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FUNCTIONAL VERIFICATION OF THE APOLLO URINE TRANSPORT SYSTEM

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Foreword

This research was initiated by the Aerospace Medical Research Laboratories, Wright-Patterson Air Force Base, Ohio, and was accomplished by the Department of Research of the Miami Valley Hospital, Dayton, Ohio, and the Biotechnology Branch, Life Support Division, Biomedical Laboratory, Aerospace Medical Research Laboratories.* This effort was supported jointly by the USAF under Project No. 7164, "Biomedical Criteria for Aerospace Flight," Task No. 716405, "Aerospace Nutrition," and NASA Manned Spacecraft Center, Houston, Texas, under Defense Purchase Request R-85, "The Protein, Water, and Energy Requirements of Man Under Simulated Aerospace Conditions." This contract was initiated by 1st Lt. John E. Vanderveen, monitored by 1st Lt. Keith J. Smith, and completed by Alton E. Prince, PhD, for the USAF. Technical contract monitor for NASA was Paul A. Lachance, PhD. The research effort of the Department of Research of the Miami Valley Hospital was accomplished under Contract AF 33(657)-11716. Bernard J. Katchman, PhD, and George M. Homer, PhD, were technical contract administrators, and Robert E. Zipf, MD, Director of Research, had overall contractual responsibility. This report was written by Bernard J. Katchman, PhD, with the technical assistance of Frank C. Corrigan.

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Abstract

A simulated aerospace study was conducted to assess the biochemical effects of space flight by determining the volume of urine output of each crewman. The Apollo urine transport system (UTS), using a radioisotope, tritium, dilution technique, was tested by four human male subjects. The Apollo UTS met minimum requirements for 14 days even when a single unit was used by four individuals. The best individual performance by a subject gave a ratio of 101.4 ±4.6%. The overall value for volume measurement from the four subjects was 100.6 ±4.6%. Any void volume may be calculated by this radioisotope method with the UTS system ±10% of its volume at the 95% confidence level. One experimental error was the incomplete mixing of the radioisotope. The practicability of this procedure in actual space missions still has to be determined.

SECTION I.
Introduction

In order to assess biochemical effects of space flight, it is necessary to know the volume of urine output of each crewman. All the urine is not needed for analysis and the total volume can be determined from a small sample by means of a suitable dilution method. The Apollo urine transport system (UTS)* was developed to use a radioisotope dilution technique. In operation, as the user urinates into the UTS, a measured amount of ^3H_2O, tritium labeled water, is injected into the urine stream which is collected in a large bag fixed to the UTS. After mixing, a portion of the urine is transferred to a small sample bag which is removed from the UTS. The contents of the large bag are then emptied and the system is ready to be used again.

The UTS was used during a simulated aerospace study by four human male subjects (ref 1). This report deals with the operational functionality of that system, with the reproducibility of radioisotope delivery, and with the reliability of the determination of urine volume.

*The Apollo urine transport system (UTS) was developed by the ARDE Company for the Manned Spacecraft Center, NASA, Houston, Texas.

SECTION II.
Methods

All the radioactive urine samples were counted in a Model 314AX Tri-Carb two-channel liquid scintillation spectrometer.* To 0.2 ml of urine in a 20 ml screw-cap counting vial,* were added 10 ml of a solution composed of 7 parts of toluene (spectrochemical quality) and 6 parts of purified Triton X-100** with 4.0 g/liter of 2,5-diphenyloxazole (PPO) and 0.1 g/liter of 1,4-bis-2-(4-methyl-5-phenyloxazolyl)-benzene (POPOP) – tT76 cocktail – and 5.0 ml of demineralized water.

To determine the volume of urine to be counted, a quenching curve was established as follows. A known amount of ^3H_2O was diluted with water, and samples of 0.2, 0.4, 0.6, 0.8, and 1.0 ml were counted in 20 ml screw-cap vials with 10 ml of the tT76 cocktail and 5.0 ml of demineralized water. The vials were shaken and then refrigerated at 0 C for 2 hours before counting. The spectrometer was set at approximately 1250 volts, tap 7, analysis mode 4; inner selector switch was set in the ON position. The red channel helipot was set at 70 to 1000 and the green channel helipot was set at 300 to 1000. The red channel counts were used in the calculations. The ^3H_2O counts exhibited straight line functions when plotted as counts minus background versus concentration, or counts were proportional to concentrations up to and including 1.0 ml. The same procedure was applied to various pooled urine samples, which were treated with the ^3H_2O.

The curves obtained for the tritiated urine samples show that counts were proportional up to a concentration of 0.4 ml (figure 1). Above the 0.4 ml concentration, the curve exhibited a high degree of quenching. The quench curve indicates that using a urine volume of 0.2 ml would insure routine counting of samples providing counts on the linear portion of the curve.

Urine was collected for analysis by means of the UTS as follows. A urine collection bottle fitted with a 2-hole rubber stopper was secured to a ring stand with a clamp. Two pieces of glass tubing bent to about a 90° angle were inserted in the rubber stopper. A piece of vacuum rubber tubing was attached to one of the glass tubes and connected to the UTS delivery valve; another piece of rubber tubing was attached to the second glass tube and to a vacuum pump. A rubber condom was attached to the UTS connector. Each subject had his own connector with which he was able to urinate into the UTS. When the subject was ready to urinate, the indicator valve was set to the URINATE position. After urination into a large urine collection bag permanently affixed to the UTS, the subject disconnected himself from the UTS and gently squeezed the bag to mix the radioisotope that had been automatically injected into the urine stream (by the indicator valve) when the indicator valve was set to the URINATE position. The indicator valve was then turned to the SAMPLE position and the sample bag was attached to the appropriate receiver on the UTS. With the sample switch turned to the ON position, an aliquot of urine was transferred from the large bag to a small bag. The sample switch was returned to the OFF position and the sample bag removed from the UTS. With the indicator valve set to the DUMP position, the contents of the large bag were emptied into the urine collection bottle. The vacuum pump was turned on for 20 seconds to empty the large bag completely. The indicator valve was set at the BY-PASS position and the vacuum pump turned on

*Packard Instrument Company, LaGrange, Illinois.
**Rohm and Haas, Inc., Philadelphia, Pennsylvania.

for 20 seconds. The UTS was kept at the BY-PASS position when not in use.

Two 0.2 ml aliquots were taken from the sample bag and the urine collection bottle; a total of four samples were taken from each urine void. The actual volume of the sample bag and urine collection bottle was measured with a graduated cylinder. Samples were counted for 10 minutes or for sufficient counts as to have the least percentage of error on a statistical basis. Counts were corrected for background and the average of two replicate samples was multiplied by five to obtain counts per milliliter. The counts per milliliter were multiplied by the milliliters of urine in the respective bag to give the total counts per bag. The large bag counts and the small bag counts were added together to give the total counts per void. The ratio of the counts per 0.2 ml minus background in the small bag to the counts per 0.2 ml minus background in the large bag times 100 is a measure of mixing efficiency.

Since the UTS malfunctioned after 8 days of operation with respect to the tritium dilution and the mechanism was repaired and recharged with tritium on the fifteenth day, the experiment was divided into two phases. Phase I included all the data from the first through the eighth day, and phase II included all the data from the fifteenth day to the end of the test.

The radioisotope volume of each phase was determined by dividing the counts per milliliter in the small bag into the average of each subject's total counts per void.

The total counts used for calculations were as follows: subject 41, 476,592 counts per minute for phase I and 573,041 counts per minute for phase II; subject 42, 468,299 counts per minute for phase I and 569,879 counts per minute for phase II; subject 43, 478,703 counts per minute for phase I and 540,131 counts per minute for phase II; and subject 44, 467,763 counts per minute for phase I and 550,395 counts per minute for phase II. The following is an example of a sample calculation using data for subject 41, phase I.

$$\text{Radioisotope volume} = \frac{476{,}592 \text{ cpm (total count)}}{2{,}015 \text{ cpm/ml of small bag sample}} = 237 \text{ ml}$$

The measured volume was 236 ml. A ratio of the radioisotope volume divided by the volumetric volume times 100 was taken on all calculated volumes and in this case the ratio was 100.4%. Daily average volumetric volumes for all subjects were plotted with respect to total average, mixing ratios, and radioisotope volume to volumetric volume in the data analysis.

SECTION III.
Results

The UTS was operational for 19 days. After 14 days it was recharged with the radioisotope. One subject did not use the UTS between the sixth and twelfth days due to a blockage in the connector. This particular connector had a screen that was clogged by urinary solids. The other connectors did not malfunction. The large bag did not leak until the seventeenth day when it was replaced. None of the sample bags leaked. The system was operational for 67 man days and a total of 283 sample bags were collected during this time. Later analysis of the urine samples indicated that between the ninth and fourteenth days, radioisotope was not discharged. However, the UTS cannot be considered faulty because the spring activation mechanism had not been fully released. This was rectified when the UTS was recharged with tritium. The orifice in the sample spigot which penetrates the sample bag and allows the urine to pass from the large bag into the sample bag was completely clogged on the nineteenth day by solids from urine. The sample switch of the UTS became progressively more difficult to operate. The build-up of solids in the sample spigot may have contributed the increased friction in the sample switch. The large mixing bag leaked around the gummed seal near the screw-in device which fastens the bag to the UTS. There was no puncture at this point; the leak appeared to be due to a separation of two gummed surfaces. In summary, the Apollo UTS is capable of continuous operation for at least 18 consecutive days and should be expected to be capable of performing continuously on a 14-day Apollo mission.

Table II is a summary of the experimental data obtained for the four subjects; the voids per day, counts per minute per milliliter of urine in the large and small bags, the volumetric volume of urine in the large and small bags, and the total counts in the large and small bags (cpm x volumetric volume) are presented. The total counts per void (sum of large and small bags) are shown in table III.

A cursory examination of the data shows large variations and fluctuations. In order to evaluate these variations and fluctuations, the mean and standard deviation were computed for each day and for each subject (table IV, column 3). These data are plotted in figures 2-5. Since the UTS is supposed to inject a constant amount of radioisotope, the total counts per void should be equal. Phase I and phase II merely separate the data obtained between recharges of the UTS with the radioactivity. Very erratic standard deviations occurred for all the subjects. Since experimental error of the volumetric measurements and the radioisotope counting should be no more than $\pm 10\%$, total counts less than 400,000 and more than 600,000 were arbitrarily omitted from the data (table IV, column 4) as shown in figures 6-9. With few exceptions, all the corrected data fall within an experimental error of $\pm 10\%$ (table IV). During phase I, the total counts decreased with time; the break occurred at the third day. The pattern for subjects 41, 42, and 44 were nearly the same; subject 43 had problems with the connector screen and the pattern for his data is not exactly like the others. The data for phase II, after the recharge and adjustment of the spring mechanism did improve over phase I, but this comparison is not really a valid one because in phase I, the total output did not begin to decrease until after the third day and the UTS failed to function at the third day in phase II.

It is important to establish the efficiency with which the UTS injects the total counts into the urine stream. This value for the total counts is needed to calculate the total volume by the radioisotope dilution method. In table IV, both the corrected and uncorrected average and mean total counts for all the samples are shown for each subject for each phase. Phase I uncorrected total counts range from 467,763 to 476,592 and the corrected total counts range from 462,151 to 488,804. Examination of the eight values show them to vary randomly among themselves. The larger standard deviations for the uncorrected data are due to the random occurrence of very high and very low averages out to the true value. This may result from an incomplete injection of the radioisotope on one occasion followed by an injection which includes what was left over from the incomplete injection on the next occasion. Since all the subjects used one UTS, these occurrences were random events. The data for phase II. in general, parallel the phase I data within the limits of the number of samples that were analyzed. There are the same erratic variations which occur in a random fashion with the total averages or mean for the uncorrected and the corrected values near one another in magnitude. The standard deviation for the phase II data is lower than that for phase I, but direct comparison may not be valid.

The efficiency of mixing of the radioisotope in the urine of the large bag was determined by the mixing ratio which is the ratio of the counts per minute per milliliter of the small bag, divided by the counts per minute per milliliter of the large bag, multiplied by 100. Complete mixing would, by definition, give a value of 100%. Table IV shows a summary (table III) of the mixing ratios for each day, phase, and subject (mean, standard deviation, and coefficient of variation). Figures 10-13 are plots of the daily means and standard deviations as a function of time. These data show that the mean and standard deviation for each day vary randomly. There is no effect of time. The overall averages for each subject by phase (table IV) are less than 100%. The coefficients of variation are between 6 and 9%; and therefore, statistically, these values are not significantly different from 100%. Nevertheless, the small sample bags have less counts than the large bags and there is a slight bias in the data; phase I was 94.7 ± 5.5, phase II was 97.8 ± 5.2, and the overall value was 94.8 ± 6.0.

The efficiency of the radiosotope dilution method was determined by the ratio of radioisotope volume divided by the volumetric volume times 100; when the radioisotope volume is identical to the volumetric volume, the ratio is 100%. Table IV shows a summary (table III) of the ratios $\left(\frac{RV}{VV} \times 100\right)$ as the average for each day, phase, and subject. Figures 14-17 are a plot of the ratios versus time. Note that in phase I, the ratio increases in one to three days and then fluctuates randomly. This is relative to the change in total counts in one to three days. In general, the ratios exceed 100% for both phases. Again, the standard deviations are so large that the ratios are not statistically significantly different from 100%. The reason for the over-estimation of radioisotope volume is simple; the radioisotope volume is calculated from the total counts per minute and the counts per minute per milliliter of the sample (small bag) as follows:

$$\frac{\text{Sample bag (cts/min/ml)}}{\text{Total (cts/min/ml)}} = \text{RV}$$

The data obtained in table IV as the mixing ratio indicated that the small bag counts were lower than they should have been with respect to the large bag. As a result, there is an apparent greater dilution, which results in a radioisotope volume that is larger than the volumetric volume. The $\left(\frac{RV}{VV} \times 100\right)$ for all the samples was 104.8 ± 13.8; for phase I was 106 ± 15, and for phase II, was 100.6 ± 5.4.

SECTION IV.
Discussion

The Apollo UTS can perform continuously for at least 14 days even when a single unit is used by four individuals. There was no malfunction of a unit, and the large permanent urine collector bag and the small sample collector bags did not rupture or leak during 14 days of operation.

The main purpose of this system is to provide accurate measurement of individual urine void volumes. The best data obtained in this study was in phase II. The best individual performance by a subject gave $\left(\frac{RV}{VV}\right)$ ratio of $101.4 \pm 4.6\%$. The overall value for the four subjects was 100.6 ± 5.4. This means that any void volume may be calculated by the radioisotope method in this system $\pm$ 10% of its volumetric volume at the 95% confidence level.

One source of experimental error, the incomplete mixing of the radioisotope and urine in the large bag, may be reduced by a procedure that would insure complete mixing. The question that remains to be answered is how practical would such a procedure be in an actual space mission. Neither the concept of a radioisotope dilution technique nor the equipment developed to effect individual void volumes can be faulted if the error as shown in this study is considered to be too large.

TABLE I

TRITIATED URINE QUENCHING DATA

Volume counted ml	$H_2{}^3O$ Cpm-Bkg	Urine I Cpm-Bkg	Urine II Cpm-Bkg	Urine III Cpm-Bkg
0.2	233	277	263	281
0.4	493	541	545	566
0.6	718	747	731	732
0.8	966	938	936	907
1.0	1175	1065	1009	1032

TABLE II

TRITIATED URINE DATA

Subject 41

Day	Cpm/ml large bag	Volume of large bag ml	Total Counts of large bag	Cpm/ml small bag	Volume of small bag ml	Total Counts of small bag
			Phase I			
1	2350	180	423,000	2375	43	102,125
1	3260	168	547,680	3000	22	66,000
1	2050	237	485,850	1890	33	62,370
1	1300	368	478,400	1205	39	46,995
1	2150	192	412,800	2015	44	88,660
2	2815	144	405,360	2575	41	105,575
2	1890	260	491,400	1940	37	71,780
2	1355	425	575,875	1200	59	70,200
2	2600	184	478,400	2125	31	65,875
2	1875	235	440,625	1585	52	82,420
3	1510	345	520,950	1370	43	58,910
3	1810	235	425,350	1620	69	111,780
3	1060	410	434,600	1010	37	37,370
3	890	570	507,300	795	11	31,005
3	1735	230	399,050	1435	50	71,750
4	1040	345	358,800	950	29	27,550
4	1190	345	410,550	1140	54	61,560
4	1280	355	454,400	1120	45	50,400
4	1100	370	407,000	1035	26	26,910
5	860	440	378,400	840	27	22,680
5	905	465	420,825	840	45	37,800
5	975	455	443,625	830	42	34,860
5	1265	350	442,750	1215	24	29,160
5	905	485	438,925	845	52	43,940
5	1275	345	439,875	1160	35	40,600
5	2150	140	301,000	1980	39	77,220
5	1680	193	324,240	1560	25	39,000
6	1055	390	411,450	1035	19	19,665
6	1225	285	349,125	1230	38	46,740
6	1090	315	343,350	1105	38	41,990
7	925	465	430,125	925	35	32,375
7	1125	425	478,125	965	38	36,670
7	1110	315	349,650	1090	39	40,560

TABLE II

TRITIATED URINE DATA, continued

Day	Cpm/ml large bag	Volume of large bag ml	Total Counts of large bag	Cpm/ml small bag	Volume of small bag ml	Total Counts of small bag
7	735	586	430,710	655	49	32,095
7	885	485	429,225	855	50	42,750
7	945	465	439,425	930	39	36,270
7	1265	290	366,850	1360	47	63,920
8	2545	138	351,121	2455	30	73,650
8	805	425	342,125	780	45	35,100
8	1335	315	426,825	1290	53	68,370
8	1120	410	459,200	1095	59	64,605
8	2695	120	323,400	2565	35	89,775
			Phase II			
15	1425	340	484,500	1430	57	81,510
16	1855	254	471,170	1785	46	81,110
16	2175	224	487,200	1940	45	87,300
16	1120	545	610,400	1050	39	40,950
16	1755	280	491,400	1625	47	76,325
16	1370	370	506,900	1380	43	56,620
17	1245	400	498,000	1330	42	58,860
17	1445	365	527,425	1380	48	66,240
17	1305	410	535,050	1335	48	64,080
17	1130	510	576,300	1065	56	59,640
19	1165	510	594,150	1165	20	23,300
19	1180	275	324,500	2345	33	77,385
19	2555	204	521,220	1485	37	54,945

TABLE II

TRITIATED URINE DATA

Subject 42

Day	Cpm/ml large bag	Volume of large bag ml	Total Counts of large bag	Cpm/ml small bag	Volume of small bag ml	Total Counts of small bag
			Phase I			
1	1865	198	369,270	1690	45	76,050
1	2080	258	536,640	1954	57	110,865
1	1410	315	444,150	1315	60	78,900
2	3995	70	279,650	3600	55	198,000
2	3395	108	366,660	3325	49	162,925
3	2220	100	222,000	1975	48	94,800
3	1890	216	408,240	1750	40	70,000
4	3540	177	626,580	3470	62	215,140
4	1235	265	327,275	1135	77	87,395
5	1340	275	368,500	1655	50	82,750
5	2185	144	314,640	1990	55	109,450
5	1610	218	350,980	1270	60	76,200
6	1285	245	314,825	1240	38	47,120
6	1675	230	385,250	1595	20	31,900
7	1320	270	356,400	1360	50	68,000
7	1050	400	420,000	985	30	29,550
8	1485	230	341,550	1445	29	41,905
8	1295	295	382,025	1300	26	33,800
			Phase II			
15	1600	330	528,000	1460	30	52,560
16	2395	210	502,950	2275	36	81,900
16	1875	250	468,750	1885	49	92,365
16	1530	335	512,550	1400	58	81,200
16	1145	445	509,525	1070	57	60,990
17	2720	182	495,040	2565	24	61,560
19	2725	192	523,200	2470	7	17,290
19	2505	222	556,110	1880	8	15,040

TABLE II

TRITIATED URINE DATA

Subject 43

Day	Cpm/ml large bag	Volume of large bag ml	Total Counts of large bag	Cpm/ml small bag	Volume of small bag ml	Total Counts of small bag
			Phase I			
1	5460	59	322,140	5355	26	139,230
1	1265	380	480,700	1230	35	43,050
1	2340	170	397,800	2225	39	86,775
1	3155	147	463,785	2925	30	87,750
1	3835	117	448,695	3525	37	130,425
2	2415	178	429,870	2195	40	87,800
2	1980	205	405,900	1750	49	77,000
2	2295	172	394,740	2370	17	40,290
2	3540	100	354,000	3265	34	111,010
3	2300	205	471,500	1965	37	72,705
3	3535	88	311,080	3405	38	129,390
3	2555	114	291,270	2455	38	93,290
3	2930	102	298,860	2805	48	134,640
4	3395	83	281,785	3270	35	114,450
4	1405	290	407,450	1375	35	48,125
4	1795	228	409,260	1640	39	63,960
4	2530	218	551,540	2365	55	130,075
5	1275	310	395,250	1085	36	39,060
5	1860	190	353,400	1845	40	73,800
5	3145	94	295,630	3045	35	106,575
			Phase II			
15	3295	114	375,630	3350	48	130,845
16	2010	252	506,520	1870	53	99,110
16	2035	232	472,120	1985	33	65,505
16	3315	124	411,060	3405	26	88,530
17	1645	310	509,950	1475	53	78,175
17	1730	275	475,750	1630	31	50,530
19	1430	350	500,500	1475	21	30,975

TABLE II

TRITIATED URINE DATA

Subject 44

Day	Cpm/ml large bag	Volume of large bag ml	Total Counts of large bag	Cpm/ml small bag	Volume of small bag ml	Total Counts of small bag
			Phase I			
1	4160	120	499,200	3695	26.5	97,918
1	3780	108	408,240	3445	45	155,025
1	2455	210	515,550	2190	29	63,570
1	2600	214	556,400	2775	50	138,750
1	2830	174	492,420	2795	38.5	107,608
1	3265	170	555,050	2610	46	120,060
2	3040	122	370,880	2990	45	134,550
2	1590	325	516,750	1495	46	68,770
2	2460	198	487,080	2315	53	122,695
2	1965	260	510,900	1400	57	79,800
2	3205	61	195,505	3040	42	127,680
3	2380	156	371,280	2315	45	104,175
3	1595	270	430,650	1540	59	90,860
3	2690	102	274,380	2590	50	129,500
3	2460	138	339,480	2500	36	90,000
3	4280	73	312,440	4060	29	117,740
3	2360	136	320,960	2220	46	102,120
4	1220	308	375,760	1150	69	79,350
4	2090	158	330,220	1860	37	68,820
4	2125	163	346,375	1880	56	105,280
4	2175	148	321,900	2205	62	136,710
5	2140	164	350,960	1755	55	96,525
5	1140	325	370,500	1005	60	60,300
5	1830	198	362,340	1695	39	66,105
5	1670	220	367,400	1540	54	83,160
5	2045	160	327,200	2000	54	108,000
5	1860	184	342,240	1845	65	119,925
5	3295	97	319,615	3185	40	127,400
5	1820	150	273,000	1730	54	93,420
6	2710	109	295,390	2555	50	127,750
6	1805	186	335,730	1755	58	101,790
6	1310	244	319,640	1355	58	78,590
6	2025	160	324,000	2045	62	126,790
6	1815	184	333,960	1885	58	109,330

TABLE II

TRITIATED URINE DATA, continued

Day	Cpm/ml large bag	Volume of large bag ml	Total Counts of large bag	Cpm/ml small bag	Volume of small bag ml	Total Counts of small bag
			Phase I			
6	2180	150	327,000	2065	52	107,380
6	1660	196	325,360	1580	60	94,800
7	1890	166	313,740	1940	50	97,000
7	2040	177	361,080	1835	57	104,595
7	3020	92	277,840	2965	56	166,040
7	2065	160	330,400	2000	60	120,000
7	2155	144	310,320	2190	60	131,400
7	2380	130	309,400	2295	61	139,995
7	4575	64	292,800	4290	20	85,800
7	2445	124	303,180	2345	50	117,270
8	1735	204	353,940	1735	54	93,690
8	2005	168	336,840	1995	61	121,695
8	1350	288	388,800	1420	57	80,940
8	2055	764	337,020	1890	51	96,390
8		208			58	
8	1515	218	330,270	1580	65	102,700
8	1975	174	343,650	1925	50	96,250
8	1745	104		1740	45	
9	1660	224	371,840	1550	54.5	84,475
9		166			66	
9		320			56.5	
9		273			56.5	
9		150			63.5	
9		85			34	

TABLE II

TRITIATED URINE DATA
Subject 44

Day	Cpm/ml large bag	Volume of large bag ml	Total Counts of large bag	Cpm/ml small bag	Volume of small bag ml	Total Counts of small bag
			Phase II			
15	3295	114	375,630	3350	48	160,800
16	2510	146	366,460	2580	68	175,440
16	3325	135	448,875	2910	52	151,320
16	2475	192	475,200	2460	53	130,380
16	2575	156	401,700	2560	78	199,680
16		150			63	
16		140			57	
17	2045	216	441,720	2050	55	112,750
17		180			40	
19	2110	220	464,200	2370	52	123,240
19	1600	220	352,000	2435	9	21,915
19	2655	188	499,140	2795	19	53,105

TABLE III

TRITIATED URINE DATA

Subject 41

Day	Total counts per void small bag + large bag	$\frac{\text{Small bag}}{\text{Large bag}} \times 100$	Calculated volume* ml	$\frac{RV}{VV} \times 100$
		Phase I		
1	525,125	101.1	201	90.1
1	613,608†	92.0	159	83.7
1	548,220	92.2	252	93.3
1	525,395	92.7	396	97.3
1	501,460	93.7	237	100.4
2	510,935	91.5	185	100.0
2	563,180	102.6	246	82.8
2	646,075†	88.6	397	82.0
2	544,275	81.7	224	104.1
2	523,045	84.5	301	104.8
3	579,860	90.7	348	89.6
3	537,130	89.5	294	96.7
3	471,970	95.3	472	105.5
3	538,305	89.3	599	98.3
3	470,800	82.7	332	118.5
4	386,430†	91.3	502	134.2
4	472,110	95.8	418	104.7
4	504,800	87.5	426	106.5
4	433,910	94.1	460	116.1
5	401,080	97.7	567	121.4
5	458,625	92.8	567	111.1
5	478,485	85.1	574	115.4
5	471,910	96.0	392	104.8
5	482,865	93.4	564	105.0
5	480,475	91.0	411	108.1
5	328,220†	92.1	241	134.6
5	363,240†	92.9	306	140.3
6	431,115	98.1	460	112.4
6	395,865†	100.4	387	119.8
6	385,340†	101.4	431	122.0
7	462,500	100.0	515	103.0
7	514,795	85.8	494	87.7
7	390,210†	93.7	437	123.4
7	462,805	89.1	728	114.6
7	471,975	96.6	557	104.1

TABLE III

TRITIATED URINE DATA, continued

Subject 41

Day	Total counts per void small bag + large bag	Small bag / Large bag x 100	Calculated volume* ml	RV / VV x 100
7	475,695	98.4	512	101.5
7	430,770	107.5	350	103.8
8	424,771	96.5	194	115.4
8	377,255	96.9	611	130.0
8	495,195	95.2	369	100.2
8	523,805	97.8	435	92.7
8	413,175	95.2	186	120.0
		Phase II		
15	566,010	100.4	401	101.0
16	553,280	96.2	321	107.0
16	574,500	89.2	295	109.6
16	651,350†	93.8	546	93.4
16	567,775	92.6	353	107.9
16	564,520	97.8	415	100.4
17	553,860	106.8	431	97.5
17	593,665	95.5	415	100.4
17	599,130	102.3	429	93.6
17	635,940†	94.2	538	95.0
19	617,450†	100.0	492	92.8
19	401,885	198.7	244	
19	576,165			

* Volume found using average of 476,592.

TABLE III

TRITIATED URINE DATA

Subject 42

Day	Total counts per void small bag + large bag	$\frac{\text{Small bag}}{\text{Large bag}} \times 100$	Calculated volume* ml	$\frac{RV}{VV} \times 100$
		Phase I		
1	445,320	90.6	277	113.9
1	647,505†	93.5	241	76.5
1	523,050	93.3	356	94.9
2	477,650	90.1	130	104.0
2	529,585	97.9	142	90.4
3	316,800†	89.0	237	160.1
3	478,240	92.6	268	104.6
4	841,720†	98.2	135	56.4
4	414,670	91.9	413	120.7
5	451,250	123.5	283	87.0
5	424,090	91.1	235	118.0
5	427,180	78.6	369	132.7
6	361,945†	96.5	378	133.5
6	417,150	95.2	294	117.6
7	424,400	103.0	344	107.5
7	449,550	93.8	475	110.4
8	383,455†	97.3	324	125.0
8	415,825	100.4	360	112.1
		Phase II		
15	580,560	91.3	390	108.3
16	584,850	95.0	250	101.6
16	561,115	100.5	302	101.0
16	593,750	91.5	407	103.5
16	590,515	93.4	533	106.1
17	556,600	94.3	222	107.7
19	540,490	90.6	231	116.0
19	571,150	75.0	303	131.7

* Volume found using average of 476,592.

TABLE III

TRITIATED URINE DATA

Subject 43

Day	Total counts per void small bag + large bag	$\frac{\text{Small bag}}{\text{Large bag}} \times 100$	Calculated volume* ml	$\frac{RV}{VV} \times 100$
		Phase I		
1	461,370	98.1	89	104.7
1	523,750	97.2	389	93.7
1	484,575	95.1	215	102.8
1	551,535	92.7	164	92.6
1	579,120	91.9	136	88.3
2	517,670	90.9	218	100.0
2	482,900	88.4	274	107.8
2	435,030	103.3	202	106.8
2	465,010	92.2	147	109.7
3	544,205	85.4	244	100.8
3	440,470	96.3	141	111.9
3	384,560†	96.1	194	127.6
3	433,500	95.7	171	114.0
4	396,235†	96.3	146	123.7
4	455,575	97.9	348	107.0
4	473,220	91.4	292	109.3
4	681,615†	93.5	202	73.9
5	434,310	85.1	441	127.4
5	427,200	99.2	259	112.6
5	402,205	96.8	157	121.7
		Phase II		
15	492,195	98.8	161	99.3
16	605,630†	93.0	289	94.7
16	537,625	97.5	272	102.6
16	499,590	102.7	159	106.0
17	588,125	94.3	366	100.8
17	526,280	89.7	331	108.1
19	531,475	103.1	366	98.6

* Volume found using average of 476,592.

TABLE III

TRITIATED URINE DATA

Subject 44

Day	Total counts per void small bag + large bag	$\frac{\text{Small bag}}{\text{Large bag}} \times 100$	Calculated volume* ml	$\frac{RV}{VV} \times 100$
		Phase I		
1	597,118	88.8	127	86.3
1	563,265	91.1	138	90.1
1	579,060	89.2	214	89.5
1	695,150†	106.7	169	64.0
1	600,028†	98.8	167	78.4
1	675,110†	79.9	179	82.8
2	505,430	98.4	156	93.4
2	585,520	94.0	313	84.3
2	609,775†	94.1	202	80.4
2	590,700	71.2	334	105.3
2	323,185†	94.9	154	149.5
3	475,455	97.3	202	100.4
3	521,510	96.6	304	92.4
3	403,880	96.3	181	119.0
3	429,480	101.6	187	107.4
3	430,180	94.9	115	112.7
3	431,720	94.1	211	115.9
4	455,110	94.3	407	107.9
4	399,040†	89.0	251	128.7
4	451,655	88.5	249	113.6
4	458,610	101.4	212	100.9
5	447,485	82.0	267	121.9
5	430,800	88.2	465	120.7
5	428,445	92.6	276	116.4
5	450,560	92.2	304	110.9
5	435,200	97.8	234	109.3
5	462,165	99.2	254	102.0
5	447,015	96.7	147	107.2
5	366,420†	95.1	270	132.3
6	423,140	94.3	183	115.0
6	437,520	97.2	267	109.4
6	398,230†	103.4	345	114.2
6	450,790	101.0	229	103.1
6	443,290	103.9	248	102.4
6	434,380	94.7	227	112.3

TABLE III

TRITIATED URINE DATA, continued

Subject 44

Day	Total counts per void small bag + large bag	Small bag / Large bag x 100	Calculated volume* ml	RV / VV x 100
6	420,160	95.2	296	115.6
7	410,740	102.6	241	111.5
7	465,675	90.0	255	108.9
7	443,880	98.2	158	106.7
7	450,400	96.9	234	106.3
7	441,720	101.6	214	104.9
7	449,395	96.4	204	106.8
7	378,600†	93.8	109	129.7
7	420,430	95.9	199	114.3
8	447,630	100.0	269	104.2
8	458,535	99.5	234	102.1
8	469,740	105.2	329	95.3
8	433,410	92.0	247	114.8
8	432,970	104.3	296	104.5
8	439,900	97.5	242	108.0
8		99.7		
9	456,315	93.4	301	107.8
9		106.0		
		Phase II		
15	536,430	101.7	164	101.2
16	541,900	102.8	213	99.5
16	600,195†	87.5	189	101.0
16	605,580†	99.4	224	91.4
16	601,380†	99.4	215	91.8
16		107.3		
17	554,470	100.2	268	98.8
19	587,440	112.3	232	85.2
19	373,915†	152.2	226	98.6
19	552,245	105.3	197	95.1

* Volume found using average of 476,592.

TABLE IV

TRITIATED URINE DATA - DAILY AVERAGES

Subject 41

Day	Mixing Ratio			$\frac{RV}{W} \times 100$			Total Counts*			Total Counts**		
	Av	S D	C V	Av	S D	C V	Av	S D	C V	Av	S D	C V
						Phase I						
1	94.3	± 3.8	4.0%	93.0	± 6.5	7%	542,776	± 42,504	7.8%	525,050	± 19,091	3.6%
2	89.8	± 8.1	9.0%	94.7	± 11.4	12%	557,502	± 53,404	9.6%	535,359	± 23,106	4.3%
3	89.5	± 4.5	5.0%	101.7	± 10.9	10.7%	519,613	± 47,271	9.1%	519,613	± 47,271	9.1%
4	92.2	± 3.6	3.9%	115.4	± 13.5	11.7%	449,313	± 50,958	11.3%	470,273	± 35,482	7.5%
5	97.4	± 3.7	3.7%	117.6	± 23.5	11.5%	439,363	± 50,060	11.4%	462,240	± 31,206	6.8%
6	99.97	± 1.69	1.6%	118.1	± 5.1	4.3%	404,107	± 23,975	5.9%	431,115		
7	95.9	± 7.2	7.5%	105.4	± 11.2	10.6%	458,393	± 38,972	8.5%	469,757	± 27,165	5.8%
8	96.32	± 1.12	1.1%	111.7	± 15.1	13.5%	446,834	± 55,965	12.5%	465,486	± 53,781	11.5%
Total Av.	93.6	± 5.4	5.7%	107.17	± 14.2	13.3%	476,592	± 72,237	15.1%	488,804	± 46,860	9.0%
						Phase II						
15	100.4			101.0			566,010			566,010		
16	93.9	± 3.3	3.5%	103.7	± 6.7	6.5%	582,285	± 39,363	6.8%	565,019	± 8,861	1.6%
17	99.7	± 5.9	5.9%	96.6	± 2.98	3.1%	595,649	± 33,594	5.6%	582,218	± 24,711	4.2%
18												
19	118.9	± 72.2	60.8%	92.8			531,833	± 114,413	21.5%	489,025	± 123,237	25.2%
20												
Total Av.	97.2	± 5.0	5.1%	99.9	± 6.10	6.11%	573,502	± 60,125	10.4%	555,079	± 55,871	10.0%

* Total counts with values > 600,000 and < 400,000.

** Total counts without values > 600,000 and < 400,000.

TABLE IV

TRITIATED URINE DATA - DAILY AVERAGES

Subject 42

Day	Mixing Ratio			$\frac{RV}{VV} \times 100$			Total Counts*			Total Counts**		
	Av	S D	C V	Av	S D	C V	Av	S D	C V	Av	S D	C V
						Phase I						
1	92.5	± 1.6	1.7%	95.1	± 18.7	19.5%	538,625	± 101,988	18.9%	484,185	± 54,964	11.4%
2	94.0	± 5.5	5.0%	97.2	± 9.6	9.8%	503,618	± 36,723	7.3%	503,618	± 36,723	7.3%
3	90.8	± 2.5	2.7%	132.4	± 39.3	29.7%	397,520	± 114,154	28.7%	478,240		
4	95.1	± 4.45	4.6%	120.7			628,195	± 301,965	48.1%	414,670		
5	97.7	± 23.2	23%	112.6	± 23.3	20.7%	434,173	± 14,869	3.4%	434,173	± 14,869	3.4%
6	95.9	± .92	.9%	125.6	± 11.3	8.9%	389,548	± 39,036	10.0%	417,150		
7	98.4	± 6.5	6.6%	109.0	± 2.1	1.9%	436,975	± 17,783	4.1%	436,975	± 17,783	4.1%
8	98.9	± 2.2	2.2%	118.6	± 9.2	7.7%	399,640	± 22,889	5.7%	415,825		
Total Av.	95.4	± 8.6	9.0%	112.3	± 19.9	17.7%	468,299	± 117,589	25.1%	452,140	± 39,300	8.6%
						Phase II						
15	91.3			108.3			580,560			580,560		
16	95.1	± 3.8	3.9%	103.1	± 2.3	22%	577,558	± 14,552	2.5%	577,558	± 14,552	2.5%
17	94.3			107.7			556,600			556,600		
18												
19	82.8	± 11.0	13.2%	116.0			555,820	± 21,680	3.9%	555,820	± 21,680	3.9%
20												
Total Av.	93.8	± 3.3	3.5%	106.3	± 5.13	4.8%	569,879	± 17,017	2.9%	569,879	± 17,017	2.9%

* Total counts with values > 600,000 and < 400,000

** Total counts without values > 600,000 and < 400,000.

TABLE IV

TRITIATED URINE DATA - DAILY AVERAGES

Subject 43

Day	Mixing Ratio			$\frac{RV}{VV} \times 100$			Total Count*			Total Counts**		
	Av	S D	C V	Av	S D	C V	Av	S D	C V	Av	S D	C V
						Phase I						
1	95.0	± 2.7	2.8%	96.4	± 7.0	7.2%	520,070	± 47,948	9.2%	520,070	± 47,948	9.2%
2	93.7	± 6.6	7.0%	106.1	± 4.2	3.9%	475,153	± 34,546	7.3%	475,153	± 34,546	7.3%
3	93.4	± 5.3	5.6%	113.6	± 10.9	9.6%	450,684	± 67,127	14.9%	472,725	± 62,002	13.1%
4	94.8	± 2.9	3.0%	113.2	± 9.1	8.0%	501,661	± 128,402	25.6%	464,398	± 12,478	2.7%
5	93.7	± 7.5	8.0%	120.6	± 7.5	6.2%	421,238	± 16,862	4.0%	421,238	± 16,862	4.0%
6												
7												
8												
Total Av.	94.2	± 4.5	4.7%	106.8	± 13.4	12.5%	478,703	± 71,480	14.9%	477,155	± 50,111	10.5%
						Phase II						
15	98.8			99.3			492,195			492,195		
16	97.7	± 4.9	5.0%	101.1	± 5.8	5.7%	547,615	± 53,721	9.8%	518,608	± 26,894	5.2%
17	92.0	± 3.2	3.4%	104.5	± 5.2	4.9%	557,203	± 43,730	7.8%	557,203	± 43,730	7.8%
18												
19	103.1			98.6			531,475			531,475		
20												
Total Av.	97.0	± 5.0	5.1%	101.4	± 4.6	4.5%	540,131	± 42,442	7.0%	529,215	± 34,067	6.4%

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* Total counts with values > 600,000 and < 400,000.

** Total counts without values > 600,000 and < 400,000.

TABLE IV

TRITIATED URINE DATA – DAILY AVERAGES

Subject 44

Day	Mixing Ratio			$\frac{RV}{VV} \times 100$			Total Count*			Total Counts**		
	Av	S D	C V	Av	S D	C V	Av	S D	C V	Av	S D	C V
Phase I												
1	92.4	± 9.2	9.9%	85.4	± 4.8	5.6%	618,289	± 54,591	8.8%	579,814	± 16,934	2.9%
2	90.5	± 10.9	12.0%	90.8	± 11.0	12.1%	522,922	± 118,588	22.7%	560,550	± 47,805	8.5%
3	96.8	± 2.6	2.6%	108.0	± 8.5	7.8%	448,704	± 42,489	9.5%	448,704	± 42,489	9.5%
4	93.3	± 6.0	6.4%	112.8	± 11.8	10.4%	441,104	± 28,186	6.4%	455,125	± 3,478	.8%
5	92.98	± 5.65	6.0%	115.1	± 9.7	8.3%	433,511	± 29,339	6.8%	443,096	± 12,125	2.7%
6	98.5	± 4.17	4.2%	110.3	± 5.5	4.9%	429,644	± 17,497	4.1%	434,880	± 11,710	2.7%
7	96.9	± 4.05	4.1%	111.1	± 8.1	7.2%	432,605	± 27,891	6.4%	440,320	± 18,762	4.3%
8	99.7	± 4.4	4.0%	104.8	± 6.4	6.1%	447,031	± 14,714	3.3%	447,031	± 14,714	3.3%
9	93.4			107.8			456,315			456,315		
Total Av.	95.6	± 6.4	6.6%	102.4	± 14.7	14.4%	467,763	± 75,495	16.0%	462,151	± 50,004	10.8%
Phase II												
15	101.7			101.2			536,430			536,430		
16	99.3	± 7.3	7.3%	95.9	± 5.1	5.3%	587,264	± 30,331	5.2%	541,900		
17	100.2			98.8			554,476			554,470		
18												
19	123.3	± 2.5	2.0%	93.0	± 6.9	7.4%	504,533	± 114.478	22.7%	569,842	± 24,886	4.4%
20												
Total Av.	101.7	± 6.8	6.6%	95.8	± 5.4	5.6%	550,395	± 69,559	12.6%	554,497	± 19,846	3.5%

* Total counts with values > 600,000 and < 400,000.

** Total counts without values > 600,000 and < 400,000.

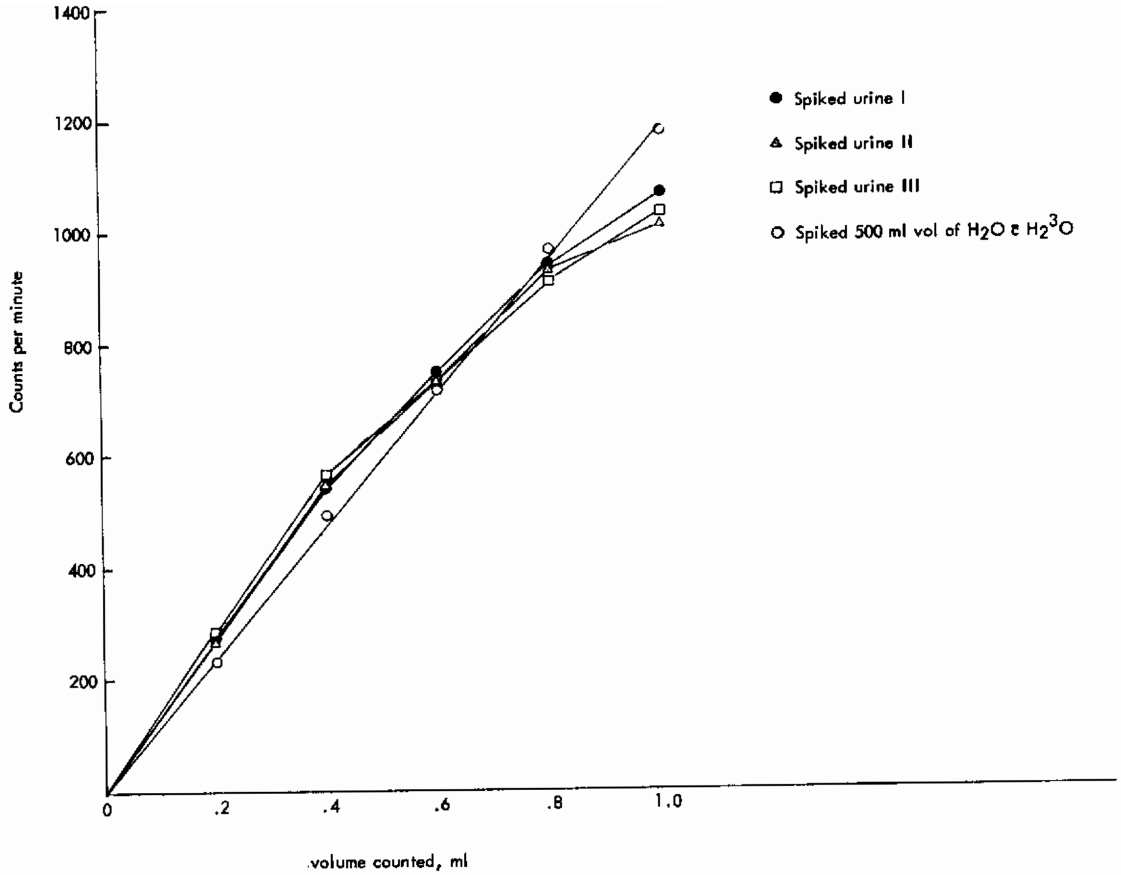

Figure 1. Quenching curve for ^3H_2O in urine.

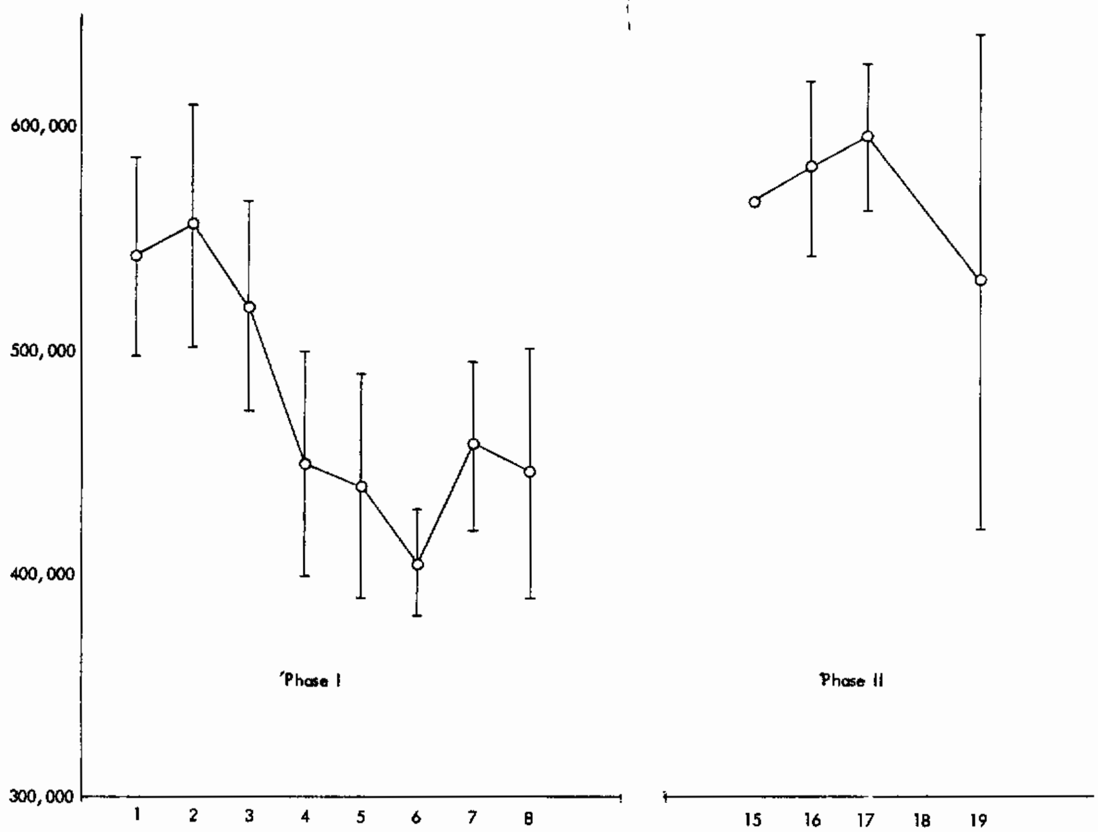

Figure 2. Daily average output, total counts (including counts <400,000 and >600,000) for Subject 41.

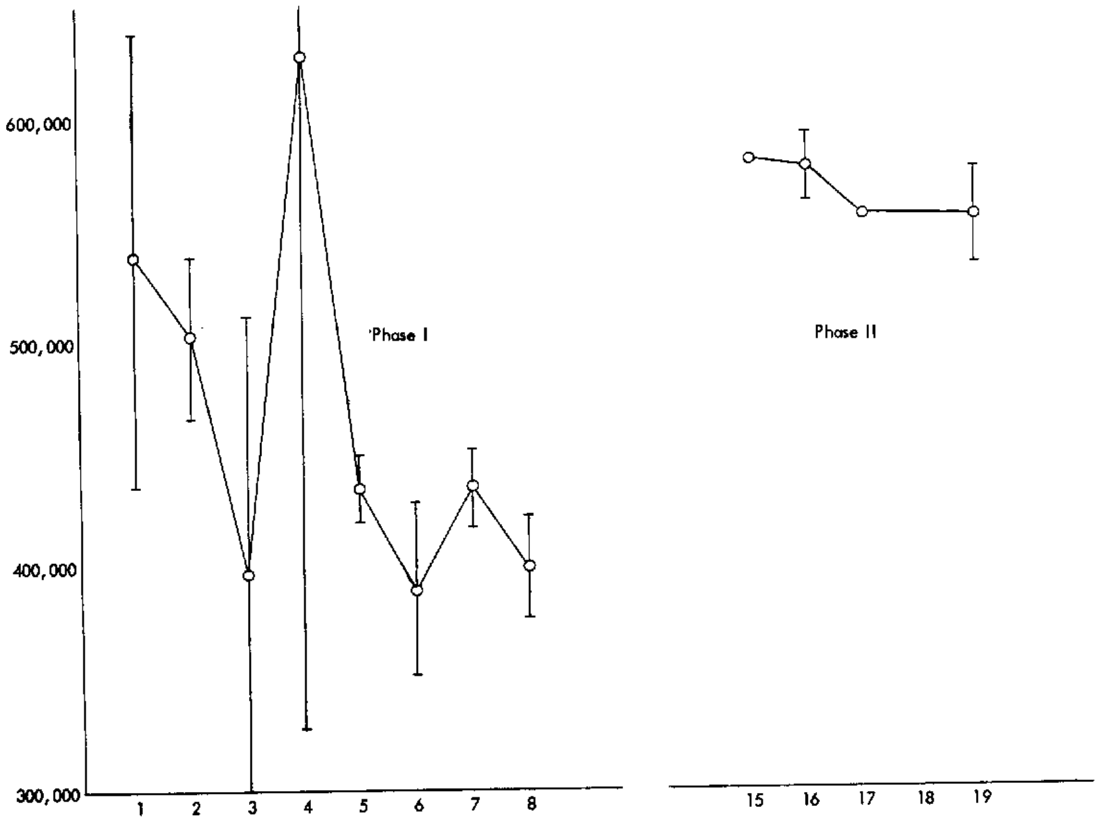

Figure 3. Daily average output, total counts (including counts <400,000 and >600,000) for Subject 42.

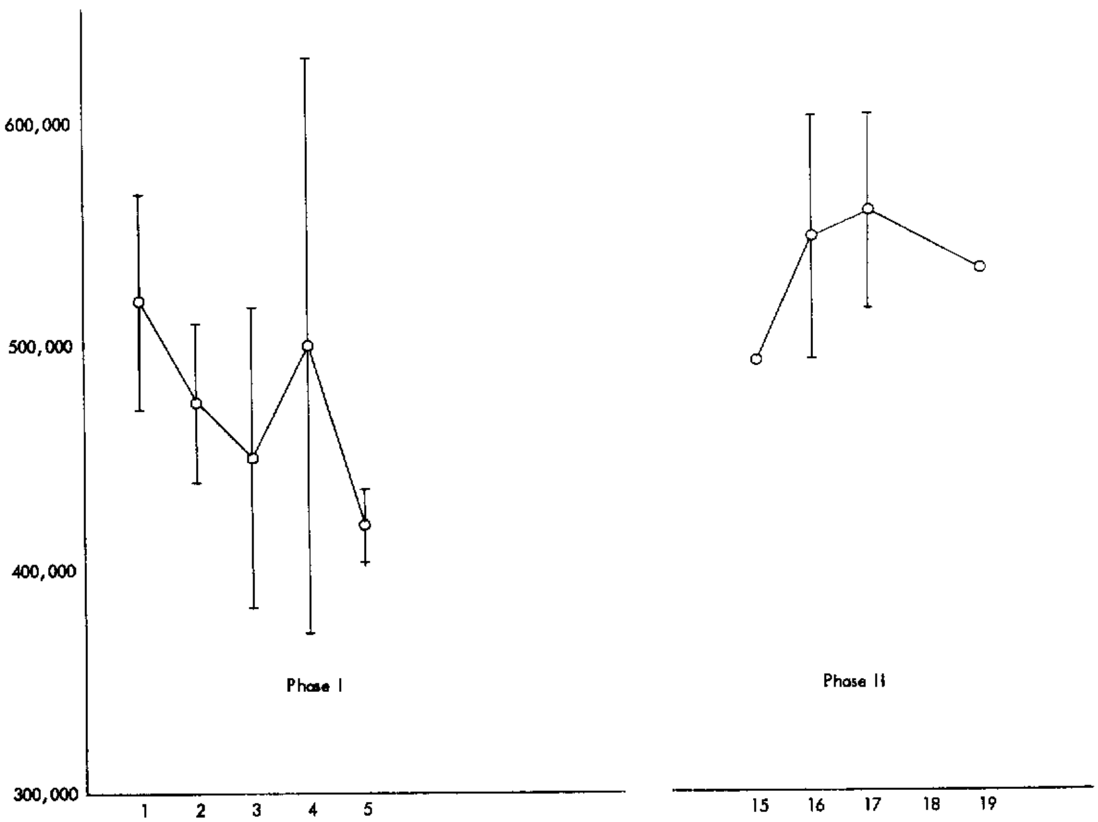

Figure 4. Daily average output, total counts (including counts <400,000 and >600,000) for Subject 43.

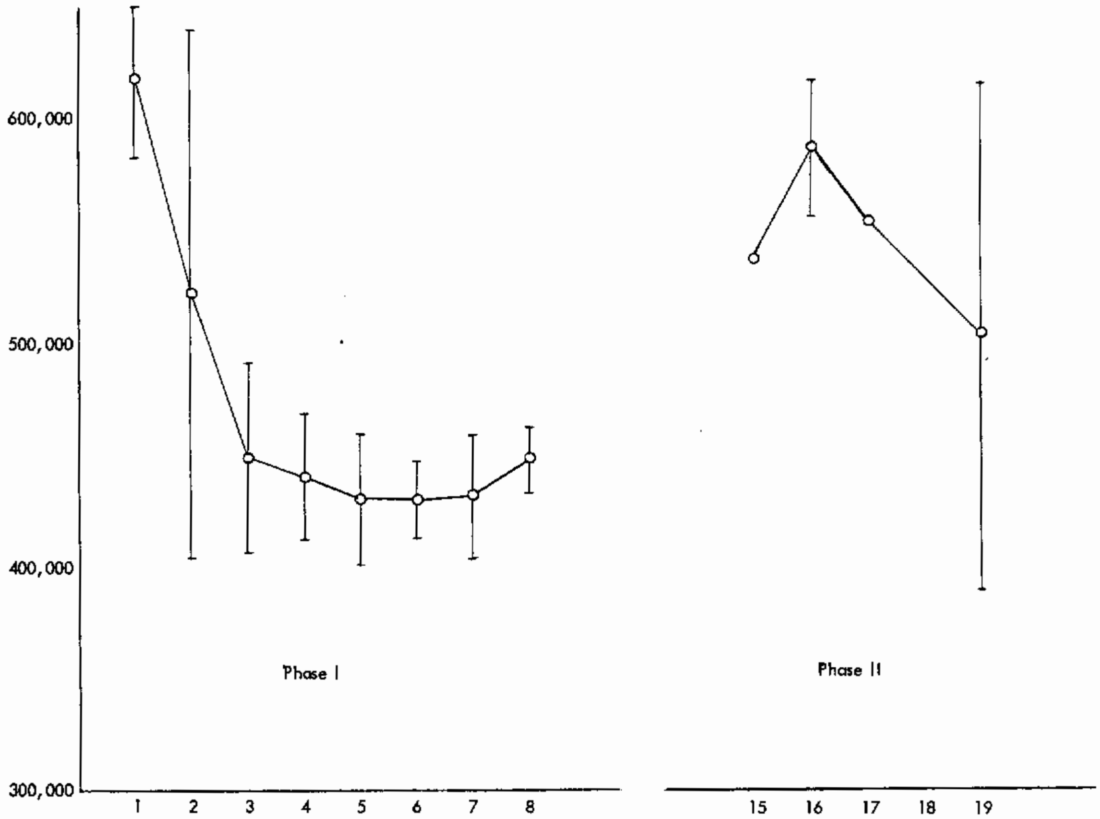

Figure 5. Daily average output, total counts (including counts <400,000 and >600,000) for Subject 44.

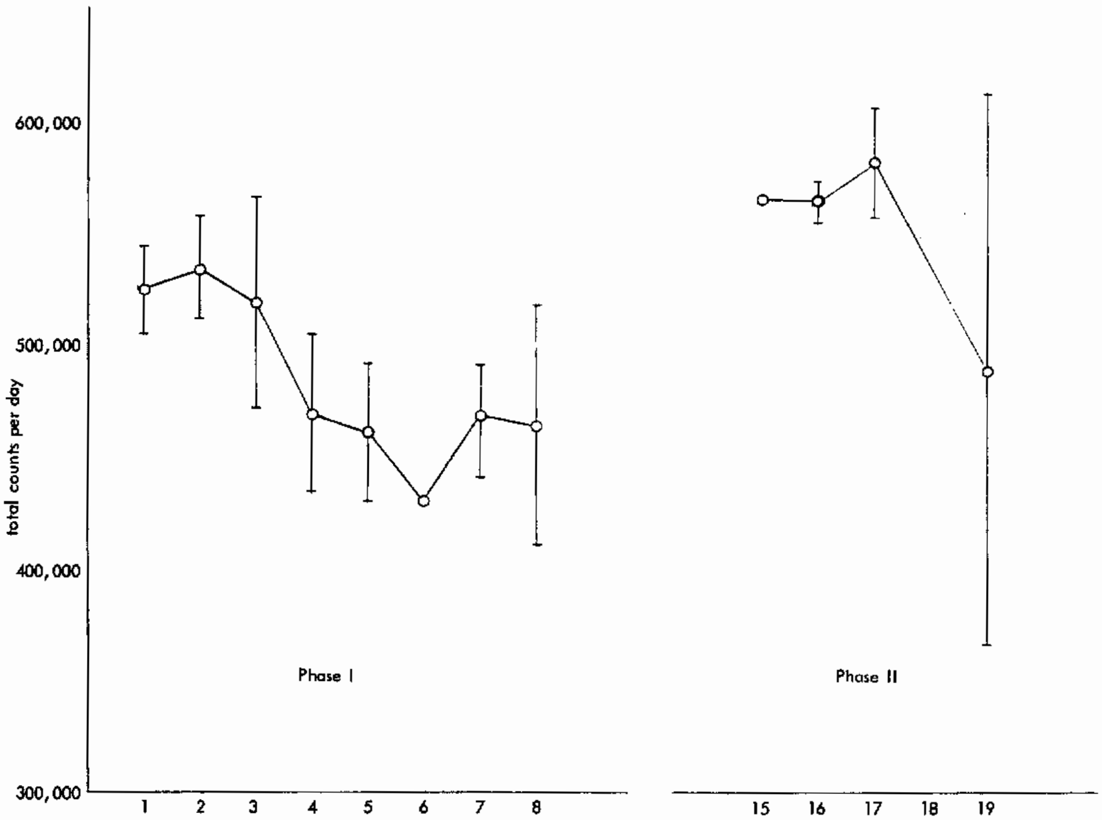

Figure 6. Daily average output, total counts (excluding counts <400,000 and >600,000) for Subject 41.

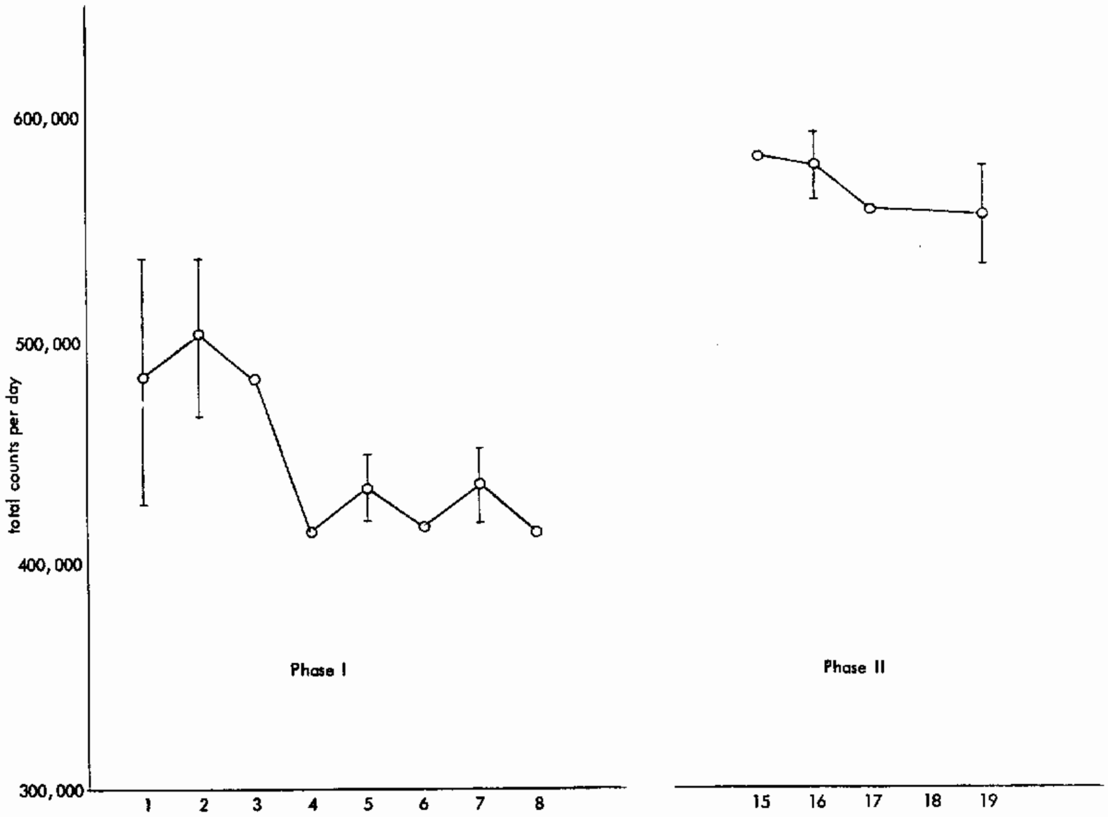

Figure 7. Daily average output, total counts (excluding counts <400,000 and >600,000) for Subject 42.

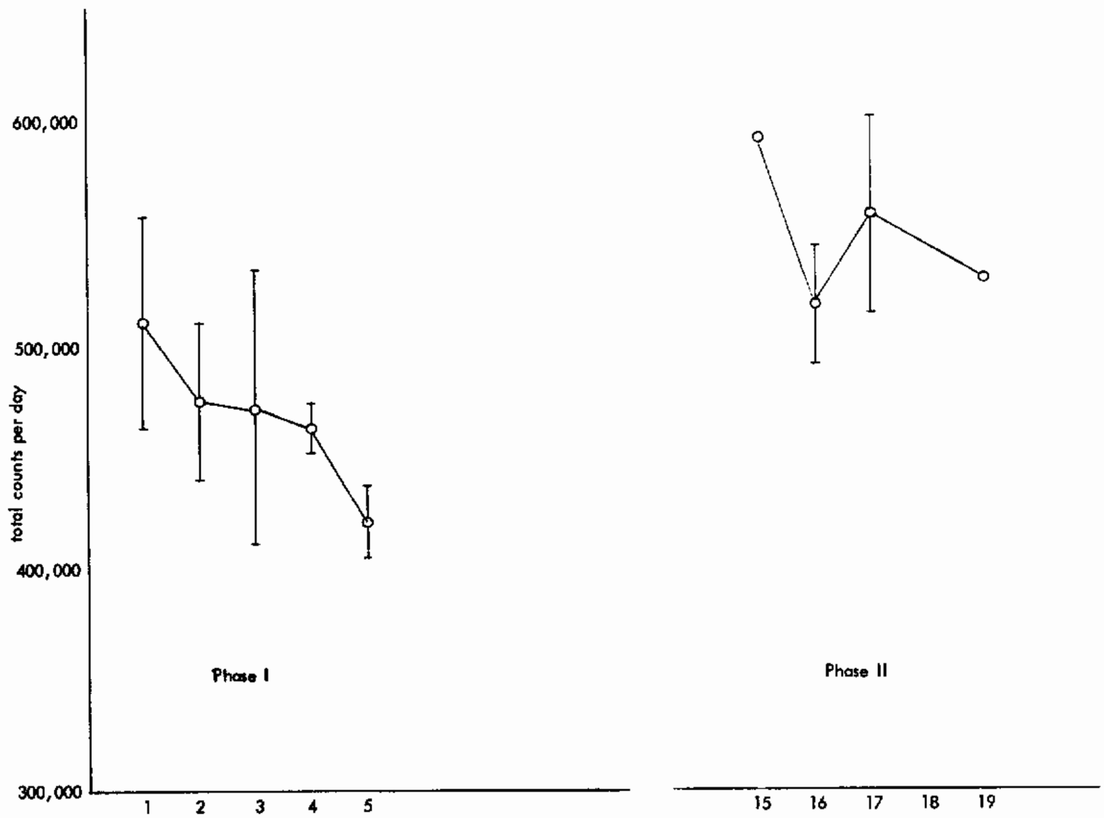

Figure 8. Daily average output, total counts (excluding counts <400,000 and >600,000) for Subject 43.

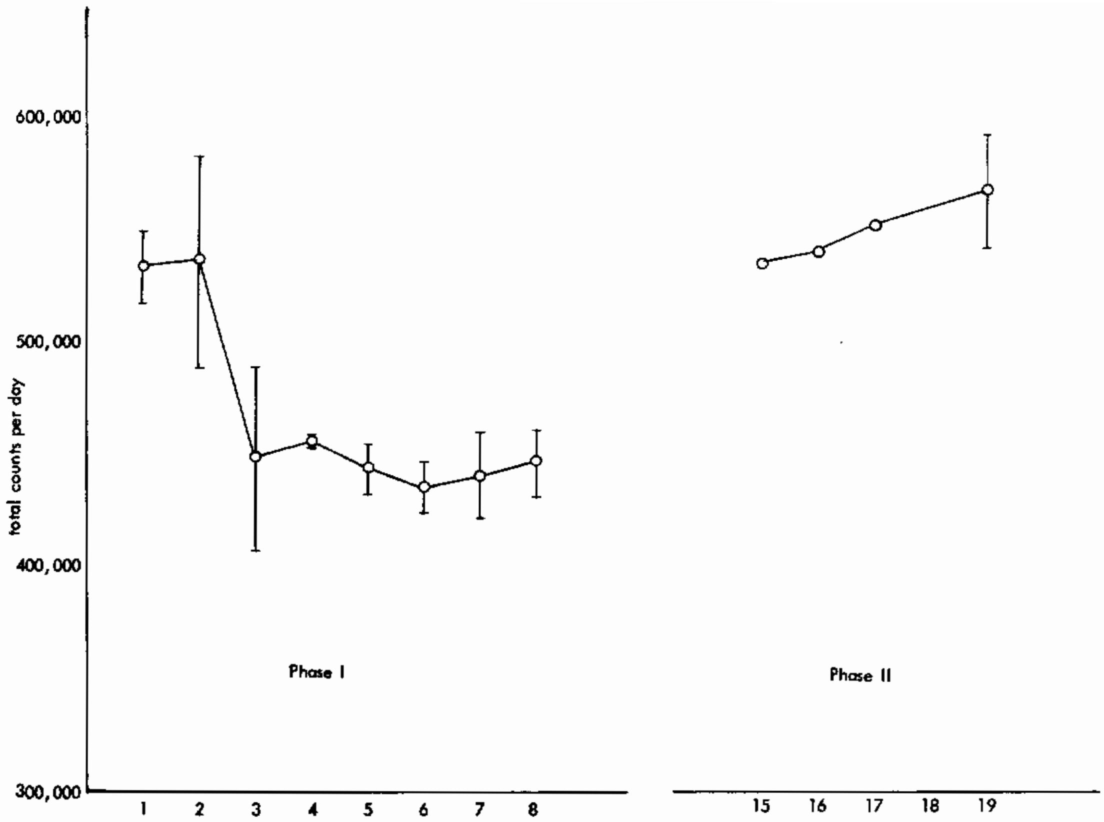

Figure 9. Daily average output, total counts (excluding counts <400,000 and >600,000) for Subject 44.

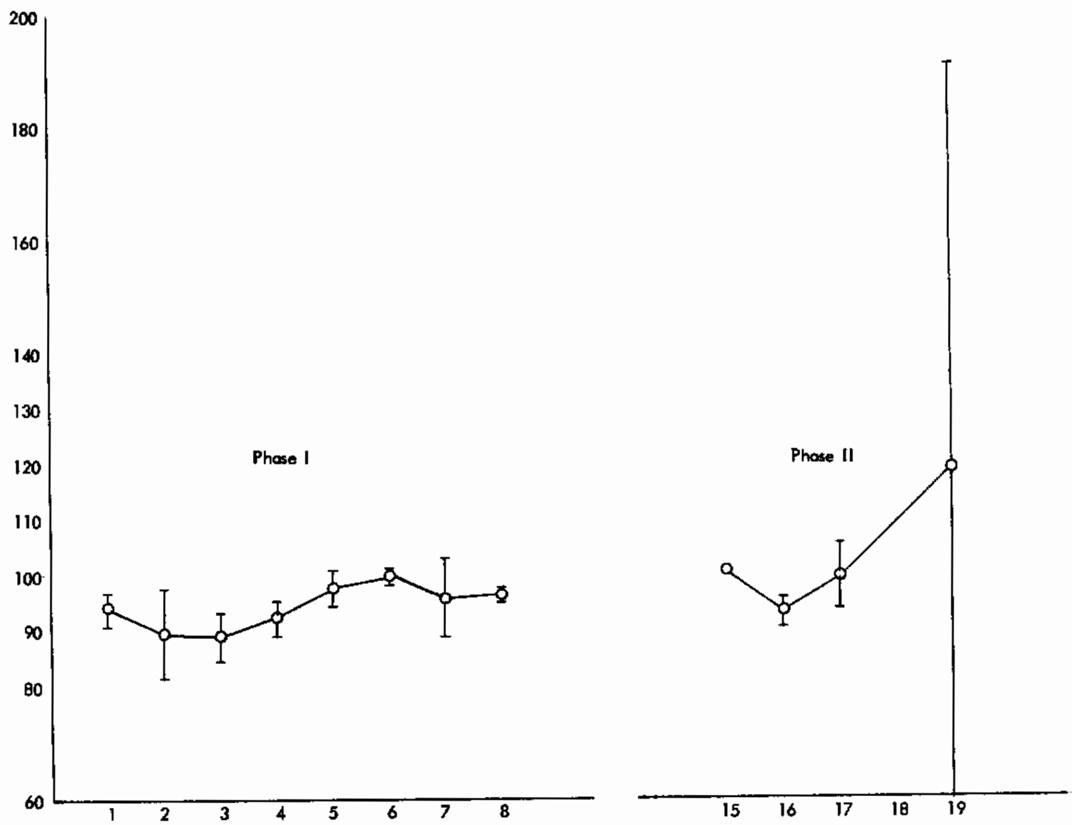

Figure 10. Daily average ratio, $\frac{\text{Small Bag}}{\text{Large Bag}}$ x 100 for Subject 41.

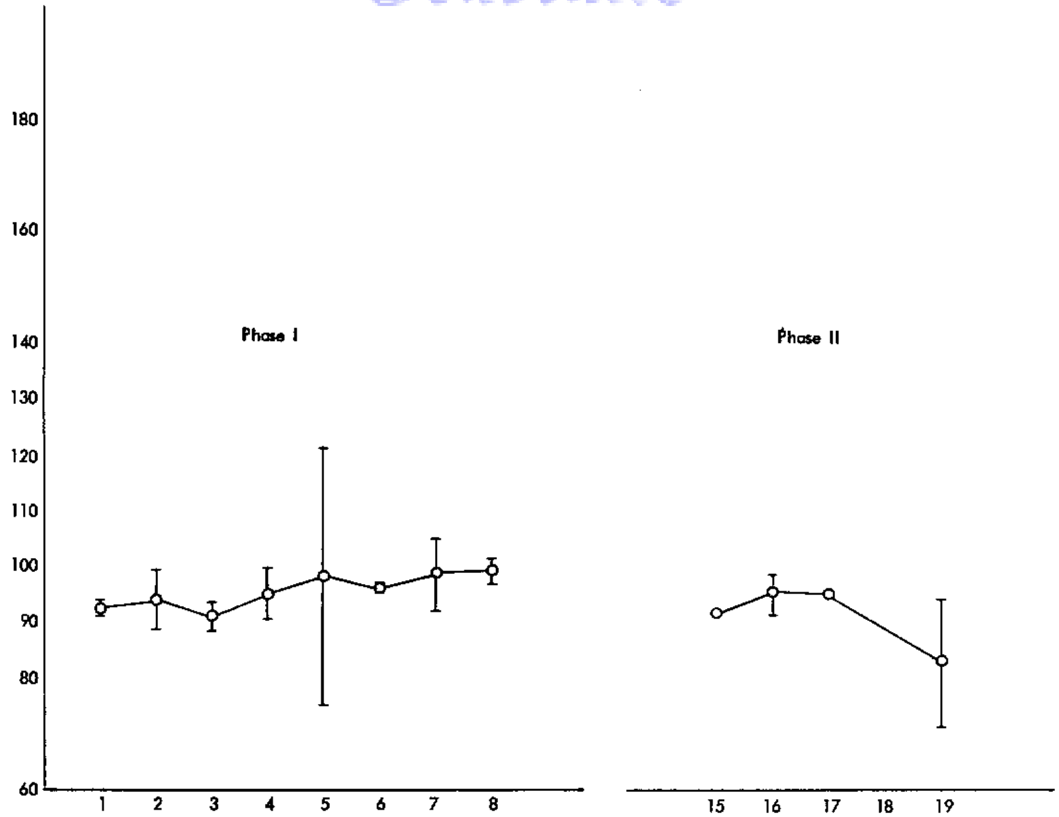

Figure 11. Daily average ratio, $\frac{\text{Small Bag}}{\text{Large Bag}}$ x 100 for Subject 42.

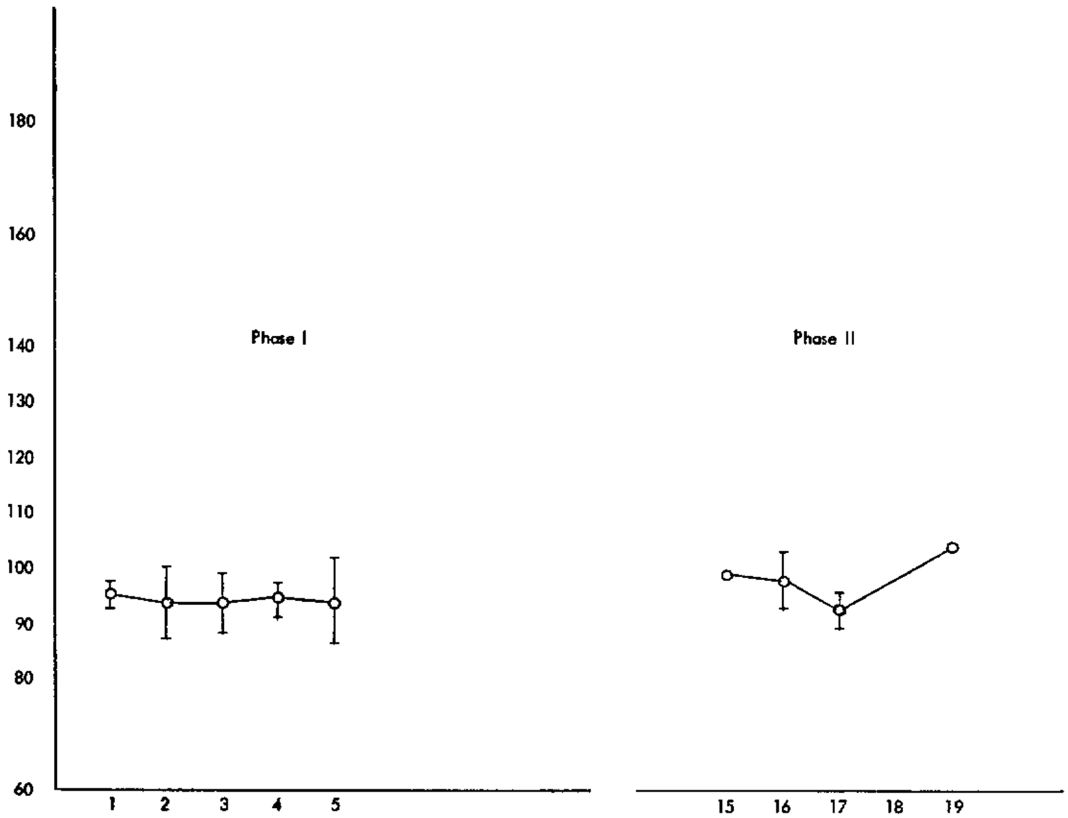

Figure 12. Daily average ratio, $\frac{\text{Small Bag}}{\text{Large Bag}}$ x 100 for Subject 43.

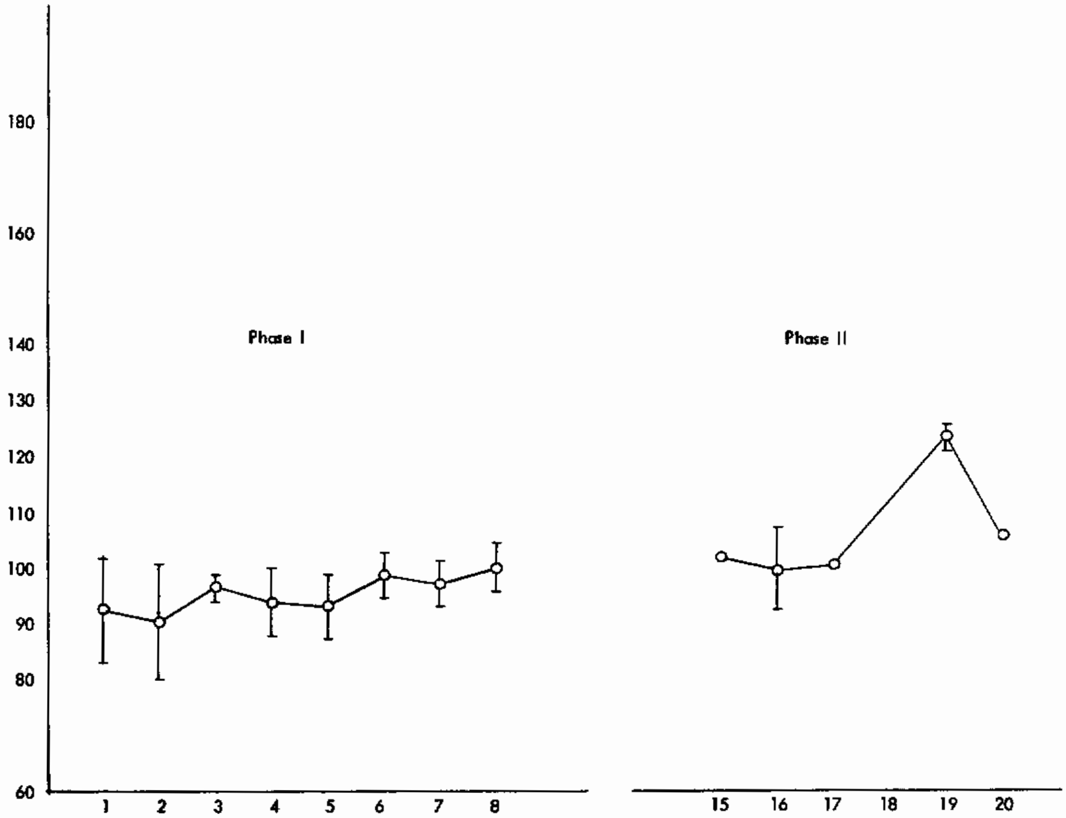

Figure 13. Daily average ratio, $\frac{\text{Small Bag}}{\text{Large Bag}}$ x 100 for Subject 44.

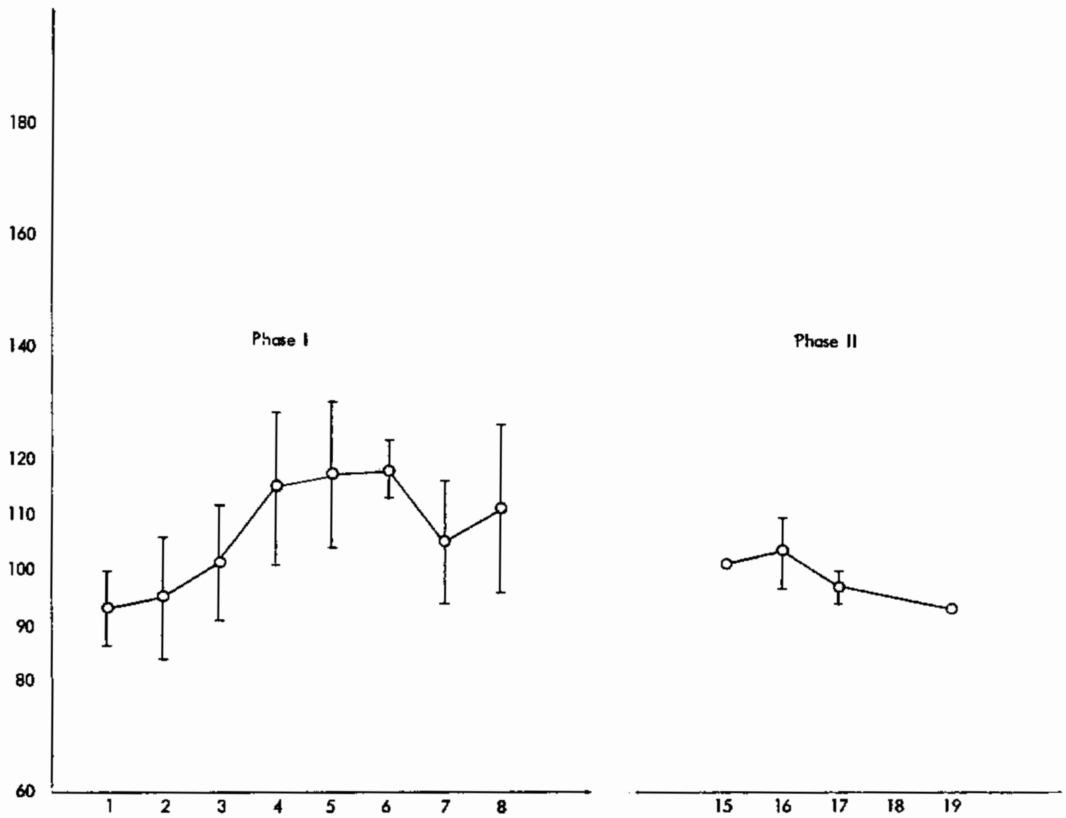

Figure 14. Daily average ratio, $\frac{\text{Small Bag}}{\text{Large Bag}}$ x 100 for Subject 41.

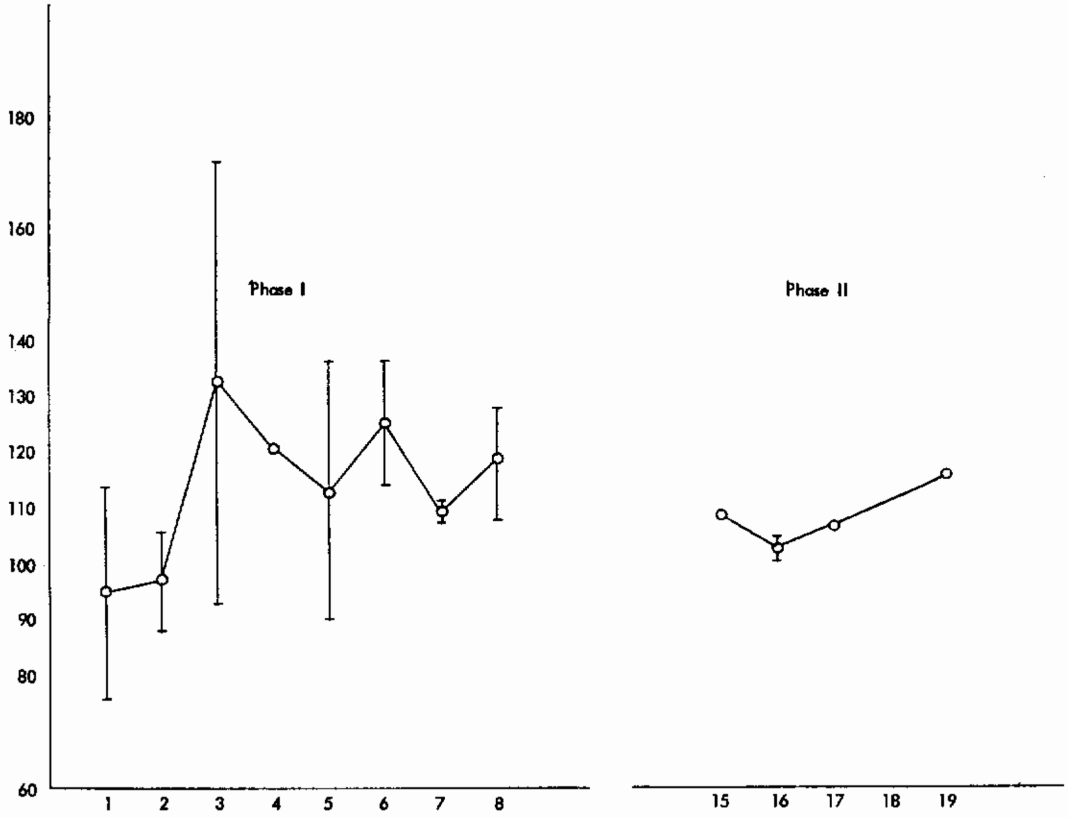

Figure 15. Daily average ratio, $\frac{\text{Small Bag}}{\text{Large Bag}}$ x 100 for Subject 42.

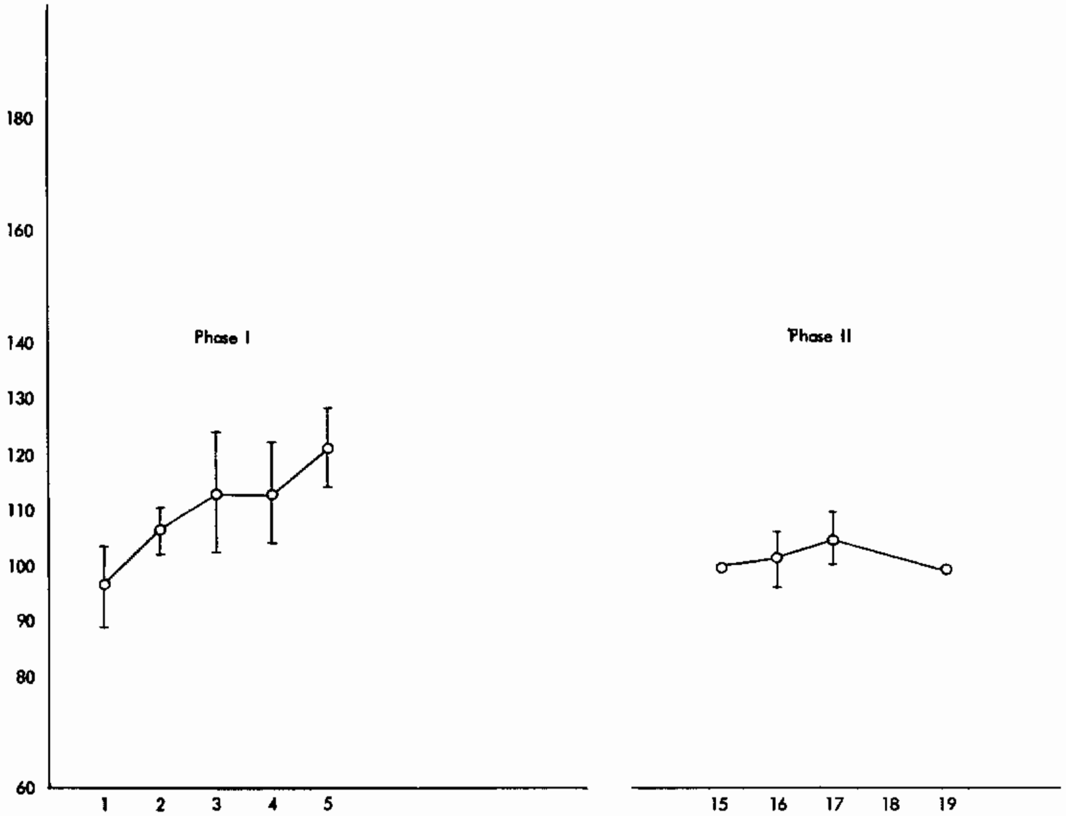

Figure 16. Daily average ratio, $\frac{\text{Small Bag}}{\text{Large Bag}}$ x 100 for Subject 43.

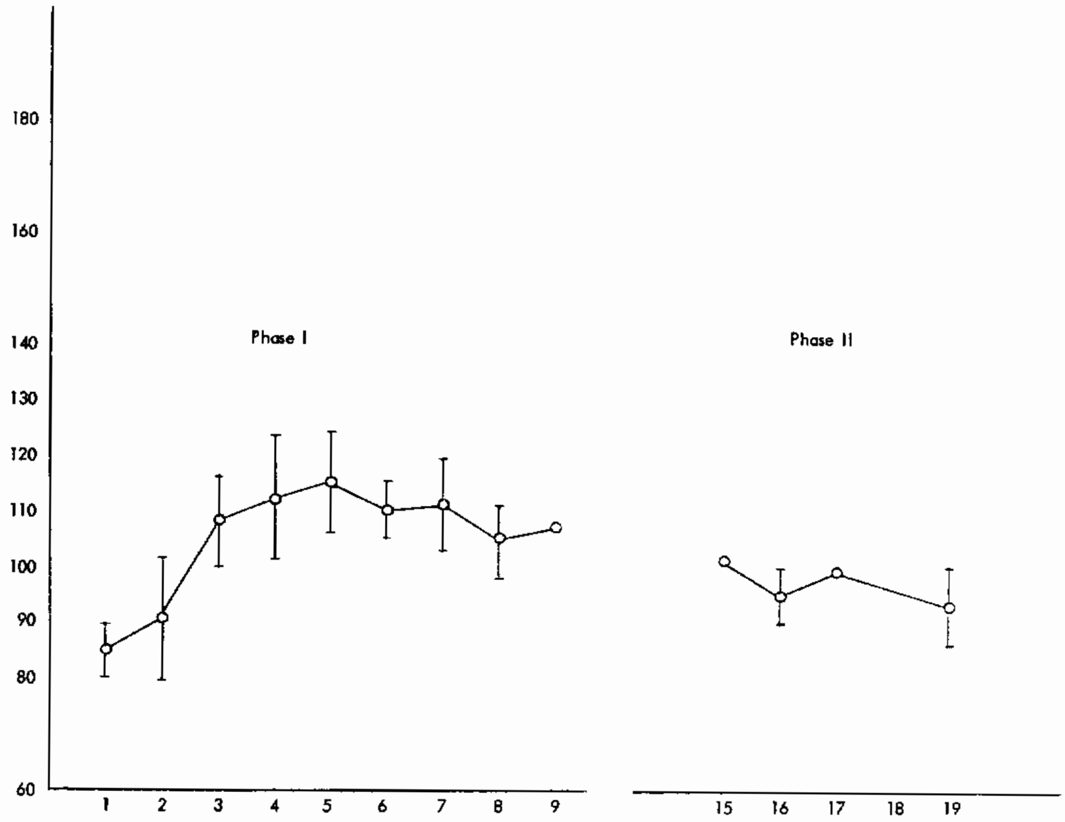

Figure 17. Daily average ratio, $\frac{\text{Small Bag}}{\text{Large Bag}}$ x 100 for Subject 44.

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13. ABSTRACT

A simulated aerospace study was conducted to assess the biochemical effects of space flight by determining the volume of urine output of each crewman. The Apollo urine transport system (UTS), using a radioisotope, tritium, dilution technique, was tested by four human male subjects. The Apollo UTS met minimum requirements for 14 days even when a single unit was used by four individuals. The best individual performance by a subject gave a ratio of 101.4 ±4.6%. The overall value for volume measurement from the four subjects was 100.6 ±4.6%. Any void volume may be calculated by this radioisotope method with the UTS system ±10% of its volume at the 95% confidence level. One experimental error was the incomplete mixing of the radioisotope. The practicability of this procedure in actual space missions still has to be determined.

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