CONCENTRATIONS OF COSMOGENIC RADIONUCLIDES IN APOLLO 17 SAMPLES: EFFECTS OF THE SOLAR FLARE OF AUGUST, 1972*, G. Davis O'Kelley, James S. Eldridge, and K. J. Northcutt, Oak Ridge National Laboratory, Oak Ridge, TN 37830.

The techniques of nondestructive gamma-ray spectrometry have made it possible to study in some detail the irradiation history of lunar samples by measuring the concentrations of radionuclides produced by solar and galactic cosmic-ray bombardment. Samples from the Apollo 17 mission proved to be of great significance to such irradiation studies because, prior to collection, these samples had been subjected to bombardment by the intense solar flare of 4-9 August 1972, the largest solar cosmic-ray event ever observed. Additionally, the Apollo 17 samples were obtained using the most advanced sampling and documentation procedures of any lunar mission.

Beginning only six days after splashdown, we analyzed 22 samples from Apollo 17 for cosmogenic radionuclide content. Results are given in Table 1. The equipment and methods of nondestructive gamma-ray spectrometry are essentially those we developed for use in other Apollo missions (1,2).

The pattern of radionuclide concentrations in Table 1 is quite distinct from that of any previous mission. The large enhancement of the yields of ^{22}Na, ^{54}Mn, and ^{56}Co is due to the August, 1972 solar flare. The high intensity of the flare made it possible for us to identify ^{7}Be in a lunar sample for the first time: in skim soil 73221 we were able to detect 450±350 dpm/kg of ^{7}Be.

Because chemical analysis data are lacking for most of the samples reported here, detailed interpretations cannot be made in some cases. However, the chemical analyses reported by the Preliminary Examination Team (3) show that the major element compositions of rocks and soils at Taurus-Littrow are similar to those of the Apollo 15 site. Further, the chemical behavior at the various sampling stations appears to be sufficiently regular to permit us to estimate target element concentrations where needed to obtain semi-quantitative interpretations of radionuclide yields.

Samples from previous missions typically showed $^{26}Al/^{22}Na$ ratios $\gtrsim 2$, if the ^{26}Al had achieved its saturation value. The ratio $^{26}Al/^{22}Na$ in most Apollo 17 samples is close to unity, because the solar flare bombardment more than doubled the amount of ^{22}Na present before the flare occurred. Uncertainties in chemical composition make it difficult to identify samples of low exposure with respect to the 0.74 m.y. half-life of ^{26}Al. Some of the samples show evidence either of partial shielding or unfavorable orientation with respect to the solar proton flux. Although complete documentation is lacking for 70185 and rake sample 78597, their low radionuclide content suggests partial shielding from solar protons. Additionally, 70135 and 76295 are boulder chips whose orientations provided partial shielding from the solar flare.

The high yields of ^{46}Sc in the Apollo 17 surface samples arise from the intense solar proton irradiation. Concentrations of ^{46}Sc, corrected for galactic cosmic-ray production in iron, correlate well with estimates and measurements of titanium target element concentrations in these samples. Because over four months elapsed after the August flare before collection of samples at Taurus-Littrow, the 16-day ^{48}V had decayed to about the level expected for bombardment of iron by galactic protons.

Both ^{56}Co and ^{54}Mn are produced by solar proton bombardment of iron. The ^{56}Co concentration in thin surface samples is especially useful as a monitor of total proton flux, since the threshold for the $^{56}Fe(p,n)$ reaction is only about 6 MeV. Information on the rigidity of the flare can be derived from the yields of ^{54}Mn, a product of higher energy proton bombardment, with a threshold of about 25 MeV. Data on 71135 and 71136, chips from a basaltic boulder, skim soil 73221, and trench top 79221 all proved to be useful samples for estimating the proton flux and rigidity of the August 1972 flare. Although some uncertainties exist concerning chemical data for some samples, we estimate the integrated proton flux for the August 1972 flare J(>10 MeV) = 1.9×10^{10} cm^{-2}. This may be compared with a recent compilation by King (4), in which the proton flux integrated for August 4-9 is given as 2.25×10^{10} cm^{-2}. If the proton energy spectrum is expressed as the function $E^{-\alpha}$, the rigidity parameter α is about 1.8. Thus, the August 1972 flare had a much higher average energy than other flares of cycle 20.

Table 1 shows data on two series of trench samples from station 3 and one series from station 9. These all show the expected high concentrations of cosmogenic radionuclides at the surface, decreasing to levels expected for galactic cosmic-ray production at depth.

References and Notes

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COSMOGENIC RADIONUCLIDES IN APOLLO 17 SAMPLES

O'Kelley, G. D. et al.

Table 1. Concentrations (dpm/kg) of Cosmogenic Radionuclides in Apollo 17 Samples. Decay Corrected to 2300 GMT, 14 December 1972.

Sample Number	^{26}Al	^{22}Na	^{54}Mn	^{56}Co	^{46}Sc	^{48}V
			Rocks			
70135	38 ± 2	33 ± 3	56 ± 6	56 ± 6	32 ± 3	10 ± 5
70185	70 ± 4	50 ± 4	95 ± 10	105 ± 10	47 ± 5	
71135	80 ± 6	95 ± 7	140 ± 30	290 ± 50	70 ± 30	
71136	90 ± 8	93 ± 9	160 ± 60	300 ± 70	70 ± 30	
71175	60 ± 3	68 ± 4	125 ± 8	120 ± 30	43 ± 12	
73215	85 ± 5	59 ± 5	36 ± 8	51 ± 20	3 ± 7	
73255	75 ± 4	88 ± 6	86 ± 20	56 ± 20	-	
73275	107 ± 5	99 ± 6	78 ± 12	96 ± 20	8 ± 5	
76295	67 ± 5	54 ± 4	38 ± 15	41 ± 7	5 ± 2	
78597	48 ± 4	33 ± 4	-	80 ± 20	25 ± 10	
79155	70 ± 3	63 ± 3	120 ± 12	153 ± 8	65 ± 3	
			Soils			
73121	189 ± 10	189 ± 10	137 ± 20	218 ± 20	15 ± 5	
73131	54 ± 3	126 ± 5	75 ± 10	119 ± 12	15 ± 3	
73141	62 ± 3	49 ± 5	26 ± 8	20 ± 10	10 ± 5	
73221	197 ± 10	310 ± 15	230 ± 30	810 ± 40	33 ± 6	
73241	92 ± 5	110 ± 5	80 ± 8	95 ± 10	10 ± 3	
73261	57 ± 4	42 ± 4	52 ± 12	5 ± 10	8 ± 5	
73281	46 ± 5	42 ± 9	50 ± 40	-	-	
76501	90 ± 9	90 ± 9	60 ± 10	120 ± 12	18 ± 4	15 ± 10
78501	90 ± 9	105 ± 10	96 ± 10	150 ± 10	30 ± 6	10 ± 8
79221	130 ± 7	165 ± 10	215 ± 20	470 ± 25	65 ± 7	30 ± 20
79261	45 ± 4	43 ± 4	44 ± 6	26 ± 10	15 ± 4	