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QUARTERLY RESEARCH REPORT TO THE NASA MANNED SPACECRAFT CENTER

THE MEASUREMENT OF RADIATION EXPOSURE OF ASTRONAUTS BY RADIOCHEMICAL TECHNIQUES

OCTOBER 2, 1972 THROUGH DECEMBER 31, 1972

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ABSTRACT

A cosmic radiation dose to the Apollo 16 crew of 180 ± 100 mR was calculated from the specific activities of ^{22}Na and ^{24}Na in pre and postflight urine specimens. The specific activities of ^{51}Cr and ^{60}Co are higher in postflight specimens than in preflight specimens, presumably due to a postflight injection of radiochromium. The ^{59}Fe and ^{137}Cs specific activities are also reported and appear to be normal.

The radiation doses received by a pilot and a navigator flying a high altitude mission during the solar flare of August 4-9, 1972 were calculated from the specific activity of ^{24}Na in their urine. These values are compared with the expected radiation dose calculated from the known shape and intensity of the proton spectrum. They demonstrate the magnitude of atmospheric shielding.

The concentrations of Ca, Na, Rb, Cs, Cr, Fe, Co, Ag, Zn, Hg, As, Sb, Se, Br, Sc, Hf, and Ta were measured in urine specimens from the Apollo 16 astronauts by neutron activation analysis. Scandium, hafnium, and tantalum concentrations are reported for

the first time. The concentrations and excretion rates of Ca, Zn, As, and Se are normal. Sodium, rubidium, cesium, and bromine exhibit significantly reduced postflight excretion rates, whereas chromium and silver are generally higher in these samples. The concentrations and excretion rates of Fe and Co are the lowest ever observed; those of Hg and Sb are lower than the high values measured after the Apollo 14 and 15 missions.

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 their 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. 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; 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 in the sample. All samples were handled according to procedures described earlier.[1] A cosmic radiation dose to the Apollo 16 crew of 180 $\pm$ 100 mR was calculated by comparing the radiosodium concentrations in their urine to those in the urine of radiotherapy patients.[2] This value is slightly lower than that previously reported[3] which was based on radiosodium activities normalized to the volume of urine rather

TABLE I

RADIOACTIVITY IN URINE FROM APOLLO 16 ASTRONAUTS

Astronaut	Flight Period	dis/min ^{22}Na per g Na	dis/min ^{24}Na per g Na	dis/min ^{51}Cr per g Cr	dis/min ^{59}Fe per g Fe	dis/min ^{60}Co per g Co	dis/min ^{137}Cs per g Cs
CDR	F-30			$>2.5\cdot10^{8}$			
CMP	F-30					$(6\pm4)\cdot10^{6}$	$(1.75\pm0.24)\cdot10^{7}$
LMP	F-30						$(9.9\pm1.8)\cdot10^{7}$
CDR	F-15	1.0 ± 0.6		$>7.6\cdot10^{8}$			
CMP	F-15						
LMP	F-15	1.0 ± 0.9					
CDR	F-5	1.8 ± 0.7					
CMP	F-5				$(1.53\pm0.46)\cdot10^{6}$		$(7.0\pm1.2)\cdot10^{6}$
LMP	F-5			$(6.33\pm0.64\cdot10^{9}$			$(1.10\pm0.30)\cdot10^{6}$
CDR	R+0	2.6 ± 1.3		$(3.91\pm0.39)\cdot10^{11}$			$(2.78\pm0.32)\cdot10^{7}$
CMP	R+0	4.1 ± 1.2	≤6400	$(4.67\pm0.47)\cdot10^{11}$		$(2.6\pm0.5)\cdot10^{7}$	$(2.18\pm0.22)\cdot10^{8}$
LMP	R+0		≤2700	$(3.82\pm0.38)\cdot10^{11}$	$>1.1\cdot10^{6}$	$(5.7\pm1.1)\cdot10^{7}$	$(4.00\pm0.41)\cdot10^{7}$
CDR	R+1	2.3 ± 1.1					
LMP	R+1	1.3 ± 1.0		$>1.1\cdot10^{11}$			$(1.08\pm0.22)\cdot10^{7}$

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rather than the more accurate normalization used here.

The high specific activities of ^{51}Cr observed in the postflight specimens reflect the injection of relatively large amounts of this radioisotope shortly after recovery. The unusually high ^{60}Co specific activities observed in two of the postflight specimens are assumed to arise from contamination present in the radiochromium tracer. The ^{59}Fe and ^{137}Cs activities are normal and within the range of values reported for previous missions.

The pre and postflight urine specimens from the Apollo 17 astronauts are presently being analyzed for their radionuclide content; the results will be presented in a later report.

During the period of August 4-9, 1972, an exceptionally intense solar flare took place. The proton flux incident on the earth from this event was monitored by orbiting satellites in three energy intervals (10-30 MeV, 30-60 MeV, and > 60 MeV). The weighted average energies of these intervals are 13.4, 37.8, and 85 MeV, respectively. The urine from the pilot and the navigator on a high altitude air sampling mission flown during this flare by the United States Air Force was collected and analyzed shortly after touchdown for its ^{24}Na content. Almost all of the solar protons were attenuated in the atmosphere above the aircraft. However, secondary neutrons generated in the air delivered a radiation dose to this pilot and navigator similar to the radiation dose received by the astronauts from secondary neutrons generated in the hull of their spacecraft. Although the peak intensity of the flare was more than 100 times higher than at the time of the air sampling flight, the particle

flux was still high enough to deliver a primary particle radiation dose of 35.49 gm rad cm^{-2} above the atmosphere. A 70 kg man exposed to this solar excursion without the benefit of atmospheric or aircraft shielding would have sustained a radiation dose of 1.55 rad.

From the specific activities of ^{24}Na in the urine of the pilot and the navigator, < 0.76 d/m/g Na and 5.23 $\pm$ 0.99 d/m/g Na, radiation doses of < 0.12 mR and 0.86 $\pm$ 0.16 mR, respectively, were calculated in comparison to specific activities of ^{24}Na in the urine of neutron-irradiated radiotherapy patients.[2] The total effective atmospheric shielding was greater than 100 g cm^{-2}, and the radiation dose reduction was greater than 1800-fold. This was expected for such a large shielding value and agrees with similar findings from an earlier solar flare.[3] Astronauts in space, however, have only their spacecraft to shield them from solar particles, and they would have received radiation doses several orders of magnitude higher than this pilot and navigator had they been in space during this solar flare.

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 Ca, Na, Rb, Cs, Cr, Fe, Co, Ag, Zn, Hg, As, Sb, Se, Br, Sc, Hf, and Ta have been measured in the pre and postflight urine specimens from the Apollo 16 astronauts by the previously described technique of instrumental neutron activation analysis[1,4,5]. The results are reported in Tables II through V.

The urinary concentrations and daily excretion rates of Sc, Hf, and Ta have not been measured previously, and the significance of the data is not immediately apparent. The urinary concentrations and excretion rates of Ca, Zn, As, and Se are all normal and indicate no loss or uptake of these elements by the astronauts.

Sodium, rubidium, cesium, and bromine exhibit significantly reduced excretion rates in postflight samples when compared to preflight specimens. Sodium, for example, demonstrates the lowest rate in the R+0 samples for all astronauts, whereas the R+1 rates again approach preflight levels. The same is true for Rb and Cs rates

TABLE II

Ca, Na, Rb, AND Cs CONCENTRATIONS IN APOLLO 16 ASTRONAUT URINE SAMPLES

Astronaut	Flight Period	Ca		Na		Rb		Cs	
		µg/ml	mg/day	µg/ml	g/day	µg/ml	mg/day	µg/ml	µg/day
CDR	F-30	<150	<310	2300	4.83	1.08	2.27	0.00298	6.26
CMP	F-30	164	94.3	1380	0.794	2.10	1.21	0.00360	2.07
LMP	F-30	<72	<160	2430	5.36	1.04	2.29	0.00334	7.36
CDR	F-15	<130	<120	2320	2.08	1.64	1.47	0.00356	3.19
CMP	F-15	171	123	1640	1.17	3.16	2.26	0.00746	5.33
LMP	F-15	<510	<830	1700	2.79	0.604	0.991	0.00192	3.15
CDR	F-5	<34	<61	2440	4.36	1.32	2.36	0.00364	6.50
CMP	F-5	192	173	2280	2.05	1.70	1.53	0.00546	4.91
LMP	F-5	<190	<450	1360	3.38	0.498	1.24	0.00184	4.57
CDR	R+0	<160	<130	957	0.780	1.40	1.14	0.00362	2.95
CMP	R+0	200	116	668	0.387	1.20	0.696	0.00260	1.51
LMP	R+0	<200	<190	1630	1.54	1.40	1.32	0.00556	5.24
CDR	R+1	<47	<56	1180	1.42	1.49	1.79	0.00466	5.59
LMP	R+1	<140	<270	1520	2.93	0.922	1.77	0.00323	6.22

TABLE III

Cr, Fe, Co, Ag, Zn and Hg CONCENTRATIONS IN APOLLO 16 ASTRONAUT URINE SAMPLES

Astronaut	Flight Period	Cr		Fe		Co		Ag		Zn		Hg	
		µg/ml	µg/day	µg/ml	µg/day	µg/ml	ng/day	µg/ml	µg/day	µg/ml	mg/day	µg/ml	µg/day
CDR	F-30	<0.0021	<4.5			0.000202	424	0.000160	0.336	0.134	0.281	<0.00072	<1.5
CMP	F-30	<0.0035	<2.0			0.000277	159	0.000154	0.0886	0.650	0.374		
LMP	F-30					0.000146	322	0.000233	0.514	0.172	0.379		
CDR	F-15	<0.00053	<0.47			0.000162	145			0.342	0.306	<0.0014	<1.3
CMP	F-15	<0.0022	<1.6			0.000246	176	0.000447	0.320	0.583	0.417		
LMP	F-15	0.00464	7.61			0.000109	179	0.000170	0.279	0.314	0.515	<0.0012	<2.0
CDR	F-5					0.000164	328	0.000158	0.282	0.208	0.371	<0.0010	<1.8
CMP	F-5			0.0226	20.3	0.000238	214	0.000296	0.266	0.535	0.482	<0.0016	<1.4
LMP	F-5	0.0122	30.3			0.000128	318	0.0000607	0.151	0.766	1.90		
CDR	R+0	0.00961	7.83			0.000164	134	0.00103	0.839	0.468	0.381	<0.0013	<1.1
CMP	R+0	0.0196	11.4			0.000276	160	0.00204	1.18	1.44	0.835		
LMP	R+0	0.0160	15.1	<0.10	<94	0.000234	220	0.00209	1.97	0.568	0.535	<0.0012	<1.1
CDR	R+1					0.000203	244	0.000885	1.06	0.300	0.360		
LMP	R+1	<0.0062	<12			0.000144	277	0.000731	1.41	0.202	0.389		

TABLE IV

As, Sb, Se, AND Br CONCENTRATIONS IN APOLLO 16 ASTRONAUT URINE SAMPLES

Astronaut	Flight Period	As		Sb		Se		Br	
		µg/ml	mg/day	µg/ml	ng/day	µg/ml	µg/day	µg/ml	mg/day
CDR	F-30	<0.13	<0.27	0.000255	536	0.0136	28.6	3.02	6.34
CMP	F-30	<0.35	<0.20	0.000362	208	0.0480	27.6	1.59	0.914
LMP	F-30	<0.082	<0.18	0.000293	646	0.0146	32.2	2.64	5.82
CDR	F-15	0.162	0.145	0.000262	235	0.0222	19.9	1.93	1.73
CMP	F-15	<0.80	<0.57	0.000310	222	0.0368	26.3	2.54	1.82
LMP	F-15	<0.14	<0.22	0.000129	212	0.0131	21.5	1.17	1.92
CDR	F-5	0.639	1.14	0.000314	560	0.0198	35.3	2.96	5.28
CMP	F-5	<0.58	<0.52	0.000278	250	0.0270	24.3	2.89	2.60
LMP	F-5	0.396	0.984	0.000177	440	0.00830	20.6	1.58	3.93
CDR	R+0			0.000325	265	0.0215	17.5	0.888	0.724
CMP	R+0	<0.10	<0.060	0.000347	201	0.0308	17.9	0.432	0.251
LMP	R+0	<0.079	<0.074	0.000506	477	0.0288	27.1	1.28	1.21
CDR	R+1	<0.13	<0.16	0.000273	328	0.0219	26.3	0.992	1.19
LMP	R+1	<0.11	<0.20	0.000240	462	0.0232	44.7	1.22	2.35

TABLE V

Sc, Hf, AND Ta CONCENTRATIONS IN APOLLO 16 ASTRONAUT URINE SAMPLES

Astronaut	Flight Period	Sc		Hf		Ta	
		µg/ml	ng/day	µg/ml	µg/day	µg/ml	µg/day
CDR	F-30	0.00000404	8.48				
CMP	F-30	0.0000203	11.7	0.0198	11.4	0.0428	24.6
LMP	F-30	0.00000240	5.29				
CDR	F-15	0.00000590	5.28				
CMP	F-15	0.00000715	5.11				
LMP	F-15	0.00000497	8.15				
CDR	F-5	0.00000366	6.53				
CMP	F-5	0.0000180	16.2				
LMP	F-5	0.0000306	76.0				
CDR	R+0	0.00000827	6.74				
CMP	R+0	0.0000115	6.67	0.00922	5.35	0.0192	11.1
LMP	R+0	0.0000253	23.8				
CDR	R+1	0.00000189	2.27				
LMP	R+1	0.00000554	10.7				

for the CDR and CMP (but not the LMP). The CMP R+0 specimen reflects the lowest observed excretion rate for these elements. These observations are apparently associated with some physiological phenomenon occasioned by space flight which effectively "shuts off" elimination of the alkali metals and their ionic counterparts, Br and (presumably) Cl.

The opposite effect is observed in the urinary excretion rates and concentrations of Cr and Ag. In these cases, postflight value are generally higher than preflight levels. The high chromium levels are presumably due to the postflight injection of a radiochromium tracer, whereas the increased excretion of silver is more likely due to ingestion of increased quantities of silver during the mission.

The reported concentrations and rates for Fe and Co are the lowest ever observed and are significantly lower values than normally expected.[1] Similarly, the reported data for Hg and Sb indicate a reversal of the inflated rates and concentrations observed in the Apollo 14 and 15 mission specimens[3] and render the high values observed for these two earlier missions even more of an anomaly than was originally suspected.

EXPENDITURES

Table VI lists the expenditures according to the task and the total cost incurred from October 2, 1972 through December 31, 1972.

Table VI

EXPENDITURES

TASK	EXPENDITURES
Determination of the Radionuclide Content of Feces and Urine from Astronauts Engaged in Space Flight	$ 1,658
Neutron Activation Analysis of Feces and Urine from Astronauts Engaged in Space Flight	2,516
TOTAL COSTS	$ 4,174

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