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QUARTERLY RESEARCH REPORT TO THE NASA MANNED SPACECRAFT CENTER

THE MEASUREMENT OF RADIATION EXPOSURE OF ASTRONAUTS BY RADIOCHEMICAL TECHNIQUES

July 5, 1971 through October 3, 1971

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ABSTRACT

The urine specimens collected pre- and postflight from the Apollo 15 mission were analyzed for their radionuclide content. Cosmic radiation dose estimates of 695 and 660 mR are calculated from the observed ^{22}Na and ^{24}Na concentrations respectively. The concentrations of ^{22}Na, ^{24}Na, ^{40}K, ^{42}K, ^{51}Cr, ^{59}Fe, and ^{137}Cs are given. The potassium excretion patterns of high postflight and low preflight levels established for previous missions appears to be reversed for this mission.

The concentrations of 23 major, minor, and trace elements in the fecal samples from the Apollo 14 astronauts are reported. Most elemental excretion rates are comparable to rates reported for earlier missions. The major exception is potassium where loss rates are the lowest ever observed. This coincides with the anomalously low excretion of potassium in postflight urine specimens. Apparent mass balance of calcium and iron continues as in the Apollo 12 and 13 missions.

Analysis of ^{210}Po in exposed Apollo 11 and 12 solar wind composition experiment foils and in blank foils of the same material yields a net equilibrium activity of $(2.29 \pm 0.34) \cdot 10^{-4}$ d/m/cm^2 of ^{210}Pb in the Apollo 12 foil. This is equivalent to an equilibrium lunar surface activity of $(3.94 \pm 0.58) \cdot 10^{-2}$ d cm^{-2} sec^{-1}.

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 astronaut or by indirect measurement, such as counting that fraction of the radionuclides excreted in the urine and feces. This latter approach was used for evaluation of radiation activation during the course of the Apollo 15 mission. In addition, 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 occasioned 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 volume of urine. All samples were handled according to procedures described earlier [1-3]. A cosmic radiation dose estimate of 695 mR is calculated based on the slightly elevated ^{22}Na concentrations in the urine samples collected during the first 24 hour period following splashdown. This estimate is obtained by comparison to the ^{22}Na concentrations in the urine of radiotherapy patients irradiated with 107 MeV protons[4] after correcting for a reduced ^{22}Na production in tissue[5] at an estimated effective proton energy of 40 MeV[1] incident on the astronauts. A somewhat more precise estimate of the dose will be obtained after analysis of the urine specimens for stable sodium content is completed.

Of the eight manned Apollo series missions, this is the first that sufficient quantities of postflight urine were available for analysis soon enough after splashdown to measure the ^{24}Na concentration in each specimen.

The astronauts were injected with ^{42}K shortly after recovery, and a correction for a small ^{24}Na contamination in this reactor produced tracer had to be applied to the observed ^{24}Na concentrations in the urine. These corrections were of about the same magnitude as the net cosmogenic ^{24}Na concentrations reported in Table I. When these ^{24}Na specific activities are compared to the specific activity of the ^{24}Na in the urine of radiotherapy patients(6), an equivalent instantaneous cosmic radiation dose of 67 mR is estimated for the end of the flight period represented by the residual ^{24}Na saturation activity. Averaging this instantaneous dose equivalent over the entire duration of the Apollo 15 mission yields a total cosmic radiation dose of 660 mR, which compares well with the value obtained above.

The concentrations of the postflight injected ^{42}K and ^{51}Cr excreted in the urine are given in Table I. The data for ^{51}Cr indicate over 76% of the injected quantity is excreted in the first 24 hours. The reported concentrations of ^{59}Fe and ^{137}Cs are within the range of what would normally be expected, though the higher postflight concentrations of ^{59}Fe indicate that this radioisotope may be a contaminant in the ^{51}Cr tracer. The average preflight concentration of ^{40}K (4.97 d/m/ml) is the highest ever observed in astronauts and is considerably higher than the average preflight level of 2.98 d/m/ml. This reflects an unusually high salt concentration in the urine of these astronauts at the time of sampling. The average ^{40}K concentration in the urine the first day after recovery (2.39 d/m/ml) is within the range normally observed at this time but somewhat lower than the 3.74 d/m/ml average, and the measured 2.09 d/m/ml for the second day after recovery is the lowest ever observed in this time period (average value of 3.75 d/m/ml). In effect, the established trend of higher postflight potassium concentrations and lower preflight concentrations in the urine has been reversed for the Apollo 15 mission. The ^{40}K concentration ratio on the first and second day postflight is 1.14 and well confirms the injected ^{42}K concentration ratio of 1.19.

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

This program has been instituted in an attempt to foresee any possible metabolic changes in astronauts caused by conditions of weightlessness and prolonged physical inactivity which are manifested by an uptake or loss of an element or elements by their bodies. The primary concern has been the terrestrially observed phenomenon of osteoporosis (loss of skeletal calcium), although changes in the uptake and excretion rates of other essential micro-constituents of the body, such as cobalt, iron, selenium, and the alkali metals, are also important.

A previously described technique of instrumental neutron activation analysis[1, 2, 6] was used to determine 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, and Ta in the returned Apollo 14 fecal samples. These concentrations are reported in Tables II through V.

Calcium and the Alkali Metals

The functional responsibility and biological importance of calcium and the alkali metals in the body is well known and has been discussed previously[2]. The fecal excretion rates of these elements are calculated from the data in Table III by dividing the total weight of each element by the number of man days of the mission.

The calcium fecal excretion rate of 330 mg/man day for the Apollo 14 mission is similar to that observed for the Apollo 12 and 13 missions[3] and continues to indicate a negligible loss of body calcium for these astronauts.

The sodium fecal excretion rate of 88 mg/man day for the Apollo 14 mission demonstrates freedom from contamination by sodium salt bactericides and apparent normal sodium excretion.

The Apollo 14 potassium fecal excretion rate is 148 mg/man day. This is the lowest ever observed[3, 7] and correlates with the unusually low post-flight urinary excretion of potassium discussed in the first section of this report. If the astronauts are ingesting potassium similar to the intake rates for the first five missions[7], the loss of body potassium is not significant during this mission.

The rubidium fecal excretion rate is 450 μg/man day, and the cesium fecal excretion rate is 1.17 μg/man day. Both values appear to be quite normal.

Elemental Groups IB, IIB, VIA, and VIII

The physiological functions of the metals located in the center of the periodic table have been discussed in an earlier report[2]. While not all of these elements have known uses in the body, some have suspected essential properties and others are known to be toxic. The concentrations of the elements of this group which were measured are given in Table III.

The Apollo 14 mission fecal excretion rates of chromium, iron, cobalt, silver, gold, zinc, and mercury are 45.3, 6180, 5.72, 20.3, 5.56, 5600, and 16.8 μg/man day respectively. These values all correspond well with the rates from the Apollo 12 and 13 missions[3], and the same conclusions drawn earlier are applicable. The gold concentrations in Table III vary by two orders of magnitude and identify samples #1 and #3 as from the same astronaut, samples #2 and #4 from a second astronaut, and sample #5 from the third astronaut.

Elemental Groups IVB, VB, VIB, and VIIB

The body chemistry and/or toxic properties of these elements from the right side of the periodic chart have also been discussed elsewhere[2]. The concentrations and total weights of the measured elements in this category are given in Table IV.

The Apollo 14 fecal excretion rates of tin, arsenic, antimony, selenium, and bromine are 2240, 13.2, 7.57, 16.7, and 29.3 μg/man day respectively. Of these, only bromine differs significantly from previously observed or expected values[2, 3, 8]. However, urinary excretion is the primary pathway for this element, and normal fecal excretion percentages are not known.

The Lanthanides, Actinides, and Groups IIIA, IVA, and VA

While the metabolic functions of these elements are not yet known, the data are reported in the hopes that they may be useful for tracing or predicting metabolic reactions or anomalies, for identification or allocation of unknown specimens, or for elucidation of biological reactions to the space environment. From the data in Table V fecal excretion rates of 30.7, <140, 306, 358, 624, and 374 ng/man day are calculated for europium, terbium, thorium, scandium, hafnium, and tantalum respectively. These values appear to be compatible with the rates from previous missions.

TASK - SEARCH FOR LUNAR ATMOSPHERE

The radon atoms present in the lunar atmosphere from the decay of surface radium embed themselves in exposed apparatus due to the kinetic energy or the decay recoil energy of the atoms. After several relatively rapid radioactive decays radon atoms are transformed into long-lived ^{210}Pb ($t_{1/2}$ = 22y). By measuring the concentration of ^{210}Po (Granddaughter of ^{210}Pb) in the returned solar wind composition experiment foils, and by making certain assumptions regarding the fraction of the radon atoms recoiled out of the foils (and initially captured by them), the radon concentration in the lunar atmosphere can be characterized. By making further assumptions regarding the lunar surface porosity and the radon diffusion coefficient, the uranium concentration in the lunar soil can also be calculated.

Pieces of the Apollo 11 and 12 SWC foils as well as several blank foils have been analyzed for ^{210}Po according to a procedure described elsewhere[6, 9]. The net equilibrium activity of ^{210}Pb in the Apollo 12 foil attributable to exposure of the foil on the lunar surface is $(2.29 \pm 0.34)\cdot 10^{-4}$ d/m/cm^2. This is equivalent to an equilibrium lunar surface activity of $(3.94 \pm 0.58)\cdot 10^{-2}$ d cm^{-2}sec^{-1}.

It is planned to publish these results in the open literature.

EXPENDITURES

The following table documents the expenditures according to task and total cost incurred from July 5, 1971 through October 3, 1971 for the work reported herein.

Task		Expenditures
Determination of the Radionuclide Content of Feces and Urine From Astronauts Engaged in Space Flight		$ 3,131
Neutron Activation Analysis of Feces and Urine From Astronauts Engaged in Space Flight		$ 3,015
Search For Lunar Atmosphere		$ 696
	Total Costs	$ 6,842

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TABLE I

RADIOACTIVITY IN URINE FROM APOLLO 15 ASTRONAUTS

Astronaut	Flight Period	dis/min/ml on 8/7/71 at 1345 PDT						
		^{22}Na	^{24}Na	^{40}K	^{42}K	^{51}Cr	^{59}Fe	^{137}Cs
CDR	F-27	0.00076 ± 0.00060		3.939 ± 0.060			0.1061 ± 0.0088	0.1248 ± 0.0076
CMP	F-28			4.500 ± 0.067		0.462 ± 0.078	0.039 ± 0.014	0.0374 ± 0.0059
LMP	F-27	0.00077 ± 0.00061		6.484 ± 0.058			0.0870 ± 0.0084	0.0921 ± 0.0071
CDR	R+0	0.0014 ± 0.0013	0.188 ± 0.033	2.080 ± 0.058	1381 ± 7	4473 ± 10	0.354 ± 0.017	0.3254 ± 0.0074
CMP	R+0	0.00178 ± 0.00094	0.775 ± 0.070	3.297 ± 0.084	1366 ± 7	2821 ± 10	0.425 ± 0.013	0.308 ± 0.011
LMP	R+0	0.00128 ± 0.00073	0.614 ± 0.058	1.786 ± 0.057	1318 ± 6	2090 ± 7	0.513 ± 0.014	0.4049 ± 0.0094
CDR	R+1		0.69 ± 0.11	1.836 ± 0.047	803.7±5.7	631.9 ± 3.6	0.2757 ± 0.0089	0.1538 ± 0.0050
CMP	R+1		0.659 ± 0.089	2.771 ± 0.059	1281 ± 7	714.5 ± 4.1	0.427 ± 0.013	0.1749 ± 0.0065
LMP	R+1		0.564 ± 0.069	1.665 ± 0.061	1329 ± 7	879.9 ± 5.2	0.205 ± 0.017	0.1010 ± 0.0064

TABLE II

Ca, Na, K, Rb, and Cs CONCENTRATIONS IN APOLLO 14 ASTRONAUT FECAL SAMPLES

	Ca		Na		K		Rb		Cs	
Sample	ppm*	g**	ppm*	mg**	ppm*	g**	ppm*	mg**	ppm*	μg**
#1	8,960	1.47	4240	695	5640	0.924	12.3	2.01	0.0382	6.27
#2	19,000	2.25	1300	156	1380	0.165	14.8	1.77	0.0332	3.96
#3	4,100	1.06	3000	772	4670	1.20	13.3	3.42	0.0243	6.25
#4	13,600	2.23	2420	398	4190	0.690	9.85	1.62	0.0313	5.14
#5	4,980	1.89	935	355	2650	1.01	8.78	3.34	0.0263	9.98

* Wet weight basis

** Total weight per defecation

TABLE III

Cr, Fe, Co, Ag, Au, Zn, and Hg CONCENTRATIONS IN APOLLO 14 ASTRONAUT FECAL SAMPLES

	Cr		Fe		Co		Ag		Au		Zn		Hg	
Sample	ppm*	μg**	ppm*	mg**	ppm*	μg**	ppm*	μg**	ppm*	μg**	ppm*	mg**	ppm*	μg**
#1	1.14	187	194	31.8	0.179	29.4	0.264	43.4	0.385	63.1	192	31.5	0.580	95.2
#2	1.08	129	250	29.8	0.124	14.8	0.395	47.1	0.0518	6.18	220	26	0.921	110
#3	0.502	129	111	28.5	0.0904	23.3	1.40	362	0.263	67.8	116	29.9	0.261	67.3
#4	3.44	567	197	32.4	0.272	44.8	0.502	82.6	0.0732	12.0	160	26	0.953	157
#5	0.552	210	117	44.3	0.111	42.2	0.0317	12.1	0.00273	1.04	102	38.9	0.0666	25.3

* Wet weight basis

** Total weight per defecation

TABLE IV

Sn, As, Sb, Se, and Br CONCENTRATIONS IN APOLLO 14 ASTRONAUT FECAL SAMPLES

	Sn		As		Sb		Se		Br	
Sample	ppm*	mg**	ppm*	μg**	ppm*	μg**	ppm*	μg**	ppm*	μg**
#1	38.5	6.31	0.491	80.5	0.271	44.4	0.444	72.8	1.00	164
#2	289	34.5	0.204	24.3	0.101	12.1	0.807	96.2	0.827	98.6
#3	30.2	7.78	0.316	81.5	0.0802	20.7	0.284	73.0	0.779	201
#4	23.9	3.93	0.547	90.0	0.454	74.7	0.566	93.1	0.753	124
#5	20.8	7.90	0.212	80.6	0.138	52.4	0.305	116	0.538	204

* Wet weight basis

** Total weight per defecation

TABLE V

Eu, Tb, Th, Sc, Hf, and Ta CONCENTRATIONS IN APOLLO 14 ASTRONAUT FECAL SAMPLES

Sample	Eu		Tb		Th		Sc		Hf		Ta	
	ppm*	ng**	ppm*	ng**	ppm*	μg**	ppm*	μg**	ppm*	μg**	ppm*	μg**
#1	0.000910	149	<0.0019	< 310	0.00935	1.53	0.0129	2.12	0.0208	3.42	0.0210	3.44
#2	0.000729	87.0	<0.0037	< 440	0.00684	0.815	0.00807	0.962	0.0156	1.86	0.00586	0.699
#3	0.000514	132	<0.0038	< 980	0.00439	1.13	0.00286	0.736	0.00734	1.89	0.00261	0.673
#4	0.00120	197	<0.0058	< 960	0.0132	2.18	0.0162	2.67	0.0288	4.74	0.0211	3.47
#5	0.000695	264	<0.0031	<1200	0.00689	2.62	0.00836	3.18	0.0130	4.94	0.00477	1.81

* Wet weight basis

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