RADON EMANATION FROM APOLLO 11, 12, AND 14 FINES, A. Yaniv* and D. Heymann, Departments of Geology and Space Science, Rice University, Houston, Texas, 77001. *On leave of absence from Department of Physics and Astronomy, Tel Aviv, University, Ramat Aviv, Israel.

The formation of α-radioactive deposits on the lunar surface involves: 1) the emanation of Rn out of regolith particles, 2) the diffusion of Rn through the void spaces of the regolith into the lunar atmosphere, and 3) the implantation of polonium into the top of the regolith. We report here on the emanation of Rn out of lunar fines. Since our experimental techniques involve a novel approach to Rn measurements we will describe these briefly (Fig. 1). The samples were sealed under vacuum (10^{-2} mm Hg) in a Pyrex container of about 10 cm³ volume. The container was directly connected with the detector, a counting bottle of about 100 cm³ volume, coated on the inside with ZnS. The lightflashes from the counter were detected with a photomultiplier. Temperatures during the experiments ranged from 27–35°C. Radon diffused from the container into the counting bottle, hence we could follow the buildup of Rn^{222} and Rn^{220}, and by closing the stopcock their decay. The background counting rate of the system was monitored extensively before and after each measurement. For long counting periods (one week) we determined background rates of 4.1 ± 0.2 cph; the error represents counting statistics only. However, we observed nonrandom fluctuations during successive 8 hour periods; i.e. drifts in background upward or downward. The smallest measured background rate (8 hr period) was 2.3 ± 0.7 cph; the largest 5.8 ± 1.0 cph. However, since more than 70% of the individual 8 hr background rates fell within 4 ± 1 cph we have adopted this value to subtract it from counting rates obtained from samples.

Apollo 14. The only clear-cut evidence for Rn emanation was obtained with the combined samples 14003 (1.9003 g) and 14259 (1.7579 g). In this case Rn atoms escaped from 3 cm thickness of fines. The activity (counting rate-background) reached a value of 11.6 ± 1.2 cph after one week. When the stopcock was closed the activity decreased more rapidly than one would have expected from Rn^{222} (t_{1/2} = 3.825 days) alone, hence we concluded
that $\text{Rn}^{220}$ ($t_1 = 54.5$ sec) was also present. The analysis of the decay curve in terms of $\text{Rn}^{222}$ and $\text{Rn}^{220}$ and their progeny was not entirely satisfactory, probably because of slight day-to-day variations in the background rates. The total Rn activity just before the closing of the stopcock was $11.2 \pm 1.2$ cph. The activity during the first 8 hours decreased to $(65 \pm 10)$% of the initial value, which corresponds to $\text{Rn}^{222}$ ($\text{Rn}^{222} + \text{Rn}^{220}$) activity ratio = 0.6 before the closing of the stopcock. In the following 16 hours the activity dropped to $(37 \pm 6)$% which corresponds to an initial $\text{Rn}^{222}$ fraction of 0.35. In the final 24 hours the activity dropped to $(20 \pm 5)$%, indicating an initial $\text{Rn}^{222}$ fraction of only 0.25. From this we calculate that the $\text{Rn}^{222}$ equilibrium activity in the counter was at least $3.7 \pm 0.4$ cph, at most $8.9 \pm 0.9$ cph. The corresponding numbers for $\text{Rn}^{220}$ are $4.5 \pm 0.5$ cph and $8.4 \pm 0.9$ cph, but these are obviously minimum values because a substantial portion of $\text{Rn}^{220}$ atoms could have decayed in the sample, or on their way to the counter.

LSPET has reported U contents of about 4 ppm and Th contents of about 13.5 ppm in five Apollo 14 fines, including 14259. The over-all efficiency for counting $\text{Rn}^{222}$ was 71% (this figure includes counter efficiency and counter/(counter + reservoir) volume ratio). Using these numbers we calculate a minimum emanation-to-production ratio (EPR) for $\text{Rn}^{222}$ of about $2 \times 10^{-3}$; a maximum EPR of about $5 \times 10^{-3}$. The corresponding numbers for $\text{Rn}^{220}$ are: $3 \times 10^{-3}$ and $5 \times 10^{-3}$ respectively.

Apollo 11 Two experiments were carried out with 6.7 g of 10084. There was no detectable increase in counting rate. The U content of 10084 is $\sim 0.5$ ppm. Hence the EPR of $\text{Rn}^{222}$ for this sample is $< 1 \times 10^{-3}$, assuming that 1 cph above background could have been detected.

Apollo 12 One experiment was carried out with 0.889 g of 12070. No significant activity was detected above background. The U content of this sample is about 1.6 ppm. From this we calculate a $\text{Rn}^{222}$ ERP of $< 3 \times 10^{-3}$.

Our result for 12070 disagrees with a previous report by Adams, Barretto, Clark, and Duval (Nature, 231 (1971) 174) who have reported an EPR value of about 0.4. Their experiment; however, was carried out in air, ours in a modest vacuum.

The small rate of radon emanation from lunar fines agrees with the observation by Lindstrom, Evans, Finkel, and Arnold (Earth Planet Sci. Lett. 11 (1971) 254) who found that $\text{Pb}^{210}$ in surface samples of lunar soil and rock is in equilibrium with the parent uranium to within 5%. These authors have suggested
that the low rate of emanation could be due to the implantation of recoiling Rn atoms in grain surfaces under the conditions prevailing on the lunar surface (no moisture, low gas pressure). However, an alternative explanation is that much of the U and Th is contained in minerals which are known or suspected to be poor Rn emanators even in the terrestrial environment. The prime candidate among the known minerals is zircon (P. Barretto, private communication). We suspect that the U, Th rich lunar mineral zircolite is another good candidate.

The emanation rate of the Apollo 14 samples means that all the Rn$^{222}$ made available for diffusion in a layer of several meters of regolith down from the surface should escape into the lunar atmosphere in order to account for the a-activity from Rn$^{222}$ and its progeny observed by Turkevich et al (Science 167 (1970) 1722) in Mare Tranquillitatis (also assuming an average U content of the lunar regolith of a few ppm). However, a more realistic estimation of the rate of Rn escape into the atmosphere must await measurements of the emanation rates for a wide range of temperatures and different types of soil.