-222 in the Lunar Atmosphere," are included as appendices.

TASK - DETERMINATION OF THE RADIONUCLIDE CONTENT OF FECES AND URINE FROM ASTRONAUTS ENGAGED IN SPACE FLIGHT

Astronauts engaged in space flight are subjected to cosmic radiation which induces radioactive isotopes in their bodies. The radiation dose received from cosmic particles can be determined from the quantities of these induced radionuclides.(1) The concentrations of the induced radioactivities can be ascertained by direct whole-body counting of the astronauts or by indirect measurement, such as counting that fraction of the radionuclides excreted in the feces and urine. This latter approach has been used on all manned Apollo missions. In addition to the induced activities, several fallout, injected, or naturally occurring radioisotopes have been measured, and variations in their concentrations may be indicative of changes in the biological life processes occassioned by the space environment or serve as identifying "fingerprints."

The concentrations of the radioisotopes listed in Table I have been normalized by dividing the decay corrected disintegration rate by the weight of feces. Those radionuclide concentrations given in Tables II and III have been further normalized by dividing the disintegration rate by the weight of respective stable elements in the sample. All samples were handled according to procedures described earlier.(1) Unmetabolized elements passing through the gastrointestinal tract randomly lower the specific activity of excreted cosmogenic radionuclides in feces and render radiation dose evaluations on this basis rather uncertain. In addition, when only a few of the fecal specimens collected during a mission are returned, such as in the case of Apollo 15, there is no assurance that those samples are representative of the entire mission or any given fraction of it.

In spite of these acknowledged faults in the system, the following calculations are made. Comparison of the specific activity of ^{22}Na in the Apollo 14 fecal specimens to that of earlier missions yields a cosmic radiation dose of 430 ± 270 mR to the astronauts. This value falls between two values reported earlier(2) which were based on the ^{7}Be in these fecal samples and the ^{22}Na in the postflight urine specimens. Although the concentration of ^{22}Na reported in Table I for the Apollo 15 mission is within the range of previously reported values, the specific activity of that sample would yield a dose of 4000 ± 1800 mR if compared to earlier specific activities. The error values correspond to only one standard deviation.

All other reported concentrations and specific activities are well within the range normally expected. The high concentrations of ^{51}Cr observed in the fecal specimens from the Apollo 15 mission indicate that the astronaut(s) received a preflight injection of radiochromium.

TASK - NEUTRON ACTIVATION ANALYSIS OF FECES AND URINE FROM ASTRONAUTS ENGAGED IN SPACE FLIGHT

This program was instituted in an attempt to foresee any possible metabolic changes in astronauts caused by conditions of weightlessness and prolonged physical inactivity which may have been manifested by an uptake or loss of an element or elements by their bodies. The primary concern had been the terrestrially observed phenomenon of osteoporosis (loss of skeletal calcium), although changes in the uptake and excretion rates of other essential microconstituents of the body, such as cobalt, iron, selenium, and the alkali metals, were also considered important. Lack of precisely known intake values have continually hampered the effectiveness of the program, although useful comparisons have been made to normal dietary intakes. Body losses of calcium, potassium, and iron were observed during early manned Apollo missions,(3) but these losses have since been checked. Since the astronauts now encounter much more physical activity than they did during the earlier missions, and since it is becoming more and more difficult to return all the inflight fecal specimens, much less have any reasonable documentation of them, it is felt that the investigation of fecal specimens should be terminated. However, it is recommended that analysis of pre- and postflight urines be continued. A complete mass balance study of all measureable elements should be accomplished during at least one space flight under well documented conditions. Such an experiment should include an analysis of all food ingested and all urine and feces excreted. Project Skylab missions will present an ideal opportunity, and it is strongly recommended that a mass balance study be undertaken on one of these.

The concentrations of Ca, Na, K, Rb, Cs, Fe, Co, Zn, Cr, Sc, Br, Se, Hg, Ag, Sb, Au, Sn, As, Eu, Tb, Th, Hf, Ta, and La have been measured in the two returned inflight fecal specimens from the Apollo 15 mission by a previously described technique of instrumental neutron activation analysis.(1, 4, 5) These are reported in Table IV. Since all specimens were not returned, fecal excretion rates cannot be calculated from this data. Most concentrations are typical of those determined for recent missions. Based on prior experience, it appears that the two samples are from different astronauts since the gold concentrations differ by an order of magnitude. The selenium concentrations are among the lowest ever observed, but the significance of this is not immediately apparent. The extraordinarily high concentrations of terbium, europium, and lanthanum must certainly be indicative of contact with large quantities of rare earth elements. However, the time and place of this exposure and its physical significance, if any, are not known.

TASK - SEARCH FOR LUNAR ATMOSPHERE

The lunar atmosphere is primarily composed of the solar wind and of gaseous radon from the decay of uranium in the lunar soil. The Solar Wind Composition (SWC) experiments, which have been flown on all lunar landing missions, are designed to characterize the solar wind. These same SWC foils are also useful for characterizing the radon in the lunar atmosphere since they collect the recoiling decay products of radon in addition to solar wind atoms.

The net ^{210}Po activities of the Apollo 11 and 12 SWC foils and the Apollo 8 and 12 spacecraft reflective thermal coatings due to exposure to the moon have been determined. From these values an equilibrium concentration of 0.082 ± 0.012 disintegrations cm^{-2} sec^{-1} of ^{222}Rn in the lunar atmosphere and an associated 0.0238 ± 0.0035 disintegrations cm^{-2} sec^{-1} of ^{210}Po on the lunar surface have been calculated for Oceanus Procellarum.

A presentation based on these findings has been prepared for the June, 1972 meeting of the American Nuclear Society. A summary of this paper, entitled, "Radon-222 Activity at Oceanus Procellarum," is reproduced in Appendix A of this report. A complete manuscript on the subject, entitled, "Radon-222 in the Lunar Atmosphere," has been submitted to Science for publication and is reproduced in Appendix B of this report.

EXPENDITURES

The following table documents the expenditures according to task and total cost incurred from January 3, 1972 through April 2, 1972 for the work reported herein.

TASK	EXPENDITURES
Determination of the Radionuclide Content of Feces and Urine From Astronauts Engaged in Space Flight	$ 1,696
Neutron Activation Analysis of Feces and Urine From Astronauts Engaged in Space Flight	$ 893
Search for Lunar Atmosphere	$ 1,175
TOTAL COSTS	$ 3,764

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TABLE I

RADIOACTIVITY IN FECES FROM APOLLO 15 ASTRONAUTS

Sample	dis/min/g Feces on 8/7/71				
	^{22}Na	^{40}K	^{51}Cr	^{59}Fe	^{137}Cs
#1	0.0049 ± 0.0023	11.74 ± 0.18	21.3 ± 2.3	0.940 ± 0.098	0.112 ± 0.024
#2		10.43 ± 0.17	10.7 ± 2.3	0.979 ± 0.098	0.210 ± 0.024

TABLE II

RADIOACTIVITY IN FECES FROM APOLLO 14 ASTRONAUTS*

Sample	dis/min ^{22}Na per g Na	dis/min ^{51}Cr per g Cr	dis/min ^{59}Fe per g Fe	dis/min ^{137}Cs per g Cs
#1	1.11 ± 0.61	$(7.2 \pm 1.7)\cdot 10^6$	$(5.62 \pm 0.57)\cdot 10^3$	$(7.15 \pm 0.79)\cdot 10^6$
#2		$(3.45 \pm 0.19)\cdot 10^7$	$(8.20 \pm 0.48)\cdot 10^3$	
#3		$(4.46 \pm 0.42)\cdot 10^7$	$(1.36 \pm 0.14)\cdot 10^4$	$(1.77 \pm 0.14)\cdot 10^7$
#4			$(7.61 \pm 0.61)\cdot 10^3$	$(1.03 \pm 0.11)\cdot 10^7$
#5	4.4 ± 3.0		$(1.15 \pm 0.10)\cdot 10^4$	$(1.04 \pm 0.12)\cdot 10^7$

* The radioactivities have been normalized by dividing the disintegration rate by the weight of the stable element and decay correcting to the splashdown date, 2/9/71.

TABLE III

RADIOACTIVITY IN FECES FROM APOLLO 15 ASTRONAUTS*

Sample	dis/min ^{22}Na per g Na	dis/min ^{51}Cr per g Cr	dis/min ^{59}Fe per g Fe	dis/min ^{137}Cs per g Cs
#1	26 ± 12	$(1.57 \pm 0.17)\cdot 10^{7}$	$(5.66 \pm 0.59)\cdot 10^{3}$	$(7.1 \pm 1.4)\cdot 10^{6}$
#2		$(1.03 \pm 0.22)\cdot 10^{7}$	$(5.63 \pm 0.56)\cdot 10^{3}$	$(6.33 \pm 0.72)\cdot 10^{6}$

* The radioactivities have been normalized by dividing the disintegration rate by the weight of the stable element and decay correcting to the splashdown date, 8/7/71.

TABLE IV

ELEMENTAL CONCENTRATIONS IN APOLLO 15 ASTRONAUT FECAL SAMPLES

	Sample #1		Sample #2	
Element	ppm*	μg**	ppm*	μg**
Ag	0.105	19.1	0.326	35.3
As	0.346	63.1	0.303	32.9
Au	1.31	239	0.137	14.9
Br	0.795	145	0.893	96.7
Ca	9900	$1.8 \cdot 10^6$	16,400	$1.78 \cdot 10^6$
Co	0.121	22.0	0.216	23.4
Cr	1.36	248	1.04	113
Cs	0.0172	3.14	0.0332	3.60
Eu	0.00327	0.595	0.00428	0.463
Fe	166	30,200	174	18,900
Hf	0.0178	3.24	0.0173	1.87
Hg	0.409	74.5	1.19	129
K	5290	962,000	5210	565,000
La			0.173	18.7
Na	190	34,600	301	32,600
Rb	22.7	4140	14.2	1540
Sb	0.163	29.8	0.256	27.7
Sc	0.0111	2.02	0.0121	1.31
Se	0.273	49.8	0.536	58.1
Sn	17.0	3100	36.4	3950
Ta	0.00892	1.62	0.0206	2.24
Tb	0.00682	1.24	0.00241	0.261
Th	0.0659	12.0	0.0170	1.85
Zn	140	26,000	146	15,800

* Wet weight basis

** Total weight per defecation

APPENDIX A

RADON-222 ACTIVITY AT OCEANUS PROCELLARUM[a]

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SUMMARY

In 1966, an equilibrium lunar surface radon-222 activity of 4 disintegrations cm^{-2} sec^{-1} was calculated(1) using terrestrial values of the radon diffusion coefficient and uranium concentration and assuming a lunar surface porosity of 0.25. An upper limit for the radon-222 activity, which was at least an order of magnitude lower than the 1966 value, was obtained in 1969 by the moon orbiting satellite, Explorer 35 (2). Turkevich(3) reports 0.029 ± 0.009 disintegrations cm^{-2} sec^{-1} at Mare Tranquillitatis from data taken with the alpha-scattering equipment on the Surveyor 5 spacecraft; however, he was unable to confirm this result with Surveyor 6 and 7 data. While Lindstrom (4) reports $4.5 \cdot 10^{-4}$ disintegrations cm^{-2} sec^{-1} for Mare Tranquillitatis from the measurement of ^{210}Pb in lunar fines, Economou and Turkevich (5) found an equilibrium activity of $(0.88 \pm 4.43) \cdot 10^{-3}$ disintegrations cm^{-2} sec^{-1} based on the returned Surveyor 3 camera visor.

In this investigation samples of the solar wind composition (SWC) foils exposed on the moon by the Apollo 11 and 12 astronauts and pieces of the reflective thermal coating from the Apollo 8 and 12 spacecraft were examined for the presence of ^{210}Po, decay product of radon-222, by alpha analysis of chemically separated polonium(6).

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[a] A paper to be presented at the American Nuclear Society meeting in June, 1972.

The decay products of radon atoms bouncing along the moon in ballistic trajectories at thermal velocities embed themselves in the SWC foil. These atoms are transformed along their decay chain to long-lived ^{210}Pb ($t_{1/2}$=22y), through ^{210}Po ($t_{1/2}$=138.4d), to stable ^{206}Pb. The progeny of radon escaping the gravitational field of the moon due to their high alpha-recoil-energy, strike the spacecraft, and are trapped in the coating. Although the original capture of incident atoms should be complete, the capture efficiency is affected by atoms recoiling out of the foil or coating during subsequent decays. In addition, the orientation of the spacecraft coating with respect to the moon is uncertain. Assumptions regarding the magnitude of these effects have been made for calculational purposes.

Due to the low exposure period of the Apollo 11 SWC foil, no ^{210}Po activity was observed in excess of that in blank foils. This indicates that the foil was not contaminated during handling or by the activity of astronauts in the vicinity of the foil during lunar exposure. From the net ^{210}Po activity observed in the Apollo 12 SWC foil an equilibrium lunar surface ^{210}Po activity of 0.0238 ± 0.0035 disintegrations $cm^{-2}sec^{-1}$ is obtained for Oceanus Procellarum. This corresponds to an atmospheric ^{222}Rn activity of 0.082 ± 0.012 disintegrations $cm^{-2}sec^{-1}$. Since the exposure of the spacecraft coatings to the moon requires an additional assumption, equilibrium activities based on their ^{210}Po content are inherently less certain than those based on the well-documented SWC foils. However, reasonable calculations yield 0.025 ± 0.011 disintegrations $cm^{-2}sec^{-1}$ and $\leq$ 0.18 disintegrations $cm^{-2}sec^{-1}$ from Apollo 8 and Apollo 12 spacecraft coatings, respectively for the equilibrium surface ^{210}Po activity. These data support the value reported by Turkevich(3) for the equilibrium ^{222}Rn daughter activity at Mare Tranquillitatis but disagree with the other measurements. Investigation of radon emanation from lunar soil(7) and consideration of diffusion models and mechanisms(4) indicate that a discussion of these results in terms of the radon diffusion coefficient, the lunar surface porosity, or variations in lunar uranium concentrations may not be relevant. Rather, the effects of the lunar vacuum and the widely varying surface temperatures are the phenomena probably most responsible for the distribution of radon on the moon's surface.

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APPENDIX B

RADON-222 IN THE LUNAR ATMOSPHERE

R. L. Brodzinski

ABSTRACT

The equilibrium concentration of ^{222}Rn above the lunar surface and of ^{210}Po of atmospheric origin on the lunar surface at Oceanus Procellarum have been calculated to be 0.082 ± 0.012 and 0.0238 ± 0.0035 disintegrations $cm^{-2}sec^{-1}$ respectively from a determination of the ^{210}Po concentration in exposed Solar Wind Composition experiment foils and in reflective coatings of lunar orbiting spacecraft.

The concentration of polonium-210 has been measured in the Solar Wind Composition (SWC) experiment foils which were exposed on the surface of the moon by the Apollo 11 and Apollo 12 astronauts. This data permits a direct calculation of the equilibrium lunar atmospheric content of Radon-222 which Kraner, et al.(1) had estimated to be 4 disintegrations $cm^{-2}sec^{-1}$ using terrestrial values of the radon diffusion coefficient and uranium concentration and assuming a lunar surface porosity of 0.25. In 1969 Yeh and Van Allen(2) set upper limits for the alpha-particle emissivity of the moon which indicated the radon-222 concentration was at least an order of magnitude lower than the provisional estimates of Kraner. Their calculations were based on alpha flux measurements made by a totally depleted gold-silicon surface barrier detector onboard the moon-orbiting spacecraft, Explorer 35.

From data obtained with the alpha-scattering equipment on the unmanned lunar probes, Surveyors 5, 6, and 7, Turkevich, et al.(3) reported an equilibrium surface activity of 0.029 ± 0.009 disintegrations $cm^{-2}sec^{-1}$ of each alpha active ^{222}Rn daughter at Mare Tranquillitatis. However, they were unable to reconcile this number with existing diffusion theory using the actual uranium concentrations measured in Apollo 11 fines. This data suggests that earth based diffusion constants are not applicable in the vacuum conditions of the moon, or that there are substantial variations in the uranium content of the moon over relatively small distances. The latter hypothesis is supported by the lack of evidence for an alpha radioactive deposit from ^{222}Rn daughters at Sinus Medii or at the rim of the highland crater Tycho.(3)

Lindstrom, et al.(4) separated lead from a sample of Apollo 11 fines to determine the amount of ^{210}Pb (another member of the ^{238}U - ^{222}Rn - ^{206}Pb

decay chain) in excess of that in equilibrium with ^{238}U. Lead-210 from the decay of radon in the atmosphere should accumulate on surface fines and increase the anticipated surface concentration since it arises from the decay of uranium at a greater soil depth and has reached the surface by means of its parent radon. Lindstrom reports a maximum excess surface activity of $4.5 \cdot 10^{-4}$ disintegrations $cm^{-2}sec^{-1}$ for ^{210}Pb at Mare Tranquillitatis - only 0.016 of that reported by Turkevich for ^{210}Po.

Economou and Turkevich(5) examined the Surveyor 3 camera visor from Oceanus Procellarum with an alpha scattering instrument for ^{210}Po resulting from radon decay. Experimental difficulties caused by the paint on the visor reduced the sensitivity of their experiment, however, they obtained an equilibrium activity of $(0.88 \pm 4.43) \cdot 10^{-3}$ disintegrations cm^{-2} sec^{-1}. This value is also considerably lower than their reported value at Mare Tranquillitatis and cannot be explained by variations in uranium concentration since the uranium content of the soil is actually higher at Oceanus Procellarum.

In an effort to resolve some of the existing discrepancies, pieces of the SWC foils exposed on the moon by the Apollo 11 and 12 astronauts were analyzed for their ^{210}Po content. Although the exposure periods of these foils were extremely short compared to those of the other sampling devices, a sensitive method for the analysis of very low levels of ^{210}Po(6) permitted relatively precise results. The Apollo 11 foil was exposed to the lunar atmosphere at Mare Tranquillitatis for 77 minutes on July 21, 1969. The Apollo 12 foil was exposed at Oceanus Procellarum for 18 hours and 42 minutes starting November 19, 1969. The Apollo 11 foil stood vertically on the lunar surface during exposure, and the Apollo 12 foil was reclined 12°.(7) A 45 cm^2 piece of the Apollo 11 foil from about 30 cm above the lunar surface, a 47 cm^2 piece of the Apollo 12 foil from approximately 45 cm above the lunar surface, and several similar size pieces of blank foils were dissolved in HNO_3, H_2O_2, $HClO_4$, and HF, taken to fumes of $HClO_4$, and cooled. Each sample was then diluted to 350 ml with 0.6 N HCl, and a small amount of ascorbic acid was added. A polished silver disc was suspended for two hours in the solution which was stirred and heated to near boiling. The autoplated ^{210}Po on the disc was analyzed with a 450 mm^2 partially depleted silicon surface barrier diode with an absolute efficiency of 0.313 and a background of less than one count in 10,000 minutes. All foils were handled in the same manner. Those foils exposed on the moon were cleaned prior to analysis by ultrasonic treatment in acetone to remove any lunar dust which might have adhered to them. Since the Apollo 11 foil received less than 7% of the exposure received by the Apollo 12 foil, it also served as an excellent blank for the Apollo 12 measurements.

The mechanism by which the SWC foil collects radon progeny is similar to that by which its design permits the collection of solar wind particles. Radon atoms bounce along the moon in ballistic trajectories since their thermal energy is insufficient to provide escape velocity. As these atoms undergo radioactive decay, relatively large amounts of kinetic energy are imparted to the daughters. Only slightly more than half of these daughters will strike the moon since most of those recoiling away from the moon will escape forever. Those recoils which strike the SWC foil embed themselves and are trapped. Again, almost half of these trapped atoms are lost by the SWC foil due to subsequent alpha decays, but this loss is very nearly compensated by the gain of secondary and tertiary decay products recoiling from the surface of the moon.

Due to the low exposure period of the Apollo 11 foil, no significant activity of ^{210}Po above that in the blank foils was observed. This finding suggests that contamination of the foil during handling or enclosure in the Sample Return Container is not significant. Furthermore, it indicates no significant interference from interstitial radon released from the lunar soil due to the activity of the astronauts in the vicinity of the SWC experiment. From the net ^{210}Po concentration in the Apollo 12 foil an equilibrium lunar ^{222}Rn activity of 0.082 ± 0.012 disintegrations $cm^{-2}sec^{-1}$ is obtained for Oceanus Procellarum. This lunar atmospheric concentration is equivalent to the total radon generated by about 7 cm of lunar soil and would support an equilibrium ^{210}Po surface activity of 0.0238 ± 0.0035 disintegrations $cm^{-2}sec^{-1}$ which agrees with that obtained for Mare Tranquillitatis by Turkevich,(3) but disagrees with his value for Oceanus Procellarum.(5) However, as he has already pointed out, his results for Oceanus Procellarum and the results of Lindstrom(4) for Mare Tranquillitatis are extremely dependent on the topmost surface layer of the samples, and there is no assurance that these surfaces were not removed prior to analysis.

Another experiment, which is similar to that of Yeh and Van Allen,(2) tends to substantiate the above results for the SWC foil. The outer reflective coating of the spacecraft (a silicon monoxide coated, aluminized capton) should also act as a collector of radon daughters escaping from the moon and striking a spacecraft in lunar orbit. Small pieces of this reflective coating were removed from the Apollo 8 and Apollo 12 spacecraft after splashdown and analyzed for ^{210}Po by the above procedure. Unfortunately the orientation of the samples on the spacecraft was not documented. If all portions of the spacecraft received equal exposure to the moon and if the spacecraft were a perfect sphere, any given area of the surface would collect one fourth of the atoms leaving the moon and striking the spacecraft. However, the spacecraft does not meet these requirements, and the exposure of the capton specimens is uncertain. Assuming the idealized geometry and rotation, the measured ^{210}Po activity in the Apollo 8 reflective coating yields a lunar equilibrium ^{222}Rn activity of 0.085 ± 0.037 disintegrations $cm^{-2}sec^{-1}$, and the Apollo 12 coating yields an activity of ≤ 0.61 disintegrations $cm^{-2}sec^{-1}$. Considering the intrinsic uncertainty of this collection device, the agreement is consistent with the result from the SWC foils. Results of lunar surface ^{210}Po measurements are summarized in Table 1.

Any attempt to interpret these data by a discussion of the radon diffusion coefficient or the lunar surface porosity is somewhat presumptuous. Also presumably irrelevant is the comparison of various uranium concentrations such as those observed in the soil at Oceanus Procellarum and Mare Tranquillitatis (1.7 and 0.55 parts per million respectively). Rather, the effects of the lunar vacuum and the widely varying surface temperatures are probably the phenomena most responsible for the distribution of radon on the moon's surface. This is not to suggest that the distribution of radon is a constant, but that its concentration at any given location is probably most effected by the temperature and the time of the lunar day. That is, the proximity of the sampling station to the terminator and its approach or recession will determine the rate of temperature change. With warming, one expects trapped interstitial radon to be released more rapidly as its kinetic energy increases, while during cooling the surface is imagined to have been "baked out" and the effusion of radon will be approaching a minimum.

Although the radon emanation rates from lunar soil into vacuum have been reported at temperatures of 25-35°C,(8) it will be necessary to make the same measurements at temperatures ranging from about -120°C to +120°C before this mechanism can be successfully correlated with measured alpha active deposits on the surface.

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TABLE 1

EQUILIBRIUM ^{210}Po ACTIVITY OF THE LUNAR SURFACE

Investigator (year)	Location(s)	Method or Device	Dis. $cm^{-2}sec^{-1}$
Kraner et al. (1966)	All	Calculation	1.3
Yeh and Van Allen (1969)	All	Orbiting Spectrometer	<0.11
Turkevich et al. (1970)	Mare Tranquillitatis	Surveyor Spectrometer	0.029 ± 0.009
Turkevich et al. (1970)	Sinus Medii and Tycho	Surveyor Spectrometer	<0.021
Lindstrom et al. (1971)	Mare Tranquillitatis	Lunar Fines	<0.00045
Economou and Turkevich (1971)	Oceanus Procellarum	Surveyor Visor	<0.005
This work	Oceanus Procellarum	SWC Foil	0.0238 ± 0.0035
This work	All	Spacecraft Coating	0.025 ± 0.011

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