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QUARTERLY RESEARCH REPORT TO THE NASA MANNED SPACECRAFT CENTER

THE MEASUREMENT OF RADIATION EXPOSURE OF ASTRONAUTS BY RADIOCHEMICAL TECHNIQUES

April 2, 1973 through June 30, 1973

by

R. L. Brodzinski

July 15, 1973

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ABSTRACT

A cosmic radiation dose to the Apollo 17 crew of <1.3 R was calculated from the specific activities of ^{24}Na in their postflight urine specimens. The specific activities of ^{42}K, ^{51}Cr, ^{60}Co, and ^{124}Sb, introduced by injection into the astronauts, are extremely high in these specimens. The ^{59}Fe and ^{137}Cs levels are also reported and appear to be normal.

The concentrations of Na, K, Rb, Cs, Ca, Sr, Ba, Cr, Fe, Co, Ag, Au, Zn, Cd, Hg, Sn, As, Sb, Se, Br, Sc, La, Sm, Eu, Tb, Hf, Ta, and Th were measured in urine specimens from the Apollo 17 astronauts by neutron activation analysis. Strontium, barium, gold, cadmium, lanthanum, samarium, europium, terbium, thorium, and tin are reported for the first time. The concentrations or excretion rates of bromine and the alkali metals exhibit significantly reduced postflight levels and are generally lower than values observed for previous missions. Chromium concentrations reflect radiochromium injections. High levels of arsenic are present in the postflight specimens. No urinary loss of body calcium is evident. Excretion of iron and scandium is similar

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to earlier missions. Antimony, silver, hafnium, and tantalum elimination rates are lower than previously encountered, and cobalt, zinc, and iron levels are lower than normally anticipated.

THE MEASUREMENT OF RADIATION EXPOSURE OF ASTRONAUTS BY RADIOCHEMICAL TECHNIQUES

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 these induced activities 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 feces and urine. The latter approach has been used on all manned Apollo missions. In addition to the induced activities, several fallout, injected, and naturally occurring radioisotopes have been measured; variations in their concentrations may be indicative of changes in the biological life processes encountered in the space environment.

The concentrations of the radioisotopes listed in Table I have been normalized by dividing each decay-corrected disintegration rate by the weight of the respective stable element. All samples were handled according to procedures described earlier.[1] A cosmic radiation dose to the Apollo 17 crew of <1.3 R was calculated by comparing the postflight ^{24}Na concentrations in their urine to those in the urine of radiotherapy patients.[2] Since ^{24}Na is short-lived compared to the duration of the mission, this

TABLE I

RADIOACTIVITY IN URINE FROM APOLLO 17 ASTRONAUTS

Astronaut	Flight Period	dis/min ^{24}Na per g Na	dis/min ^{42}K per g K	dis/min ^{51}Cr per g Cr	dis/min ^{59}Fe per g Fe	dis/min ^{60}Co per g Co	dis/min ^{124}Sb per g Sb	dis/min ^{137}Cs per g Cs
CDR	F-30						$(3.57 \cdot 0.27) \cdot 10^{8}$	$(1.76 \cdot 0.28) \cdot 10^{7}$
CMP	F-30			$\cdot 9.9 \cdot 10^{7}$		$(1.9 \cdot 0.7) \cdot 10^{7}$	$(4.2 \cdot 0.9) \cdot 10^{7}$	$(3.22 \cdot 0.36) \cdot 10^{7}$
LMP	F-30			$(1.66 \cdot 0.03) \cdot 10^{9}$	$\cdot 2.1 \cdot 10^{6}$			$(1.78 \cdot 0.23) \cdot 10^{7}$
CDR	F-15			$(5.07 \cdot 0.03) \cdot 10^{10}$			$(4.7 \cdot 1.0) \cdot 10^{7}$	$(2.8 \cdot 1.9) \cdot 10^{6}$
CMP	F-15			$(9.69 \cdot 0.01) \cdot 10^{10}$				$(1.28 \cdot 0.58) \cdot 10^{7}$
LMP	F-15			$(8.39 \cdot 0.15) \cdot 10^{10}$	$\cdot 3.6 \cdot 10^{5}$		$(2.4 \pm 1.3) \cdot 10^{7}$	$(1.65 \cdot 0.22) \cdot 10^{7}$
CDR	F-5			$> 6.0 \cdot 10^{10}$				$(2.88 \cdot 0.96) \cdot 10^{7}$
CMP	F-5			$(1.296 \pm 0.004) \cdot 10^{10}$	$> 3.0 \cdot 10^{6}$	$(1.1 \pm 0.4) \cdot 10^{7}$		$(4.01 \cdot 0.56) \cdot 10^{7}$
LMP	F-5			$\cdot 3.4 \cdot 10^{10}$			$(3.9 \pm 1.7) \cdot 10^{7}$	$(1.15 \pm 0.24) \cdot 10^{7}$
CDR	R+0	<680	$(2.34 \cdot 0.01) \cdot 10^{6}$	$(1.480 \cdot 0.004) \cdot 10^{11}$		$(4.67 \pm 0.1\ ) \cdot 10^{8}$	$(1.62 \cdot 0.14) \cdot 10^{8}$	$(1.87 \pm 0.28) \cdot 10^{7}$
CMP	R+0	<1000	$(2.49 \pm 0.02) \cdot 10^{6}$	$(6.00 \pm 0.03) \cdot 10^{10}$		$(5.8 \pm 0.18) \cdot 10^{8}$	$(1.5 \pm 0.3) \cdot 10^{8}$	$(1.19 \pm 0.52) \cdot 10^{7}$
LMP	R+0	<880	$> 4.2 \cdot 10^{6}$	$(9.91 \pm 0.03) \cdot 10^{10}$		$2.26 \pm 0.04) \cdot 10^{9}$	$(3.96 \cdot 0.31) \cdot 10^{8}$	$(2.39 \pm 0.28) \cdot 10^{7}$

calculation assumes a constant radiation exposure throughout the mission. This value is somewhat more reliable than reported earlier[3] due to the more accurate normalization methods used here. However, due to the probability of postflight injection of uncertain amounts of ^{24}Na, only an upper limit for the radiation dose can be calculated by this technique.

The specific activities given for ^{42}K again reflect the postflight injection of this radiotracer; those of ^{51}Cr show injection of this isotope between F-30 and F-15, as well as postflight. The contamination of the radiochromium tracer with ^{60}Co and ^{124}Sb is also demonstrated by these data. Particular attention is called to the unprecedented high levels of postflight ^{60}Co. The specific activities reported for ^{59}Fe and ^{137}Cs appear normal and are similar to values obtained for earlier missions.

Neutron Activation Analysis of Feces and Urine from Astronauts Engaged in Space Flight

This program was initiated in an attempt to foresee any possible metabolic changes in astronauts caused by conditions of weightlessness and prolonged physical inactivity which might 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 Co, Fe, Se, and the alkali metals, were also important.

The concentrations of Na, K, Rb, Cs, Ca, Sr, Ba, Cr, Fe, Co, Ag, Au, Zn, Cd, Hg, Sn, As, Sb, Se, Br, Sc, La, Sm, Eu, Tb, Hf, Ta, and Th have been measured in the preflight and postflight urine specimens from the Apollo 17 astronauts by the previously described technique of neutron activation analysis.[1,4,5] These results and the corresponding daily excretion rates are reported in Tables II through VIII.

The urinary concentrations of Sr, Ba, Au, Cd, La, Sm, Eu, Tb, and Th have not been measured previously; the significance of the data is not immediately apparent. The concentrations and excretion rates of Sn are also reported for the first time; these data reflect normally expected excretion patterns[6] as do the data for Hg and Se.

As in earlier missions[7] reduced postflight excretion of the alkali metals and bromine is demonstrated. The Na

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TABLE II

Na, K, Rb, and Cs CONCENTRATIONS IN URINE SAMPLES FROM APOLLO 17 ASTRONAUTS

Astronaut	Flight Period	Na		K		Rb		Cs	
		mg/ml	g/day	mg/ml	g/day	µg/ml	mg/day	ng/ml	µg/day
CDR	F-30	1.88	2.82	<1.4	<2.1	0.782	1.17	2.59	3.89
CMP	F-30	1.40	2.79	<1.3	<2.6	0.856	1.70	2.25	4.48
LMP	F-30	1.90	3.28	<1.7	<3.0	1.13	1.95	2.96	5.11
CDR	F-15	1.86	1.95	<1.5	<1.6	1.82	1.88	5.10	5.28
CMP	F-15	1.12	3.14	<1.2	<3.3	0.762	2.13	2.30	6.44
LMP	F-15	1.38	2.69	<1.4	<2.8	1.23	2.40	3.76	7.33
CDR	F-5	1.06	0.413	<1.1	<0.43	1.09	0.425	3.31	1.29
CMP	F-5	0.320	0.650	0.774	1.57	0.792	1.61	1.68	3.41
LMP	F-5	1.03	1.50	<1.1	<1.6	1.64	2.39	3.50	5.09
CDR	R+0	0.292	0.457	0.500	0.783	0.589	0.922	2.26	3.54
CMP	R+0	0.280	0.911	0.356	1.16	0.429	1.40	1.54	5.01
LMP	R+0	0.928	0.627	<1.1	<0.72	1.60	1.08	4.84	3.27

TABLE III

Ca, Sr, AND Ba CONCENTRATIONS IN URINE SAMPLES FROM APOLLO 17 ASTRONAUTS

Astronaut	Flight Period	Ca		Sr		Ba	
		µg/ml	mg/day	ng/ml	µg/day	ng/ml	mg/day
CDR	F-30	<78	<120	<55	<83	<110	<0.16
CMP	F-30	<72	<140	<68	<130	<470	<0.94
LMP	F-30	<84	<140	<44	<75	<780	<1.3
CDR	F-15	<81	<83	<68	<71	<130	<0.13
CMP	F-15	<66	<180	<42	<120	<260	<0.73
LMP	F-15	<72	<140	<43	<84	<610	<1.2
CDR	F-5	<60	<23	<65	<25	<110	<0.044
CMP	F-5	<110	<220	<37	<75	<210	<0.43
LMP	F-5	<55	<81	<60	<87	<130	<0.19
CDR	R+0	<93	<150	<47	<74	<77	<0.12
CMP	R+0	<110	<340	<33	<110	<180	<0.59
LMP	R+0	<55	<37	<73	<49	<150	<0.10

TABLE IV

Cr, Fe, AND Co CONCENTRATIONS IN URINE SAMPLES FROM APOLLO 17 ASTRONAUTS

Astronaut	Flight Period	Cr		Fe		Co	
		ng/ml	µg/day	ng/ml	µg/day	pg/ml	ng/day
CDR	F-30	<3.2	<4.8	<29	<44	207	311
CMP	F-30	<3.6	<7.2	<54	<110	149	297
LMP	F-30	4.81	8.30	<36	<62	184	317
CDR	F-15	28.4	29.4	<30	<31	271	280
CMP	F-15	8.81	24.7	<30	<83	146	409
LMP	F-15	16.3	31.8	<39	<76	170	332
CDR	F-5	<2.7	<1.0	134	52.3	310	121
CMP	F-5	6.68	13.6	<31	<64	310	629
LMP	F-5	<2.5	<3.7	<28	<41	246	358
CDR	R+0	15.3	23.9	90.2	141	153	239
CMP	R+0	20.4	66.4	<26	<83	212	690
LMP	R+0	59.3	40.1	<32	<21	300	203

TABLE V

Ag, Au, Zn, Cd, AND Hg CONCENTRATIONS IN URINE SAMPLES FROM APOLLO 17 ASTRONAUTS

Astronaut	Flight Period	Ag		Au		Zn		Cd		Hg	
		pg/ml	ng/day	ng/ml	µg/day	ng/ml	µg/day	ng/ml	µg/day	pg/ml	µg/day
CDR	F-30	<16	<24	<1.1	<1.7	339	509	<100	<160	<690	<1.0
CMP	F-30	<49	<97	<1.0	<2.0	293	583	<96	<190	<820	<1.6
LMP	F-30	<45	<77	<1.2	<2.1	500	863	<120	<200	<500	<0.85
CDR	F-15	<48	<50	<1.2	<1.3	467	483	<120	<120	<840	<0.87
CMP	F-15	<57	<160	<0.96	<2.7	339	949	<91	<250	<490	<1.4
LMP	F-15	30.6	59.7	<1.1	<2.1	362	706	<110	<220	<510	<1.0
CDR	F-5	<200	<78	<0.98	<0.38	288	112	<96	<38	<810	<0.32
CMP	F-5	<36	<73	<0.82	<1.7	291	591	<64	<130	<420	<0.85
LMP	F-5	<54	<79	<0.92	<1.3	646	940	<91	<130	<730	<1.1
CDR	R+0	<80	<120	<0.71	<1.1	382	598	<56	<88	<590	<0.93
CMP	R+0	<67	<220	<0.75	<2.4	270	878	<59	<190	<410	<1.3
LMP	R+0	<62	<42	<1.0	<0.69	978	661	<100	<70	<910	<0.62

TABLE VI

Sr, As, Sb, Se, AND Br CONCENTRATIONS IN URINE SAMPLES FROM APOLLO 17 ASTRONAUTS

Astronaut	Flight Period	Sn		As		Sb		Se		Br	
		ng/ml	µg/day	ng/ml	µg/day	pg/ml	ng/day	ng/ml	µg/day	µg/ml	mg/day
CDR	F-30	<79	<120	<29	<43	148	222	23.8	35.7	1.88	2.82
CMP	F-30	<74	<150	<28	<56	310	617	16.0	31.8	2.11	4.20
LMP	F-30	<38	<65	<34	<59	184	317	19.3	33.3	2.06	3.55
CDR	F-15	<97	<100	<32	<33	354	366	37.7	39.0	2.32	2.40
CMP	F-15	<45	<120	<25	<69	119	333	15.2	42.6	1.44	4.03
LMP	F-15	<42	<81	<28	<55	172	335	12.6	24.6	1.82	3.55
CDR	F-5	<94	<37	<23	<9.0	243	94.8	29.6	11.5	0.928	0.362
CMP	F-5	<40	<81	<8.1	<16	196	398	8.98	18.2	0.678	1.38
LMP	F-5	<83	<120	<23	<33	136	198	26.4	38.4	0.954	1.39
CDR	R+0	<70	<110	231	362	284	444	15.8	24.7	0.187	0.293
CMP	R+0	<39	<130	59.5	194	143	465	9.56	31.1	0.220	0.716
LMP	R+0	<100	<70	728	492	320	216	32.4	21.9	0.903	0.610

TABLE VII

Sc, La, Sm, Eu, AND Tb CONCENTRATIONS IN URINE SAMPLES FROM APOLLO 17 ASTRONAUTS

Astronaut	Flight Period	Sc		La		Sm		Eu		Tb	
		pg/ml	ng/day	ng/ml	µg/day	ng/ml	µg/day	pg/ml	ng/day	pg/ml	ng/day
CDR	F-30	<5.5	<8.3	<4.3	<6.5	<0.80	<1.2	<6.9	<10	<110	<160
CMP	F-30	<2.9	<5.8	<4.1	<8.2	<0.71	<1.4	<8.1	<16	<110	<210
LMP	F-30	<5.1	<8.8	<5.0	<8.6	<0.95	<1.6	<5.3	< 9.2	<56	< 97
CDR	F-15	<6.9	<7.2	<4.5	<4.7	<0.91	<0.94	<8.8	<9.1	<130	<130
CMP	F-15	<4.4	<12	<3.7	<10	<0.75	<2.1	<5.9	<16	<64	<180
LMP	F-15	<5.1	<9.9	<4.3	<8.3	<0.82	<1.6	<6.2	<12	<61	<120
CDR	F-5	<6.3	<2.4	<3.4	<1.3	<0.89	<0.35	<7.2	<2.8	<130	<49
CMP	F-5	<4.0	<8.2	<3.0	<6.1	<0.28	<0.58	<5.9	<12	<57	<120
LMP	F-5	<6.8	<9.9	<3.1	<4.6	<0.85	<1.2	<7.6	<11	<110	<160
CDR	R+0	<5.3	<8.3	<2.6	<4.0	<0.28	<0.43	<7.1	<11	<92	<140
CMP	R+0	<4.1	<13	<2.9	<9.5	<0.27	<0.87	<5.5	<18	<55	<180
LMP	R+0	<5.3	<3.6	<2.9	<2.0	<1.0	<0.69	<7.6	<5.1	<140	<94

TABLE VIII

Hf, Ta, AND Th CONCENTRATIONS IN
URINE SAMPLES FROM APOLLO 17 ASTRONAUTS

Astronaut	Flight Period	Hf		Ta		Th	
		pg/ml	ng/day	pg/ml	ng/day	pg/ml	ng/day
CDR	F-30	<140	<210	<86	<130	<230	<350
CMP	F-30	<180	<350	<100	<200	<360	<720
LMP	F-30	<120	<200	<64	<110	<270	<470
CDR	F-15	<170	<180	<86	<89	<280	<290
CMP	F-15	<110	<300	<55	<150	<210	<600
LMP	F-15	<120	<240	<62	<120	<260	<510
CDR	F-5	<160	<64	<81	<32	<270	<100
CMP	F-5	<97	<200	<54	<110	<180	<370
LMP	F-5	<150	<220	<70	<100	<250	<370
CDR	R+0	<120	<190	<63	<99	<190	<300
CMP	R+0	<91	<290	<57	<190	<170	<560
LMP	R+0	<190	<130	<85	<57	<310	<210

concentrations and the bromine elimination rates exhibit a decline for the period from thirty days prior to the mission to immediately after the mission. The Na and Cs concentrations are uniformly lowest for the CMP, while the Br excretion rates are uniformly lowest for the CDR. The elimination of Na, K, Rb, Cs, and Br is generally lower than observed for previous missions[4,7-9] and is significantly lower than normal,[6] particularly in the F-5 and R+0 specimens.

The opposite effect is observed in the urinary excretion rates and concentrations of Cr and As. The elimination of chromium vacillates from low values on F-30 and F-5 to high values on F-15 and R+0 and is generally higher than previously observed values. These peak excretion periods reflect the injection of radiochromium tracers into the astronauts. The daily excretion rates of arsenic are extraordinarily high in the postflight specimens, but it is uncertain whether the presence of this element is from assimilation during the mission or from contamination present in the injections.

No loss of body calcium via urinary excretion is evident from these data. In fact, the CDR F-5 and LMP R+0 specimens exhibit the lowest excretion rates of calcium ever observed and are well below normally expected rates.[6]

The iron and scandium concentrations and excretion rates are similar to those observed for previous missions· those of iron remain below normal values.[6] The rates of Co and Zn, however, are generally lower than values reported for previous

missions, as well as being lower than normal.[6] The concentrations and excretion rates of Sb, Ag, Hf, and Ta show a similar decline from levels of earlier missions.

In summary, the well-characterized reduction in postflight excretion of bromine and the alkali metals is demonstrated, chromium excretion reflects the injection of radiochromium tracers, arsenic is at extraordinarly high levels in the postflight specimens, and no significant loss of any essential element has been determined for the Apollo 17 astronauts through urinary elimination.

EXPENDITURES

Table IX lists the expenditures according to the task and the total cost incurred from April 2, 1973 through June 30, 1973.

Table IX

EXPENDITURES

Task	Expenditures
Determination of the Radionuclide Content of Feces and Urine from Astronauts Engaged in Space Flight	$ 704
Neutron Activation Analysis of Feces and Urine from Astronauts Engaged in Space Flight	2,883
TOTAL COSTS	$ 3,587

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