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A COMPARATIVE STUDY OF THE PHYSIOLOGICAL EFFECTS OF IMMERSION AND BED REST

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by
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FOREWORD

This study is part of a program concerned with a quantitative demonstration of the feasibility and general effectiveness of a short-radius centrifuge in an orbital laboratory. It was supported by the Crew Systems Division, Manned Spacecraft Center, Houston, Tex., with Mr. W. V. Judy, Space Medicine Branch, serving as technical monitor. Dr. W. J. White was the principal investigator for the Douglas Aircraft Company, Inc., Santa Monica, Calif.

The authors acknowledge the timely and effective technical direction by Dr. Lawrence F. Dietlein, Head of the Biomedical Research Office, Crew Systems Division.

The Food and Drug Administration, Department of Health, Education, and Welfare, classifies the silicone fluid, used in this study as the immersion medium, as an investigatory new drug. Accordingly, an investigational plan was filed with FDA (Form FD 1573) as a condition for receiving and conducting research with a drug limited by federal law. A report of clinical findings is on file with the Dow Corning Corporation, Midland, Mich., supplier of the drug. The report is catalogued by the Missile and Space Systems Division, Douglas Aircraft Company, Inc., as Report No. DAC-59000. The report is augmented by directly related research data contributed by the Douglas Aircraft Company, Inc., resulting from Independent Research and Development program, Account No. 81241-0002. Dr. J. W. Nyberg was the physician responsible for this aspect of the study.

This report is catalogued by the Missile and Space Systems Division, Douglas Aircraft Company, Inc., as Report No. DAC-59226.

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SUMMARY

The purpose of the study was to compare the physiological responses of 10 subjects, each serving as his own control, during alternate 10-day periods of immersion and bed rest. Functional, diagnostic, and monitoring tests conducted before, during, and after the 10-day testing periods were used to follow physiological changes produced by these two analogs of null gravity and to quantitatively compare their effects. Fluid silicone was used as the immersion medium.

Neither immersion nor bed rest produced appreciable changes in Master's two-step test of exercise tolerance, resting oxygen consumption, tolerance to acceleration in the $+g_z$ direction, visual and auditory acuity, or in ECG and heart sounds recorded during tilt-table testing. There were no significant changes in microscopic or qualitative analysis of the urine for sugar, acetone, or protein; resting blood pressure, temperature, heart, and respiration rate; blood and urine chemistries or kidney and liver functions.

No serious complications were noted in any of the subjects during immersion or bed rest. Neither analog produced a free-water diuresis. The results of the study confirm the detrimental effects of prolonged immersion and bed rest on orthostatic tolerance and extracellular fluid volume. Both analogs brought about a deterioration in the mechanisms essential for adequate circulation in the erect position. This was shown by increased incidence of presyncopal reactions, by declines in pulse pressure, and by increased heart rate during tilt-table testing. Experimental conditions produced reductions in plasma, blood, and extracellular fluid volumes; declines in maximum oxygen consumption; and some impairment of postural equilibrium. Losses in body weight were progressive, the average was approximately 2% of initial weight. A negative free-water clearance was obtained in all subjects during immersion and bed rest.

Differential effects of the two environments are seen in orthostatic tolerance, fluid compartments, and renal function. The incidence of presyncopal reactions was higher and occurred earlier during immersion and bed during bed rest. Heart rates were higher and pulse pressures were lower during immersion than during bed rest. After 5 days of immersion and bed rest, the extracellular fluid decreased by 3% and 2%, respectively. After 10 days, the net decrease in fluid was 5% during immersion and 7% during bed rest. The conditions of immersion produced a larger loss in plasma volume after 5 days than did bed rest, but the net loss after 10 days was approximately the same for both environments. Changes in blood volume were parallel to those of plasma volume. Immersion produced an elevated urine flow, as evidenced by a comparison of urine outputs in the two environments and by higher urine outputs than fluid intakes during immersion. During bed rest the subjects produced a more concentrated urine, both with respect to individual electrolytes and solute load. During immersion the daily solute load excreted by the kidney was higher, urine output was larger, and osmolar clearance was higher.

The silicone fluid, immersion tanks, filtration, and cooling equipment met the requirements of the experiment. Except for two subjects, skin problems that developed during immersion were trivial. An effort to relate the occurrence of skin problems to bacteria, water, and contamination of the silicone was inconclusive. During a 6-month period following the study, the subjects were free of abnormal physical signs, symptoms, and skin problems.

INTRODUCTION

There are two experimental environments which are reproducible on Earth--at low cost and risk--that can furnish valid contributory data concerning the effects of prolonged null gravity on man. One environment is immersion and the other is bed rest; neither produces null gravity, but both produce physiological changes similar to those seen during post-flight medical examinations of American and Russian astronauts. The close relation of these two analogs with the null gravity of orbital flight justifies intense research if conclusions are to be drawn with due caution. Questions remain, however, as to the quantitative difference in the physiological effects produced by the two methods, and which of the analogs is most valid for predicting the effects of weightlessness on human physiology.

It is the purpose of this study, therefore, to compare the physiological responses of 10 subjects, each serving as his own control, during alternate 10-day periods of immersion and bed rest. Functional and diagnostic tests conducted prior to, during, and following the 10-day period are used to compare the relative effects of the two analogs. Fluid silicone is the immersion medium. Because silicone immersion is under study by Gerow (refs. 1 and 2) as an adjunct in the treatment of the burned patient, additional tests were included to define the effects of silicone immersion on unburned subjects.

There are a number of good general reviews and specialized comments on the biomedical implications of null gravity. Probably the most comprehensive reviews are those of Wunder (ref. 3) and McCally and Lawton (ref. 4). The report by Dietlein and Judy (ref. 5) on the cardiovascular conditioning experiment conducted during the flight of Gemini VII is representative of specialized comments.

METHODS

Experimental Plan

The study was divided into two 25-day experimental periods. The first 12 days of the experiment included 9 days of conditioning exercise, followed by 3 days of baseline (B) measurements and exercise. A 3-day baseline-recovery (BR) period followed the 10-day testing (T) period. Because each subject served as his own control, a period of 44 days was allowed for reconditioning following the first baseline-recovery period and the start of the next testing period.

The purpose of the conditioning exercise was to establish a daily level of metabolic activity at least 1 000 kcal greater than that expected during the testing period. The exercise consisted of three periods per day on the bicycle ergometer and three periods per day on the treadmill. Treadmill exercise consisted of running at 5 mph on a 10% grade for 10 min. Measured caloric value of this regimen was 150 kcal, for a total caloric expenditure of 450 kcal/day. Exercise on the bicycle ergometer consisted of a pedaling rate of 60 rpm at a power setting of 200 W. Each period lasted 17 min and resulted in a caloric expenditure of 160 to 170 kcal, for a total expenditure of 480 to 510 kcal/day. Exercise on the ergometer was done in the supine position. Thus, the caloric value of the conditioning regimen on each of the 12 days preceding the testing period was approximately 1 000 kcal/day/man.

During the 3-day baseline and baseline-recovery periods, the subjects resided in the biodynamic ward, but were not confined to beds or tanks. Functional and biochemical tests were conducted during these periods and the monitoring procedures were started.

During the 10-day testing period, the subjects remained horizontal, either in bed or in the tank. The only restriction placed on their movement

in bed was that the long axis of the cardiovascular system remained horizontal at all times; while in the tank, the only restriction was that they be immersed to neck level (suprasternal notch). Emunctory functions were performed in the horizontal position. A traveling hoist and body-support frame were used to lift the subjects out of the immersion fluid for these functions. Figs. 1 and 2 show an immersed subject and the support frame.

Monitoring and routine bed-fast nursing care were provided 24 hours a day during the baseline and testing periods.

Immersion Medium

To avoid the problems of skin maceration and infection during prolonged water immersion, the decision was made to use fluid silicone (dimethylpolysiloxane) as the immersion medium. The physical properties of this fluid make it particularly attractive as a water substitute in aerospace research. It is inert and nonvolatile, bacteriostatic and filterable, water repellent, and dielectric. The specific gravity of the fluid is 0.968 and its viscosity is 100 centistokes. Water, by comparison, has both a specific gravity and a viscosity of 1.0. Other members of the silicone family (ethyl methyl, ethyl phenyl, and so forth) were available, but Dow Corning 360 Medical Fluid was selected because of the experience gained in its use with severely burned patients.

Three separate tanks and filtration units were used. The fiberglass reinforced plastic tanks were 86 in. long, 32 in. wide, and 24 in. deep. Approximately one-half the tank was filled with silicone. Tygon and neoprene hoses connected the tanks with their respective filtration units. Pumps maintained the silicone at a pressure of 30 psi on the inlet sides of the filtration units. The diatomaceous earth filtration units had an effective filtering area of 10 sq ft. Cooling units were installed between the filtration units and the tanks to dissipate the heat transmitted to the fluid by the subject and by the continuous pumping required to prevent accumulation of water, debris, and bacteria. Fig. 3 shows the filtration and cooling units. A portable pump and filtration unit were used several times a day to remove hair, food, and large water droplets from the tanks.

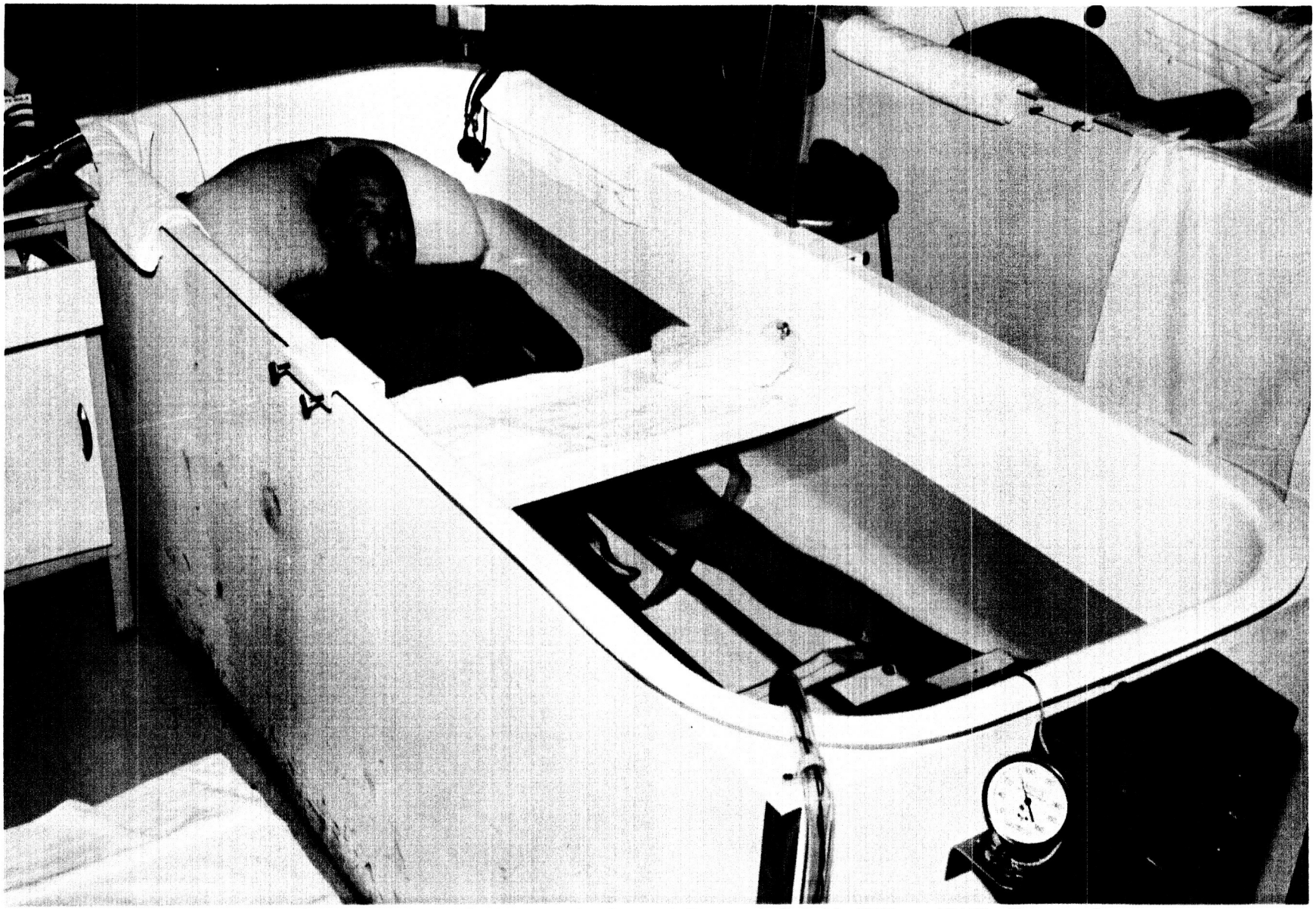

Figure 1. Immersion Tank Subject on the Support Frame, Inflatable Pillow, Utility Tray, and Temperature Alarm System

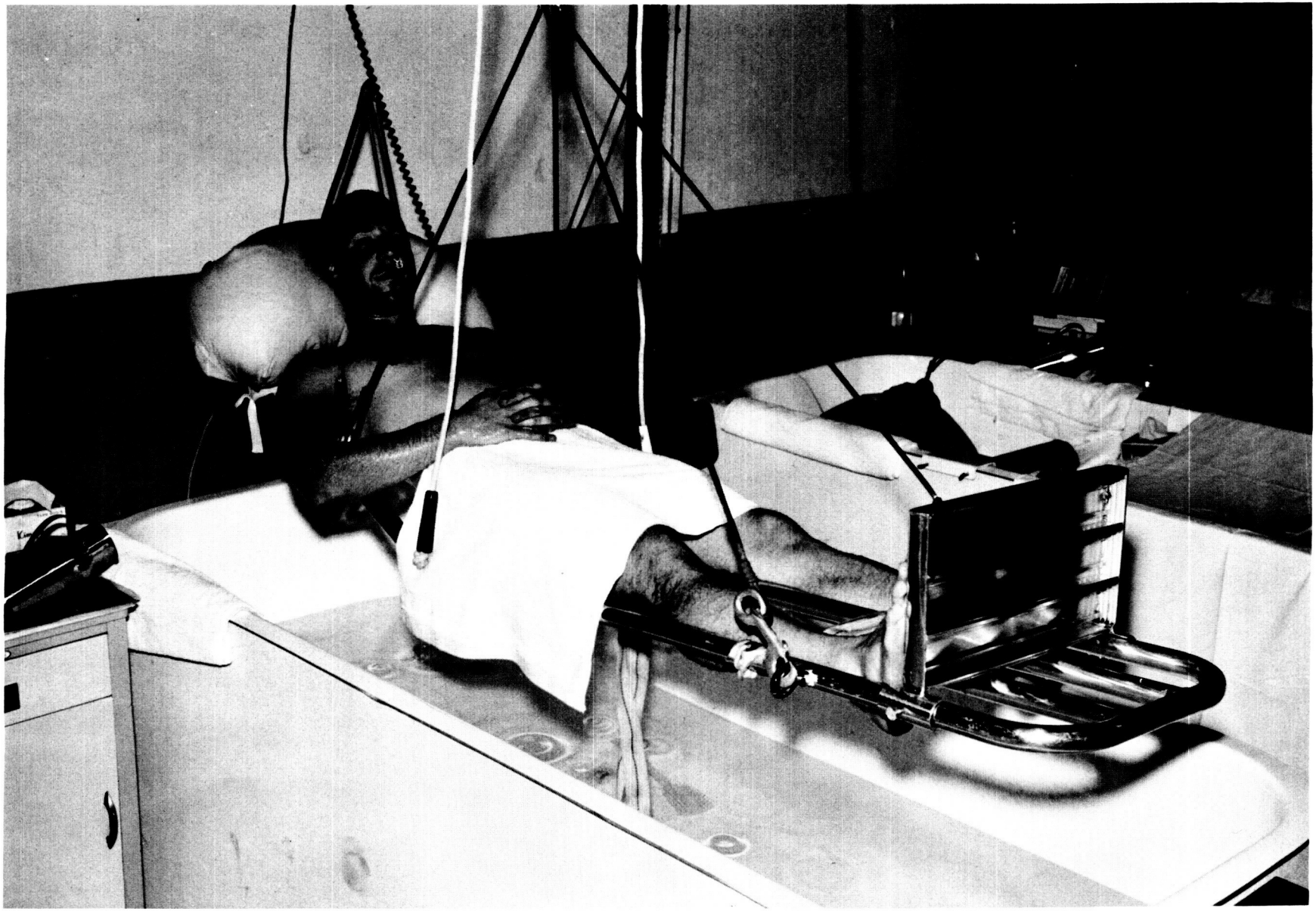

Figure 2. Operation of Support Frame During the Test Period.

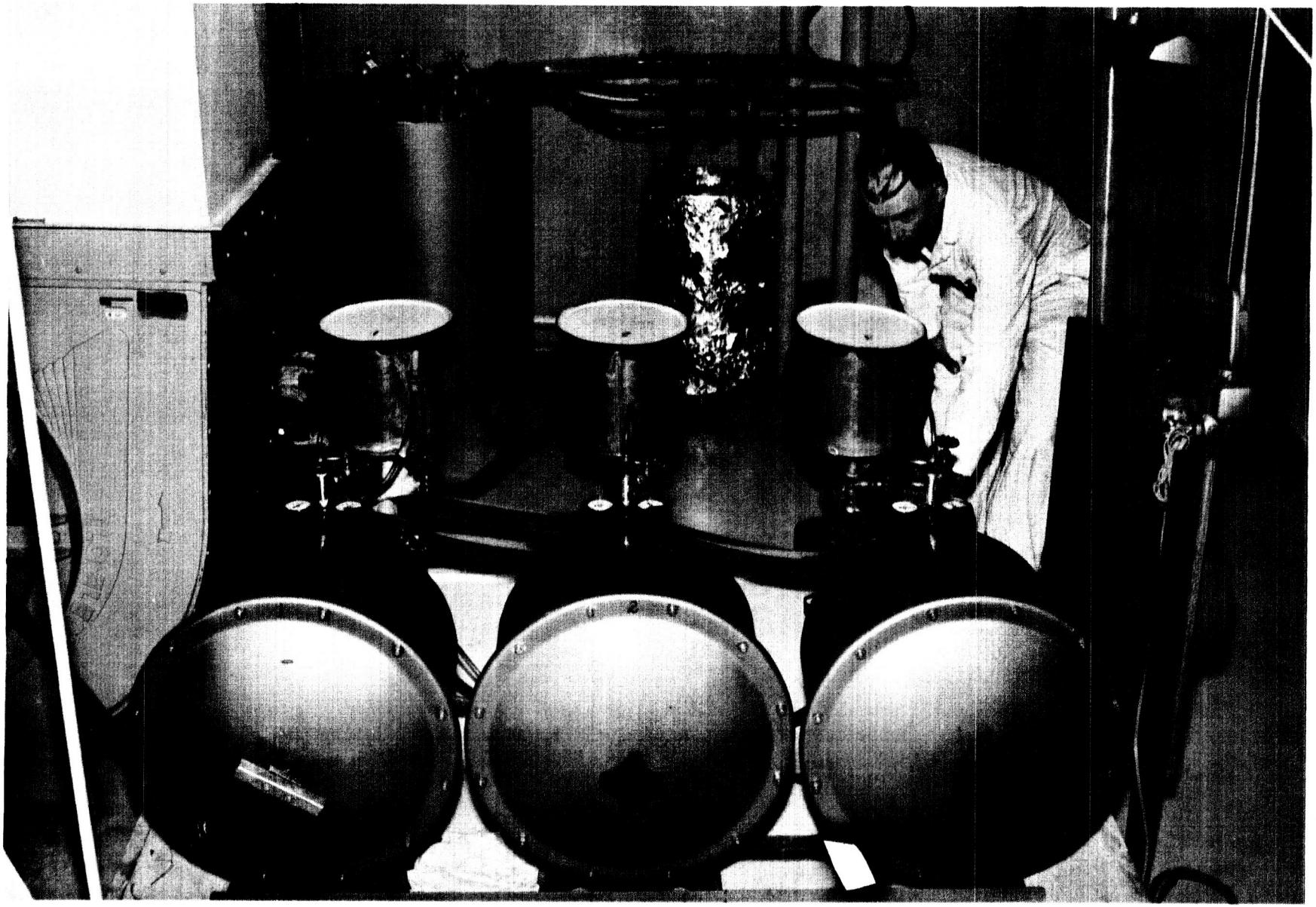

Figure 3. Filtration Units in Foreground – Dual Cooling Units in Background

Subjects

During two separate periods of testing, 10 subjects were studied while on a constant diet. From the original population of 12 subjects, Subject JG was removed prior to experimentation on B-3 for tilt-table intolerance; Subject GK was withdrawn from immersion on T-4 after he developed maceration and erythema of both feet; and Subject RM completed 10 days of bed rest and 8 days of immersion before being withdrawn because of skin problems. All subjects were paid volunteers. Before the study, the subjects were briefed thoroughly on the nature of the experiment, the probable risks, and the steps to be taken to ensure their health and welfare. During the course of the experiment, they were informed of any changes. Also, at the conclusion of the study they were told of the findings and given the final technical report to read. The subjects were free to withdraw from the experiment at any time. Admitting history, physical examination, Master's electrocardiogram (ECG), urinalysis, and blood analysis of each subject were normal. Physical characteristics of the subjects are shown in Table I. Each subject served twice in the study, first in one environment and then in the other; separation between successive testing periods was 44 days. The subjects were placed on a diet calculated to be 2 100 kcal. Average daily calcium intake was calculated to be from 0.6 to 1.0 g.

Baseline and Intercurrent Measures

Table II lists the functional, biochemical, and monitoring tests performed during the study. These can be further subdivided into baseline measurements made prior to, and after, each test period, and the intercurrent measures. The table gives the dates of each administration of the tests.

The tilt-table test was used to measure the functional reserve of the cardiovascular system. The subject, seated in a saddle, was tilted to 70°, feet downward, for 20 min (unless syncope intervened). Fig. 4 shows a subject on the tilt table. Heart rate and blood pressure readings were taken every minute before, during, and after the tilt test. The subject was allowed

TABLE I

PHYSICAL CHARACTERISTICS OF SUBJECTS

Subject	Age	Height (cm)	Weight (kg)	Plasma volume/ lean mass (ml/kg)
BB	22	177.2	75.15	57.0
LB	26	168.9	61.11	42.7
EH	22	181.4	68.53	61.1
JH	21	174.6	71.98	63.1
BI	22	185.7	75.42	60.0
GK [a]	22	176.6	88.73	57.9
LL	22	176.9	78.77	56.6
RM [b]	25	190.5	83.49	53.6
BS	22	177.5	74.16	52.8
LS	24	174.6	71.20	58.4
WW	26	180.6	74.43	56.0

[a]Withdrawn from immersion for medical reasons on T-4.
[b]Withdrawn from immersion for medical reasons on T-8.

to rest quietly for 5 min prior to, and following, head-up tilt. ECG and phonocardiograms were taken continuously during the tilt test. All tilt-table tests were conducted by the same physician.

Acceleration tolerance was determined by bioassay runs on the centrifuge. The subjects were seated in a free-swinging cab. The distance from the heart to center of rotation was 182 in. A modification of the conventional bioassay technique was used (ref. 6). Each run was conducted at a rate of onset of acceleration of 0.1 g/sec until blackout, followed by a slow decay of acceleration. Blackout, or loss of tolerance, was the level of acceleration at which the central vision was lost. During these runs, heart rate and ECG were monitored.

Figure 4. Tilt Table at 70° With Saddle Support

TABLE II

BASELINE AND INTERCURRENT MEASURES

Tests	Date of determination				
Functional					
Orthostatic tolerance	B-3	T-2	T-4	T-8	T-10
ECG and phonocardiogram	B-3	T-2	T-4	T-8	T-10
Acceleration tolerance	B-2	-	-	-	BR-1
Maximum oxygen intake--exercise	B-3	-	-	-	BR-3
Oxygen consumption--rest	B-3	-	T	-	BR-2
Master's two-step ECG	B-1	-	-	-	BR-3
Body weight and composition	B-3	-	-	-	BR-3
Postural equilibrium	B-1	-	-	-	BR-1
Audiometry	B-1	-	-	-	BR-3
Visual testing	B-1	-	-	-	BR-3
Biochemical					
Total body water ($H_2{}^3O$)	B-1	-	T-5	-	T-10
Extracellular fluid (Br^{82})	B-1	-	T-5	-	T-10
Plasma and blood volumes (T-1824)	B-1	-	T-5	-	T-10
Blood--Electrolytes, Ca, P, electrophoresis, creatinine, hematocrit, hemoglobin, RBC count and morphology, WBC count, morphology and differential, cephalin cholesterol flocculation, thymol turbidity, SGOT	B-1	-	T-5	-	T-10
Urine--Electrolytes, Ca, P, creatinine, osmolarity, specific gravity, routine, micro, pH, 17 OH-Ketosteroids, catecholamines	B	-	T	-	BR
PSP	B	-	-	-	BR
BSP	B	-	-	-	BR
Blood--Silicone analysis	B	-	T-5	-	BR
Urine--Silicone analysis	B	-	T-5	-	BR
Cultures--Nose, throat, and urine	B	-	PRN	-	-
Silicone					
Cultures			Daily		
Water analysis	B	-	T-5	-	BR
Irritants testing	B	-	-	-	BR
Miscellaneous contaminants	B	-	T-5	-	BR
Monitoring					
Fluid intake/output Blood pressure Heart and respiration rates Temperature			Daily		
Physical examination					

Note: Baseline (B) was on June 23 or July 9, 1965 for the first testing period and Aug. 19 or Sept. 4, 1965 for the second period.

Measurement of maximum oxygen intake consisted of running on a motor-driven treadmill at three different speeds (6, 7, and 8 mph) at grades of 8, 10, and 12%. A 30-min rest period separated the successive runs. The duration of a run was 3 min; expired air was collected in a Douglas bag during the final minute of the run. Volume measurements were made with a wet-gas meter; chemical analysis of the expired air for oxygen, nitrogen, and carbon dioxide content was made with the use of gas chromatography.

Oxygen consumption at rest was measured in the conventional manner. Although this measurement was made at the same time each day with the subjects resting quietly, they were not in a fasting state. Two methods for determining oxygen consumption were used--chemical analysis of a sample drawn from a Douglas bag, and the quantity of oxygen consumed from a known supply contained in a respirometer.

A routine Master's two-step test with a 12-lead ECG was taken in the conventional manner. The results of this test were analyzed by a board-certified cardiologist.

Body composition was determined on the basis of a human-body volumeter and a formula developed by Allen (ref. 7). Both lean body mass and fat were calculated. A precision scale was used to measure body weight.

The Graybiel-Fregly posture test uses rails that are a modification of those originally used to screen American astronauts. In the present study, the short form of this postural equilibrium test was used. There were five trials on each of the following three tasks:

(1) Walking heel-to-toe, with arms folded against the chest, on a 0.75 in. rail for five steps or until balance could not be maintained.

(2) Standing heel-to-toe, with eyes open and arms folded, on the 0.75 in. rail until the subject fell off the rail.

(3) Standing on a 2.25 in. rail, with eyes closed and arms folded, until the subject fell off the rail.

Scoring was based on the best three out of five trials; maximum scores were 15 steps for walking and 180 sec for standing.

Audiograms and visual testing were done in a conventional manner with a Bekesy-type audiometer and the Armed Forces Visual Tester.

The experimental plan called for a variety of hematological and biochemical analyses.* These analyses are listed in Table II. Urine and blood samples were analyzed in a conventional manner.

Total body water and extracellular fluid were determined using radioisotopes; plasma and blood volumes were determined using Evans blue (T-1824). Tritium was used to calculate the total body water; extracellular fluid was determined with Br^{82}. Because equipment was not available for differentiating Br^{82} from I^{131}, the decision was made to use the dye technique rather than I^{131} for determining plasma volume. The subjects were classified as radiological workers, and the radiation dose was maintained within the limits specified by The Bureau of Standards Handbook 69.

Irritants testing of the silicone was conducted prior to and following each testing period. The testing consisted of intracutaneous injections into rabbits of unused silicone, used silicone, and normal saline solution. Observations were made of the test sites at 24-, 48-, and 72-hour intervals. Analysis of the silicone for water and miscellaneous contaminants was conducted by the Dow Corning Corporation.

The silicone was monitored continuously for color, odor, and temperature. Diatomaceous earth and charcoal were added to the filtering units, the amount depended upon the color, odor, and water content of the fluid. Approximately 1 lb of diatomaceous earth per day was added to each filtering unit. The temperature of the silicone was maintained at approximately 89°F (range 87° to 91° F) by adjusting the flow of silicone through the cooling units. Subjects selected the temperatures at which they felt comfortable.

*Routine tests were performed by the Bio-Science Laboratories; specialized tests were performed by Dr. H. S. Lipscomb, Baylor University.

Monitoring tests, shown in Table II, followed hospital ward routine and the results were recorded by the nurse on each of the three 8-hour shifts. Medical summaries, prepared by the duty nurse and augmented by the experimenters, included subject reaction to the conditions of the experiment and their attitudes toward each other and the staff.

RESULTS

Functional Tests

The results of the tilt-table test of orthostatic tolerance are summarized numerically in Table III. It shows that both analogs brought about a deterioration in the mechanisms essential for adequate circulation in the erect position, as indicated by syncope or tendency to syncope during tilt-table testing; by general declines in pulse pressure; and by increased heart rate on the tilt table. The incidence of presyncopal reactions was higher and occurred earlier in the 10-day period during immersion than during bed rest. During immersion, there were 22 presyncopal episodes as compared with 15 during bed rest. Heart rates were higher and pulse pressures were lower during immersion than they were during bed rest.

Table IV shows that of the subjects who served during alternate 10-day periods of immersion and bed rest, one subject (RM) showed evidence of cardiovascular deterioration in both environments, but did not show a tendency to faint in either environment; three subjects (BB, LB, and EH) experienced presyncopal symptoms during immersion but none during bed rest; three subjects (BI, GK, and LS) experienced an equal number of presyncopal episodes in both environments; and the three remaining subjects (WW, BS, and JH) experienced syncopal reactions more frequently during the immersion period than during bed rest. Time to presyncopal symptoms while on the tilt table was approximately the same for each subject and analog. Increases in recumbent resting heart rates were progressive and were generally higher during immersion than during bed rest. Average heart rates during 70° head-up tilt increased progressively in both groups; however, there was a greater increase in heart rate during immersion when compared with bed rest (Table V).

TABLE III

TILT-TABLE TEST--SUMMARY

Date of determination	Immersion				Bed rest			
	No. of subjects	No. of syncopy	Average of integrated heart rate	Average of integrated pulse pressure	No. of subjects	No. of syncopy	Average of integrated heart rate	Average of integrated pulse pressure
B-3	11	0	77	30	11	0	77	30
T-2	11	6	102	17	11	4	94	24
T-4	10	5	113	17	10	4	102	22
T-8	10	7	107	22	10	3	103	25
T-10	9	4	113	20	10	4	103	24

Note: Heart-rate entries are in beats per minute; pulse pressures are in mm Hg

TABLE IV

TIME AND OCCURRENCE OF SYNCOPE

Subject	Immersion				Bed rest			
	T-2	T-4	T-8	T-10	T-2	T-4	T-8	T-10
BB	-	-	19	12	-	-	-	-
LB	-	10	-	-	-	-	-	-
EH	-	-	8	-	-	-	-	-
JH	9	5	4	6	-	12	-	14
BI	6	-	20	4	-	5	12	7
GK	15	*	*	*	17	*	*	*
LL	-	-	-	-	-	15	-	10
RM	-	-	-	*	-	-	-	-
BS	15	18	13	-	17	-	17	-
LS	6	16	6	9	6	8	5	6
WW	5	5	7	-	14	-	-	-
Average	9	11	11	8	14	10	11	9

Notes: (1) Entries are in minutes to presyncopal symptoms
(2) *Subjects withdrawn from immersion

No specific changes occurred in the ECG's and phonocardiograms recorded during tilt-table testing, the recordings were always within normal limits.

Tolerance to positive acceleration was measured before and after a 10-day testing period. A summary of the results of this test is shown in Table VI. Tolerance was measured using a single, gradual onset run (0.1 g/sec) to blackout. In the event blackout did not occur, all runs were terminated arbitrarily at +5 g_z. These data show no changes in tolerance to positive acceleration as a result of experimental conditions. Typically,

TABLE V

AVERAGE HEART RATES BEFORE AND DURING 70° TILT

Subject	Average 5-min heart rate before tilt										Average heart rate during tilt									
	Immersion					Bed rest					Immersion					Bed rest				
	B	T-2	T-4	T-8	T-10	B	T-2	T-4	T-8	T-10	B	T-2	T-4	T-8	T-10	B	T-2	T-4	T-8	T-10
BB	82	75	84	78	80	73	82	85	93	83	95	117	131	126	132	93	115	122	121	120
LB	75	72	79	88	82	84	68	72	72	70	87	93	102	109	99	68	72	83	80	75
EH	60	53	54	58	65	56	52	54	56	63	75	78	80	81	96	67	77	83	82	95
JH	68	70	86	76	83	77	76	88	80	67	80	128	128	120	133	82	119	132	127	129
BI	69	66	69	69	70	65	66	68	70	64	75	114	124	130	111	74	99	110	108	98
GK	57	60	*	*	*	56	58	*	*	*	72	88	*	*	*	72	79	*	*	*
LL	93	92	112	101	100	78	86	90	100	106	116	140	148	139	148	83	120	125	138	134
RM	50	55	60	52	*	52	51	54	51	50	69	91	100	87	*	76	83	94	87	86
BS	55	60	61	57	64	54	57	53	56	57	74	110	111	97	111	67	90	86	97	98
LS	57	56	60	59	56	60	54	60	50	58	72	76	93	80	77	72	74	83	72	82
WW	48	56	64	59	58	56	60	62	66	66	61	82	114	104	110	67	103	103	115	112
Average	65	65	73	70	73	65	65	69	69	68	80	102	113	107	113	75	94	102	103	103

Notes: (1) Entries are in beats per minute
(2) *Subjects withdrawn from immersion

TABLE VI

ACCELERATION TOLERANCE

Subject	Date of determination		
	Baseline	Baseline - recovery	
		Immersion	Bed rest
BB	4.6	4.6	4.2
LB	5.0[a]	4.7	4.8
EH	3.7	2.8	3.9
JH	4.0	3.5	3.6
BI	3.1	2.9	3.2
GK	3.9	*	*
LL	3.6	1.5[b]	3.5
RM	3.7	*	3.8
BS	3.2	3.3	2.3
LS	3.0	3.6	3.2
WW	4.4	4.2	4.3
Average	3.7	3.7	3.7

Notes: (1) All entries in $+g_z$ units at heart level
(2) [a]Terminated at maximum g; not included in mean
(3) [b]Terminated at maximum heart rate; not included in mean
(4) *Subjects withdrawn from immersion

Subject LL showed a pronounced tachycardia when stressed. Unfamiliarity with this typical response caused the medical monitor to terminate the run when the heart rate exceeded an arbitrary maximum of 180 beats/min. The ECG, except for changes commonly seen at these rates, was within normal limits. Repeated runs on the centrifuge confirmed that this was a typical response for this individual and in no way indicated abnormality.

Measurements of maximum oxygen intake on the treadmill shows that both environments produce significant musculo-skeletal and cardiovascular deconditioning. However, no trend is apparent that would indicate a differential effect of immersion or bed rest on oxygen consumption during exercise.

Oxygen consumption while at rest was measured before, during, and after the 10-day testing period. Two methods were used--chemical analysis of samples drawn from a Douglas bag and the quantity used from a fixed oxygen supply in a respirometer. The results are shown in Table VII for each subject, experimental condition, and method. These data show, where direct comparisons are possible, that the resting metabolic levels of subjects in fluid immersion and at bed rest are the same.

A Master's two-step ECG, taken before and after the experiment, showed no abnormalities and no loss in exercise tolerance.

Changes in body weight and composition are shown in Table VIII. Losses in weight were progressive in all subjects and ranged from 0.20 to 3.29 kg. Average weight loss during immersion was 1.59 kg and during bed rest was 1.54 kg, or approximately 2%. Subject BI showed the largest weight loss and Subject BS the smallest. A 2% decrease in lean body mass is associated with immersion, and a 2% increase in this mass is associated with bed rest. Body fat and total weight decreased systematically; losses in fat were 15% during immersion and 13% during bed rest.

The results of the Graybiel-Fregly postural equilibrium test are summarized in Table IX. The conditions of the experiment resulted in a general decrement in the number of steps taken on the 0.75-in. rail before falling off, the number of seconds the subject could stand with eyes open on the 0.75-in. rail, and the number of seconds the subject could stand with eyes closed on the 2.25-in. rail.

Audiometric and visual testing showed that hearing and vision were unaffected by the conditions of the experiment.

TABLE VII

OXYGEN CONSUMPTION AT REST

Subject	Medium	Date of determination														
		B-3	T-1	T-2	T-3	T-4	T-5	T-6	T-7	T-8		T-9		T-10		BR-2
		Resp	D.B.	Resp	D.B.	Resp	D.B.	Resp	D.B.	D.B.	Resp	D.B.	Resp	D.B.	Resp	D.B.
BB	Immersion		0.27	0.29	0.31	0.33	0.26	0.40	0.29		0.32	0.26			0.29	
	Bed rest															
LB	Immersion															
	Bed rest		0.21	0.24	0.22	0.21	0.22	0.24	0.23		0.25	0.23			0.26	
EH	Immersion															
	Bed rest		0.29	0.34	0.27	0.31	0.32	0.31	0.29		0.28	0.32			0.28	
JH	Immersion		0.28		0.29	0.29	0.26	0.31	0.27		0.27	0.31			0.32	
	Bed rest	0.30	0.34	0.31	0.30	0.31	0.27	0.29		0.27	0.31		0.35	0.25		0.27
BI	Immersion		0.31	0.32	0.29	0.38	0.31	0.31	0.32		0.29	0.34			0.32	
	Bed Rest															
GK	Immersion	0.32	0.36	0.27	0.34	0.35	*	*	*	*	*	*	*	*	*	*
	Bed rest															
LL	Immersion		0.33		0.23	0.31	0.30	0.35	0.28		0.35	0.29			0.37	
	Bed rest	0.32	0.32	0.33	0.30	0.32	0.41	0.34		0.31	0.35		0.36	0.28		0.30
RM	Immersion		0.28	0.29	0.27	0.39	0.26	0.51	0.27		0.28	*	*	*	*	*
	Bed rest															
BS	Immersion	0.30	0.29	0.30	0.30	0.28	0.29	0.28		0.30	0.27		0.29	0.28		0.29
	Bed rest		0.26		0.27	0.30	0.28	0.33	0.29		0.26	0.28			0.30	
LS	Immersion															
	Bed rest		0.26	0.32	0.23	0.35	0.23	0.31	0.27		0.27	0.27			0.32	
WW	Immersion	0.35	0.31	0.33	0.31	0.32	0.34	0.32		0.37	0.35		0.38	0.31		0.28
	Bed rest		0.30		0.29	0.32	0.28	0.32	0.29		0.33	0.27			0.35	

Notes: (1) Entries are in L/min and are corrected to BTPS
(2) D.B.--Douglas bags utilized for determinations
(3) Resp--Collins respirometer utilized for determinations
(4) *Subjects withdrawn from immersion

TABLE VIII

BODY WEIGHT AND COMPOSITION

Subject	Medium	Date of determination					
		Baseline			Baseline - recovery		
		Total	Lean	Fat	Total	Lean	Fat
BB	Immersion	76.84	59.25	17.59	74.27	55.96	18.31
	Bed rest	75.15	57.30	17.85	74.12	54.56	19.56
LB	Immersion	61.11	47.45	13.66	60.32	45.92	14.40
	Bed rest	60.44	50.04	10.40	59.30	50.25	9.05
EH	Immersion	68.53	58.26	10.27	68.32	57.66	10.66
	Bed rest	68.09	59.52	8.57	66.52	59.99	6.53
JH	Immersion	72.25	52.79	19.46	70.01	50.20	19.81
	Bed rest	71.98	50.48	21.50	70.67	50.12	20.55
BI	Immersion	75.09	62.96	12.13	71.80	62.80	9.00
	Bed rest	75.42	57.72	17.70	72.45	60.15	12.30
GK	Immersion	88.73	62.48	26.25	87.37	*	*
	Bed rest	*	*	*	*	*	*
LL	Immersion	78.38	63.64	14.74	76.50	63.27	13.23
	Bed rest	78.77	58.73	20.04	77.59	61.04	16.55
RM	Immersion	83.52	72.88	10.64	82.12	74.87	7.25
	Bed rest	83.49	75.02	8.47	81.49	71.44	10.05
BS	Immersion	74.16	60.64	13.52	73.70	61.30	12.40
	Bed rest	74.22	63.85	10.37	73.73	62.86	10.87
LS	Immersion	71.20	61.32	9.88	69.91	59.57	10.34
	Bed rest	71.41	61.63	9.78	69.99	61.79	8.20
WW	Immersion	74.43	62.12	12.31	72.39	60.89	11.50
	Bed rest	75.19	64.85	10.34	72.91	63.97	8.94

Notes: (1) Entries are in kg
(2) *Subject withdrawn from immersion

TABLE IX

POSTURE TESTS--SUMMARY

	Baseline	Baseline - recovery	
		Immersion	Bed rest
Walking			
Total steps	149	129	136
Change		-20	-13
Average no. steps	13.5	11.7	12.4
Percent change		-13%	-9%
Standing -- eyes open			
Total seconds	662	411	465
Change		-251	-197
Average time	60.2	37.4	42.3
Percent change		-38%	-30%
Standing -- eyes closed			
Total seconds	907	566	845
Change		-341	-62
Average time	82.5	51.5	76.8
Percent change		-38%	-17%

Biochemical Tests

The effects of immersion and bed rest on plasma volume, hematocrit, blood volume, and extracellular fluid are summarized in Table X. Immersion for 5 days resulted in an average plasma volume loss of 729 ml or 23%. After 5 days of bed rest, the average plasma volume loss was 469 ml or 14%.

TABLE X

FLUID COMPARTMENT VALUES--SUMMARY

Compartment	Medium	Date of determination						
		B-1	T-5			T-10		
		Volume	Volume	Percent change	Change	Volume	Percent change	Change
Plasma volume	Immersion	3 238	2 509	-23%	-729	2 804	-13%	-434
	Bed rest	3 285	2 816	-14%	-469	2 796	-15%	-489
Hematocrit	Immersion	43%	49%	+ 6%	-	45%	+ 2%	-
	Bed rest	43%	47%	+ 4%	-	45%	+ 2%	-
Blood volume	Immersion	5 497	4 780	-13%	-717	4 970	-10%	-527
	Bed rest	5 543	5 123	- 8%	-420	4 919	-11%	-624
Extracellular fluid	Immersion	18.69	18.05	- 3%	- 0.64	17.71	- 5%	- 0.98
	Bed rest	18.73	18.32	- 2%	- 0.41	17.44	- 7%	- 1.29

Notes: (1) Plasma volume--Total blood volumes in ml
(2) Extracellular fluid in liters

After 10 days of immersion and 10 days of bed rest, the net plasma loss was 434 ml or 13% and 489 ml or 15%, respectively. During the last 5 days of immersion, there was a relative increase in plasma volume.

Total blood volume was calculated from plasma volume and hematocrit (allowing 4% for the plasma trapped between red cells). Immersion for 5 days resulted in an average blood volume loss of 717 ml or 13%. After 5 days of bed rest, the average blood volume loss was 420 ml or 8%. After 10 days of immersion, blood volume increased with a resulting net loss of 527 ml or 10% of the baseline volume. Bed rest for 10 days resulted in a continued decrease in blood volume, the net loss was 624 ml or 11%.

After 5 days of immersion, extracellular fluid decreased by 640 ml or 3%. Bed rest for 5 days resulted in a loss of 410 ml or a 2% decrease in extracellular fluid. A net loss of 980 ml or a 5% decrease in extracellular fluid was found after 10 days of immersion and 1 290 ml or a 7% loss was found after 10 days of bed rest.

Tritium was used to calculate total body fluid. Because of the difficulties inherent in the use of this procedure, the results are equivocal and are not presented here.

Plasma, blood, and extracellular fluid volumes are shown in Table XI for each subject and experimental condition. The data from Subject GK are not included in this table because the subject was withdrawn from immersion on T-4.

There were no significant changes in blood chemistries as a result of the conditions of the experiment. Table XII summarizes the results of the chemistries performed at regular intervals during the two testing periods.

A majority of the subjects developed a trend toward increased hemoglobin, hematocrit, and red-cell count by the 5th and 10th days of testing; however, no difference between immersion and bed rest environments were apparent. White-blood cell counts were essentially normal. Sodium, potassium, chlorides, bicarbonate, calcium, phosphorus, creatinine, and SGOT all

TABLE XI

FLUID COMPARTMENTS

Subject	Medium	Date of determination								
		B-1			T-5			T-10		
		Plasma volume	Blood volume	Extra-cellular fluid	Plasma volume	Blood volume	Extra-cellular fluid	Plasma volume	Blood volume	Extra-cellular fluid
BB	Immersion	3 160	5 550	18.3	2 320	4 560	17.6	2 675	5 050	17.6
	Bed rest	3 265	5 560	18.9	3 080	5 810	18.8	2 615	4 680	18.9
LB	Immersion	2 025	3 450	14.2	1 730	3 260	14.3	1 810	3 040	14.2
	Bed rest	2 230	3 670	14.5	1 730	3 110	13.6	1 760	3 050	13.5
EH	Immersion	3 555	6 050	18.5	2 960	6 040	18.8	2 840	5 000	16.5
	Bed rest	3 680	5 960	19.3	2 550	4 500	18.7	2 745	4 760	18.9
JH	Immersion	3 395	5 600	17.2	2 425	4 420	17.0	2 630	4 630	16.9
	Bed rest	3 185	5 250	18.0	2 585	4 720	17.5	2 760	4 700	17.2
BI	Immersion	3 220	5 490	21.0	2 520	4 780	18.3	2 705	4 930	18.6
	Bed rest	3 460	5 800	20.9	3 580	6 520	18.9	2 765	4 860	19.1
LL	Immersion	3 140	5 440	18.1	2 535	4 710	18.9	2 865	5 130	18.4
	Bed rest	3 325	5 860	19.1	2 560	4 920	19.0	2 995	5 370	18.6
RM	Immersion	3 620	6 060	21.9	2 960	5 300	20.5	4 020	6 520	22.0
	Bed rest	4 020	6 630	21.9	3 630	6 500	21.8	3 370	6 030	11.8
BS	Immersion	3 205	5 200	19.0	2 290	4 250	18.2	2 760	4 860	17.9
	Bed rest	2 935	5 160	17.3	2 700	4 760	19.2	2 820	4 890	18.6
LS	Immersion	3 580	6 200	19.1	2 805	5 500	18.6	2 750	5 200	16.9
	Bed rest	2 860	5 120	18.4	2 730	4 990	17.9	2 785	5 080	19.2
WW	Immersion	3 480	5 930	19.6	2 540	4 980	18.3	2 980	5 340	18.1
	Bed rest	3 885	6 420	19.0	3 010	5 400	18.8	3 340	5 780	18.6

Notes: (1) Plasma volume--Blood volume in ml
(2) Extracellular fluid in liters

Test	Medium	BB			LB			EH	
		B	T-5	T-10	B	T-5	T-10	B	T-5
Hbg (gm %)	Immersion	14.7	16.1	15.7	15.1	16.5	14.2	14.3	16.2
	Bed rest	14.6	16.3	15.5	13.4	15.5	15.7	13.8	14.7
Hct (%)	Immersion	45	51	49	43	49	42	43	49
	Bed rest	43	49	46	41	46	44	40	45
RBC (millions)	Immersion	4.3	5.1	5.6	5.3	5.8	5.1	5.3	5.7
	Bed rest	5.2	5.8	5.4	4.5	5.4	5.4	4.8	5.3
WBC (thousands)	Immersion	9.4	7.2	7.8	8.2	9.1	6.6	8.0	6.9
	Bed rest	9.6	8.0	8.0	4.5	6.0	5.7	6.1	4.9
Na^+ (meq/L)	Immersion	141	140	143	144	141	146	144	143
	Bed rest	146	143	152	145	139	132	140	137
K^+ (meq/L)	Immersion	4.7	4.4	4.9	4.3	5.7	4.5	5.1	5.3
	Bed rest	5.1	5.0	5.4	4.2	3.8	4.2	4.3	4.1
Cl^- (meq/L)	Immersion	106	99	101	100	105	98	103	103
	Bed rest	101	109	107	108	98	100	104	103
HCO_3^- (meq/L)	Immersion	26	22	26	35	27	36	29	25
	Bed rest	34	25	31	28	24	27	23	23
Ca^{++} (meq/L)	Immersion	4.9	5.2	5.1	4.8	5.1	5.1	4.6	5.2
	Bed rest	4.5	4.9	5.2	5.0	5.5	5.2	4.9	5.2
P (mg %)	Immersion	3.0	3.5	4.3	3.8	3.6	3.8	4.6	4.3
	Bed rest	4.6	3.6	3.4	2.6	2.9	3.6	3.1	3.8
Cephalin flocculation	Immersion	0	0	0	0	0	0	3+	2+
	Bed rest	0	0	1+	0	0	0	3+	1+
Creatinine (mg %)	Immersion	1.12	1.20	0.96	1.20	0.94	1.00	1.20	0.98
	Bed rest	1.10	1.00	1.60	1.11	0.89	0.84	1.07	0.98
Thymol turbidity (units)	Immersion	2	2	1	9	6	5	4	3
	Bed rest	1	1	1	6	8	4	3	6
SGOT (units)	Immersion	38	23	25	42	25	35	23	2
	Bed rest	26	22	24	31	27	26	20	

*No determination on specified date

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TABLE XII

BLOOD CHEMISTRIES

Subject and date of determination											
	JH			BI			GK		LL		
T-10	B	T-5	T-10	B	T-5	T-10	B	T-5	B	T-5	T-10
15.2	13.9	16.3	15.4	14.2	15.9	16.1	15.7	16.5	15.2	15.9	16.6
15.5	13.9	15.7	15.0	14.3	15.3	14.6	15.7	*	15.0	17.2	17.5
45	41	47	45	43	49	47	47	51	44	48	46
44	41	47	43	42	47	45	*	*	45	49	46
5.5	4.7	4.8	5.1	4.6	5.1	5.4	*	5.8	5.4	5.1	4.8
5.5	*	5.6	5.4	5.2	5.4	5.2	5.1	*	*	6.0	5.0
7.3	5.5	7.2	7.2	6.8	7.3	7.6	5.5	7.5	7.8	6.6	7.2
5.6	6.2	4.9	6.7	8.9	6.3	9.3	6.6	*	6.0	8.0	6.3
143	144	144	137	138	137	138	138	142	134	135	138
136	145	145	149	145	144	146	137	*	140	141	143
5.0	4.8	5.2	5.3	4.3	4.3	4.2	5.1	5.0	4.7	4.9	4.6
4.4	5.0	5.3	5.8	4.8	4.6	4.6	5.2	*	4.8	5.0	4.9
100	104	91	111	104	100	103	105	100	103	90	104
102	106	106	107	103	108	105	102	*	108	104	99
37	29	34	25	25	25	26	28	34	29	33	28
27	24	35	23	32	27	34	30	*	30	40	25
5.2	5.2	5.7	5.3	5.0	5.9	5.2	4.8	5.0	4.9	5.1	5.0
5.1	4.9	5.5	5.3	4.7	5.1	5.0	5.2	*	4.7	5.1	4.8
4.0	3.2	3.2	3.8	2.8	2.5	3.8	2.2	3.4	3.2	3.1	4.1
4.4	3.1	3.5	2.5	3.7	3.9	2.5	3.1	*	3.1	3.4	3.0
3+	*	2+	0	0	0	1+	0	1+	*	2+	0
3+	1+	3+	2+	2+	2+	2+	*	*	2+	2+	0
1.00	0.94	1.10	0.96	1.05	1.00	0.93	0.89	1.20	0.97	1.30	1.00
0.82	1.20	0.94	1.40	1.20	1.20	1.00	1.10	*	1.00	0.84	1.30
5	*	4	5	5	6	5	5	5	*	3.8	5
5	3	5	4	9	7	7	*	*	2	4	3
18	39	23	25	28	28	28	39	26	27	23	23
23	55	30	23	39	31	33	38	*	33	26	22

RM			BS			LS			WW		
B	T-5	T-10	B	T-5	T-10	B	T-5	T-10	B	T-5	T-10
15.2	15.5	13.7	13.3	15.7	15.4	14.6	16.9	16.6	14.2	16.0	15.4
14.6	15.9	15.1	15.2	15.1	16.1	16.1	16.8	16.2	13.7	15.0	14.3
42	46	40	40	48	45	44	51	49	43	51	46
41	46	46	45	45	44	46	47	47	41	46	44
4.5	5.4	4.9	*	5.5	4.7	5.2	5.9	5.7	*	5.6	5.1
5.4	5.5	5.0	5.1	5.0	5.1	4.9	5.3	5.5	5.3	4.6	5.4
3.4	7.0	5.5	4.4	5.4	7.6	5.7	8.3	7.4	4.5	5.9	7.7
7.0	8.3	8.1	4.0	*	6.9	6.0	5.2	6.1	4.9	6.1	6.2
140	136	137	140	142	138	144	146	145	141	147	144
143	142	154	135	138	133	136	137	138	141	140	133
4.6	4.0	4.6	4.4	4.5	4.4	4.4	5.5	4.7	5.2	5.1	5.5
4.6	4.9	4.6	4.9	5.1	4.3	4.1	4.0	4.2	5.3	5.4	4.7
102	100	101	108	103	105	103	104	105	106	104	105
103	107	100	104	93	109	108	102	99	104	92	106
27	24	28	27	35	25	32	24	35	28	33	24
35	22	36	29	34	26	23	22	22	29	32	28
5.0	5.0	4.8	4.8	5.0	4.8	4.2	4.7	4.7	4.7	5.3	4.9
4.7	5.1	4.6	5.2	5.2	4.9	4.7	4.8	4.7	5.1	5.7	5.2
3.1	3.0	3.9	3.1	3.4	3.1	3.8	3.4	2.6	3.3	4.0	3.5
3.6	3.9	3.7	3.0	4.1	3.1	2.9	3.2	3.3	3.3	3.6	3.8
2+	0	2+	1+	2+	0	0	0	2+	1+	1+	0
2+	3+	3+	*	1+	0	0	0	0	*	1+	0
1.13	0.97	0.77	1.00	1.20	1.60	0.99	1.10	1.00	0.98	0.85	1.40
0.98	0.93	1.20	1.30	1.20	1.10	1.06	0.95	0.85	0.92	1.20	0.96
5	4	2	3	6	4	3	3	4	0	3	2
2	2	4	0	4	2	3	4	4	*	1	2
26	23	23	40	33	13	30	29	25	29	28	30
30	22	29	33	27	26	35	23	23	26	23	30

TABLE XIII

BROMSULPHALEIN RETENTION TEST

Subject	Date of determination	
	Baseline	Baseline - recovery
BB	0.1 (2.5)	2.0 (1.0)
LB	5.3	2.7
EH	2.5	3.0
JH	3.6	2.3
BI	2.0 (2.7)	* (3.0)
GK	4.6	3.4
LL	0.1	1.4
RM	1.3 (2.8)	2.4 (2.0)
BS	0.2	2.5
LS	1.6	3.0
WW	1.8	1.6

Notes: (1) Entries in percent of retention
(2) Parenthetical entries were obtained during bed rest
(3) *No determination

TABLE XIV

SERUM ELECTROPHORESIS

Subject	Medium	Date of determination																			
		Baseline							T-5							T-10					
				Globulins							Globulins							Globulins			
		Total protein	Albumin	Alpha 1	Alpha 2	Beta	Gamma	A/G ratio	Total protien	Albumin	Alpha 1	Alpha 2	Beta	Gamma	A/G ratio	Total protein	Albumin	Alpha 1	Alpha 2	Beta	Gamma	A/G ratio
BB	Immersion	6.7	4.4	0.3	0.5	0.9	0.6	2.0	7.4	5.2	0.3	0.5	0.9	0.5	2.4	6.8	4.4	0.3	0.6	0.8	0.7	1.8
	Bed rest	6.5	4.8	0.3	0.4	0.6	0.4	2.9	6.9	4.8	0.2	0.5	0.7	0.7	2.3	6.7	4.5	0.3	0.6	0.7	0.6	2.1
LB	Immersion	8.4	5.6	0.3	0.5	1.1	0.9	2.0	8.3	5.5	0.2	0.5	1.1	1.0	1.9	7.7	3.9	0.3	0.9	1.5	1.1	1.1
	Bed rest	8.0	5.1	0.2	0.4	1.2	1.1	1.7	8.7	5.7	0.3	0.6	1.1	1.0	1.9	8.3	4.4	0.4	0.7	0.8	1.3	1.1
EH	Immersion	7.5	4.9	0.2	0.5	1.0	0.9	1.9	8.1	5.7	0.2	0.6	0.9	0.7	2.1	8.0	4.9	0.3	0.6	1.1	1.1	1.5
	Bed rest	6.9	4.8	0.2	0.5	0.7	0.7	2.4	7.9	4.7	0.2	0.6	1.1	1.3	1.5	7.9	5.0	0.2	0.7	1.1	0.9	1.7
JH	Immersion	7.6	6.0	0.2	0.4	0.6	0.4	3.7	8.1	5.7	0.3	0.5	0.8	0.8	2.4	7.8	5.3	0.3	0.6	0.8	0.8	2.0
	Bed rest	7.6	5.1	0.3	0.6	0.8	0.8	2.1	7.7	5.3	0.3	0.5	0.8	0.8	2.2	7.5	4.9	0.2	0.6	0.8	1.0	1.9
BI	Immersion	7.3	4.9	0.3	0.5	0.8	0.8	2.0	7.9	5.1	0.3	0.7	0.9	0.9	1.8	7.9	5.2	0.3	0.6	0.9	0.9	1.8
	Bed rest	6.8	4.3	0.3	0.5	0.8	0.9	1.8	7.4	5.1	0.3	0.4	0.8	0.8	2.3	7.7	4.9	0.3	0.5	0.8	1.2	1.7
GK	Immersion	7.8	5.2	0.3	0.5	1.0	0.8	2.0	7.5	5.1	0.2	0.6	0.8	0.8	2.1	*	*	*	*	*	*	*
	Bed rest	8.0	5.3	0.2	0.6	0.9	1.0	1.9	*	*	*	*	*	*	*	*	*	*	*	*	*	*
LL	Immersion	7.2	5.1	0.2	0.4	0.7	0.8	2.5	6.9	4.7	0.2	0.6	0.7	0.7	2.2	7.5	4.8	0.3	0.6	1.1	0.7	1.8
	Bed rest	6.8	4.9	0.3	0.4	0.6	0.6	2.6	6.7	4.6	0.3	0.5	0.7	0.6	2.1	6.7	4.5	0.2	0.5	0.8	0.7	2.1
RM	Immersion	7.1	5.2	0.2	0.4	0.6	0.7	2.8	7.0	5.1	0.3	0.3	0.7	0.6	2.6	6.9	4.5	0.3	0.5	0.7	0.9	1.9
	Bed rest	7.2	5.3	0.3	0.3	0.6	0.7	2.7	7.1	5.2	0.3	0.3	0.7	0.6	2.8	7.5	5.0	0.3	0.5	0.8	0.9	1.9
BS	Immersion	7.6	4.5	0.4	0.6	1.0	1.1	1.5	7.5	4.8	0.3	0.4	0.9	1.1	1.9	7.4	5.0	0.2	0.5	0.8	0.9	2.1
	Bed rest	8.1	5.7	0.2	0.4	0.8	1.0	2.5	7.2	4.8	0.2	0.5	0.9	0.8	2.0	7.4	5.0	0.2	0.4	0.9	0.9	2.0
LS	Immersion	6.4	4.7	0.2	0.2	0.7	0.6	2.8	7.3	5.3	0.2	0.3	0.7	0.8	2.4	6.9	4.1	0.4	0.6	0.9	0.9	1.5
	Bed rest	7.1	4.5	0.4	0.5	0.8	0.9	1.7	7.5	4.7	0.4	0.5	0.9	1.0	1.7	7.4	5.1	0.3	0.4	0.8	0.8	2.1
WW	Immersion	6.9	4.9	0.2	0.4	0.7	0.7	2.4	7.4	5.1	0.2	0.5	0.8	0.8	2.2	7.0	5.0	0.2	0.5	0.7	0.6	2.5
	Bed rest	7.6	5.4	0.2	0.4	0.7	0.9	2.4	7.2	4.8	0.3	0.5	0.9	0.7	2.1	7.5	5.4	0.3	0.5	0.7	0.6	2.6

Notes: (1) Entries are in g%, except for A/G ratio
(2) *Subject withdrawn from immersion

30-1 30-2 30-3

Test	Medium	BB						
		B	T-1	T-2	T-3	T-5	T-6	T-7
Specific gravity	Immersion	1.012		1.018	1.016	1.014	1.014	
	Bed rest			1.018		1.020		
Osmolality (m0sm/kg)	Immersion	475	427	460	532	505	540	
	Bed rest	524		521		595		
pH	Immersion	6.6		6.8	6.4	6.0	6.8	
	Bed rest	6.4		6.0		6.0		
Na^+ (meq/24 hr)	Immersion	162	171	194	98	116	56	
	Bed rest	116		130		125		
K^+ (meq/24 hr)	Immersion	52	76	81	122	93	51	
	Bed rest	91		103		112		
Ca^{++} (meq/24 hr)	Immersion	7.1	9.6	7.4	8.0	6.3	3.8	
	Bed rest	4.4		6.4		8.1		
Cl^- (meq/24 hr)	Immersion	161	183	198	135	97	68	
	Bed rest	148		157		147		
P (g/24 hr)	Immersion	0.89	0.68	1.1	0.98	1.1	0.46	
	Bed rest	0.36		0.71		1.1		
Creatinine (mg/24 hr)	Immersion	1 510	1 595	1 504	1 800	1 900	885	
	Bed rest	1 298		1 440		2 230		
17-Hydroxy-Ketosteroids (mg/24 hr)	Immersion					12.1		8.0
	Bed rest							
Epinephrine (µg/24 hr)	Immersion						5.5	
	Bed rest							
Norepinephrine (µg/24 hr)	Immersion						27.6	
	Bed rest							
PSP (%)	Immersion							
15 min		41						
30 min		17						
60 min		18						
120 min		13						
Total excretion		89						

									LB	
T-8	T-9	T-10	BR	B	T-1	T-2	T-3	T-5	T-6	T-7
1.020	1.012					1.021		1.014		
1.012		1.010		1.022		1.021	1.028	1.026	0.019	
636	419			701		773		570		
520		525		810	849	760	918	878	666	
6.4	6.8			5.9		6.0		6.0		
6.5		6.0		6.8		6.5	6.0	6.0	6.8	
182	131			59		109		92		
107		75		146	151	137	124	118	92	
88	88			31		73		80		
75		54		27	45	89	71	68	48	
11.0	8.8			4.3		8.5		12.0		
9.2		5.7		7.6	11	11	9.2	7.4	5.0	
196	166			47		127		122		
103		94		149	176	191	153	124	100	
1.2	0.90			0.57		0.78		1.2		
0.76		0.56		0.67	0.69	0.74	1.1	0.83	0.57	
2 170	1 658			960		1 640		1 890		
1 825		1 245		1 025	1 428	1 600	1 660	1 392	832	
	12.0		6.8					7.9		3.9
10.5		10.5	7.7						5.5	
35.9		50.0	57.7						16.3	
			39	39					15	
			12	17					10	
			19	15					16	
			14	9.1					21	
			84	80					62	

TABLE XV — URINE CHEMISTRIES - Cor

Subject and date o										
				EH						
T-8	T-9	T-10	BR	B	T-1	T-2	T-3	T-5	T-6	T-7
1.019		1.012				1.031		1.012		
1.020	1.024			1.016		1.018	1.028	1.027	1.027	
738		560		646		919		670		
638	775			612	653	752	912	861	980	
6.0		6.0		6.4		6.4		6.0		
6.4	6.0			6.6		6.7	6.0	6.8	6.8	
121		91		260		101		62		
164	79			258	155	148	64	89	109	
80		74		93		135		95		
45	52			98	85	92	24	104	87	
12.0		9.6		3.6		7.8		7.5		
11.0	7.8			7.1	11.0	8.0	7.7	7.9	6.5	
122		107		227		146		88		
162	104			280	155	171	96	95	129	
1.01		0.85		1.3		1.0		0.98		
0.76	0.60			1.3	0.64	0.97	1.1	1.2	0.92	
1 880		1 345		1 792		1 910		1 810		
1 675	1 090			1 660	1 420	1 400	1 548	1 743	1 120	
	8.1		6.4					6.1		7.6
8.8		18.2	15.3						7.1	
22.0		22.9	30.7						23.8	2
			45	7.9					36	
			26	44					27	
			17	22					21	
			12	10					16	
			100	84					100	

ıtinued

f determination

									JH	
T-8	T-9	T-10	BR	B	T-1	T-2	T-3	T-4	T-5	T-6
1.008		1.008		1.018		1.020				1.027
1.025	1.018				1.026		1.028		1.016	1.024
452		440		410		665	784	672		767
880	592				593		1 095		1 265	732
6.5		6.5		6.0		6.0				6.8
6.4	6.4				6.0		6.0		8.0	6.8
133		162		200		115	77	31		71
146	155				135		167		67	60
81		140		66		54	47	69		41
69	76				70		47		74	74
12.0		17.0		14.0		7.9	10.0	8.5		6.8
11.0	12.0				13.0		13.2		13.0	6.7
136		185		214		123	96	58		79
156	168				163		148		88	65
0.93		1.22		1.6		0.95	0.96	0.83		0.40
1.2	1.1				0.92		1.0		0.86	0.81
1 745		2 120		2 208		1 510	1 550	1 430		1 000
1 775	1 620				1 600		1 700		1 750	1 300
	7.6		7.3		8.2		7.0		7.0	
7.4		9.2	5.9			11.0		7.5		4.1
										3.8
23.2		26.7	41.8			36.6		44.3		14.9
										8.9
			36	32						
			29	21						
			22	16						
			16	11						
			100	80						

1

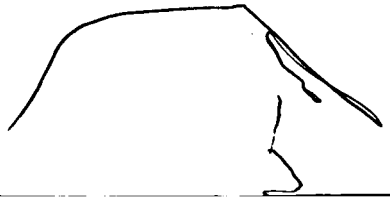
31-4

T-7	T-8	T-9	T-10	BR	B	T-1	T-2	T-3	T-5
1.026	1.023	1.023		1.018	1.019		1.012	1.014	1.01
1.025			1.020	1.018			1.018		1.01
535	430	487		375	681	459	356	446	467
862			545	347	821		501		440
6.5	6.4	6.5		6.0	6.2		6.8	6.0	6.4
6.4			6.4	6.0	5.9		5.9		6.0
133	136	116		55	29	172	155	74	67
47			120	36	95		126		79
85	82	78		60	42	65	51	48	65
51			79	18	45		76		57
15.0	15.0	16.0		14.0	5.9	15.0	13.0	13.1	13.7
8.2			14.0	7.9	8.6		11.0		8.8
139	143	128		46	59	170	157	91	65
63			144	46	85		151		85
0.89	0.97	0.9		1.3	0.53	0.76	0.82	1.1	1.3
0.52			1.16	0.46	0.90		0.87		0.83
1 564	1 425	1 540		1 530	948	1 975	1 622	1 870	2 115
1 050			1 590	940	1 854		2 118		1 71
6.0		6.5		3.9					7.9
2.8		5.3		4.3					
	5.1		3.3	11.8					
	10.4		9.2	14.3					
	47.0		53.1	60.4					
	17.4		17.8	47.9					
				41	47				
				22	22				
				16	20				
				12	15				
				91	104				

BI					
T-6	T-7	T-8	T-9	T-10	BR
1.009		1.017 1.006	1.010	1.006	
203		547 432	6.8	375	
6.8		6.4 6.0	362	6.5	
17		157 60	105	59	
40		97 55	86	54	
6.8		23.0 15.0	16.0	13.0	
45		154 55	129	72	
0.82		2.0 0.90	0.92	0.52	
770		3 470 2 020	1 730	1 675	
	6.7		8.4		1.6
4.9		14.6		7.2	9.3
15.6		59.1		24.5	66.1
					38 22 18 12 90

Test	Medium	B	T-1	T-2	T-3	T-5
Specific gravity	Immersion		1.023		1.016	1.02
	Bed rest	1.019		1.029		
Osmolality (m0sm/kg)	Immersion		860		775	1 056
	Bed rest	839		940		
pH	Immersion		6.0		6.0	5.9
	Bed rest	6.4		6.0		
Na^+ (meq/24 hr)	Immersion		203		135	44
	Bed rest	173		32		
K^+ (meq/24 hr)	Immersion		96		71	74
	Bed rest	68		55		
Ca^{++} (meq/24 hr)	Immersion		17.0		15.2	12.0
	Bed rest	16.0		7.2		
Cl^- (meq/24 hr)	Immersion		208		169	75
	Bed rest	197		65		
P (g/24 hr)	Immersion		1.6		1.4	1.3
	Bed rest	1.6		0.87		
Creatinine (mg/24 hr)	Immersion		2 680		2 140	1 900
	Bed rest	2 605		1 620		
17-Hydroxy-Ketosteroids (mg/24 hr)	Immersion					
	Bed rest		11.5			
Epinephrine - (µg/24 hr)	Immersion					
	Bed rest			10.6		
Norepinephrine (µg/24 hr)	Immersion					
	Bed rest			20.2		
PSP (%)	Immersion					
15 min		42				
30 min		25				
60 min		16				
120 min		12				
Total excretion		95				

Notes: *Subjects withdrawn from immersion
●Specimen not obtained



GK*					LL					
T-6	T-7	T-8	T-10	BR	B	T-1	T-2	T-3	T-4	T-5
1.023	1.023		1.026	1.028	1.017	1.025	1.024	1.016		1.016
800	795		795	841	707	766	763	856 596	729	720
6.4	6.4		6.1	6.0	6.2	6.0	6.0	6.0		6.4
96	78		91	110	146	230	74	72 188	72	154
108	62		46	49	69	71	66	81 73	72	95
18.0	13.0		15	14	9.9	8.9	5.7	8.4 9.8	7.1	9.0
127	97		89	115	167	239	91	103 198	80	161
1.5	0.80		1.36	1.1	1.2	0.84	0.96	0.99 0.94	0.75	0.90
2 560	1 520		1 710	1 810	2 610	2 400	2 160	2 290 2 250	1 665	2 300
	8.6	11.2		10.5		8.8		7.8		11.6
5.9		8.2	4.3	7.8			8.8		7.2	
27.7		26.6	27.6	28.9			47.9		27.6	
				46 22 16 9 93	39 24 16 12 91					

						RM*						
T-6	T-7	T-8	T-9	T-10	BR	B	T-1	T-2	T-3	T-5	T-6	T-7
1.029	1.030	1.024	1.030		1.021	1.030		1.019	1.023	1.017	1.015	
1.010	1.021			1.021	1.026			1.028		1.022		
772	600	520	570		490	1 020	650	748	782	623	586	
365	690			587	793	661		903		675		
6.8	6.4	6.6	6.6		6.0	6.2		6.4	6.0	6.4	6.4	
7.0	6.4			6.7	6.0			6.0		6.0		
99	146	166	136		92	36	153	166	66	47	49	
46	109			178	60			149		109		
65	105	100	94		49	40	46	60	41	89	69	
47	130			90	98			66		52		
9.4	11.0	12.0	12.0		11.0	3.0	10	15	9.5	14.4	8.3	
3.5	9.9			8.4	10.0	12.0		15		13		
112	162	169	127		68	51	143	190	85	74	60	
60	114			175	94	88		170		138		
0.59	0.95	1.1	1.3		0.92	0.51	0.74	1.3	0.95	1.2	0.96	
0.22	1.2			1.07	1.9	0.89		1.1		1.1		
1 520	1 990	2 030	2 500		2 110	642	1 440	1 955	1 241	2 070	1 195	
737	2 970			2 220	2 590	1 582		2 135		1 950		
	7.6		6.7							7.0		7.1
	11.0		10.3									
5.1		9.4		4.5	12.4						5.8	
6.6		7.3		7.7	6.0							
12.9		22.6		20.3	42.6						17.7	
8.3		27.9		60.0	34.8							
					42	42						
					23	18						
					16	13						
					10	7						
					91	80						

TABLE XV. Concluded

URINE CHEMISTRIES

Subject and date of determination												
			BS									
T-8	T-10	BR	B	T-1	T-2	T-3	T-4	T-5	T-6	T-7	T-8	T-9
1.018				1.025		1.015		1.016	1.020	1.019		
1.014	1.012		1.018		1.020				1.025	1.026	1.030	1.028
685				620		593		800	590	617		
666	640		736		634	734	653		570	680	700	632
6.0				6.0		6.8		6.2	7.0	6.4		
6.0	6.5		6.4		6.8				7.0	6.4	6.5	6.8
75				227		148		57	57	112		
93	116		118		139	104	111		122	69	145	139
56				87		75		78	68	95		
45	88		56		93	74	76		77	57	93	94
13.0				11.0		9.8		10.0	6.0	11.0		
15	21		9.7		9.4	9.0	9.4		9.5	7.3	11	12
93				248		168		90	67	145		
105	128		155		168	121	112		143	98	150	151
1.0				1.0		0.81		0.90	0.57	0.97		
0.93	1.34		0.78		0.90	0.92	0.93		0.72	0.53	1.0	1.1
1 700				2 300		1 820		1 500	1 100	1 700		
1 725	2 115		1 978		2 180	1 900	1 795		1 440	1 395	2 030	2 130
										6.1		7.3
				3.8		5.1		5.6		3.3		4.0
4.8									2.5		4.0	
					7.0		7.9		8.3		10.6	
14.6									4.2		10.9	
					42.6		31.9		7.6		12.0	
		34	42									
		24	23									
		12	20									
		8	13									
		78	98									

		LS										
T-10	BR	B	T-1	T-2	T-3	T-5	T-6	T-7	T-8	T-9	T-10	BR
1.024	1.018			1.023		1.024			1.020		1.010	
	1.023	1.027		1.021	1.015	1.024	1.021		1.020	1.020		
605	643	675		699		656			950		635	
	635	908	644	705	489	753	721		866	672		
6.8	6.0	6.4		6.3		6.0						
	6.4	6.6		6.8	6.4	7.0	7.0		6.4	6.4		
169	21	214		160		87			58		140	
	194	119	136	131	100	76	64		154	172		
106	46	49		91		60			56		96	
	51	45	54	95	78	90	37		88	97		
14.0	7.5	9.2		9.5		8.0			6.4		9.8	
	14.0	7.1	5.0	9.7	8.4	7.2	2.7		7.3	11.0		
174	58	202		179		138			68		165	
	147	148	133	170	131	88	67		159	192		
1.25	0.42	0.09		0.94		1.2			0.87		1.14	
	1.4	0.92	0.72	1.1	0.91	0.72	0.31		1.3	1.5		
2 100	1 028	1 710		2 020		2 130			1 470		1 970	
	2 030	1 495	1 310	1 885	1 749	1 640	565		2 130	2 180		
	4.1											
	3.1					5.6		7.5		6.5		5.6
5.8												
3.4	12.8						3.5		8.4		7.0	10.3
24.3												
29.1	25.5						5.1		9.5		8.5	22.3
	37	42										44
	26	23					62					20
	17	5.9					15					23
	12	11					11					17
	92	82					88					100

WW											
B	T-1	T-2	T-3	T-4	T-5	T-6	T-7	T-8	T-9	T-10	BR
	1.024		1.012		1.021	1.020	1.019			1.019	1.028
1.011		1.019				1.017	1.025	1.030	1.023		1.023
	680		554		820	610	611			580	1 050
417		571	487	515		356	498	607	410		438
	6.6		6.7		6.4	6.8	6.0			6.6	9.0
6.6		6.4				6.8	6.5	6.4	6.9		6.0
	184		248		81	77	94			154	44
281		126	85	86		75	126	125	107		108
	103		66		84	93	94			96	39
54		64	70	79		58	79	79	96		58
	12.0		10.7		13.0	9.5	14.0			18.0	5.9
18.0		12.0	13.0	14.0		10.0	14.0	20.0	17.0		19.0
	208		232		96	98	127			235	68
312		137	114	104		88	142	130	133		81
	1.1		0.84		1.0	0.70	1.0			1.19	0.49
1.4		1.0	1.0	0.91		0.43	0.84	1.1	1.0		1.4
	2 360		1 840		2 100	1 585	2 100			2 280	1 095
3 052		2 180	1 810	2 090		1 080	2 250	2 280	2 380		2 050
							9.8		7.7		3.0
	4.2		7.4		11.5		9.1		6.3		2.8
						7.2		8.4		10.5	14.0
		11.9		11.9		6.6		11.3		9.3	15.6
						16.9		20.7		25.6	42.6
		39.1		42.1		9.9		19.8		19.7	36.4
22											19
23											20
29											31
25											6
99											76

remained within normal limits and no difference or trends were apparent when comparing the same subjects in the two environments.

Cephalin cholesterol flocculation and thymol turbidity determinations were within normal limits for a majority of the subjects. Thymol turbidity determinations for Subject LB, on two different days, were 9 units and 8 units; however, follow-up determinations were within normal limits. The other liver function studies on this subject were normal. Subject EH showed cephalin cholesterol flocculation values of 3+ on four occasions; however, the remainder of his liver function studies were normal. One cephalin cholesterol flocculation determination on Subject JH was 3+; however, the remainder of his liver function studies were normal. During bed rest, determinations of cephalin cholesterol flocculation on Subject BI were 2+ on three dates while thymol turbidity was 9 units, 7 units, and 7 units on three different dates. During immersion testing 6 weeks later, these determinations on this subject were within normal limits. Cephalin cholesterol flocculation determinations on Subject RM were 3+ on two occasions during immersion, but dropped to 2+ during bed rest 6 weeks later. The remainder of his liver function studies were consistently normal. None of these subjects manifested any clinical signs or symptoms of liver disease.

Liver function tests (bromsulphalein retention), performed as a cautionary measure prior to and following silicone immersion, were within normal limits on all subjects throughout the course of testing. The results of these tests are shown in Table XIII.

Variations in total protein, globulin, and albumin fractions were not consistently related to the conditions of the experiment. The results of this analysis are shown in Table XIV.

Routine urinalysis showed no remarkable changes attributable to the conditions of the experiment. Microscopic examinations of the urine were negative. Urine pH, specific gravity, and osmolality were within normal limits. All urine samples were free of sugar, acetone, and protein.

During immersion and bed rest, sodium and potassium levels remained within normal limits. There was, however, a trend toward increased sodium, potassium, and chloride excretion at the onset of immersion and

bed rest. There was also a trend toward retention of these three ions upon termination of immersion and bed rest. Most subjects showed urinary chloride values which were below normal on several dates. This was consistent throughout immersion and bed rest. Most subjects showed urinary chloride values which were below normal on several dates. This was consistent throughout immersion and bed rest.

Calcium levels remained within normal limits for subjects during immersion and bed rest. Phosphorus excretion was slightly above normal on several dates for the majority of subjects, but similar changes occurred during both immersion and bed rest. These data are shown in Table XV.

Creatinine values varied over a wide range for all subjects throughout the course of the study; however, all values were essentially normal and were on the high side. No trends were observed when comparing the two environments.

Excretion of 17-Hydroxy-Ketosteroids was within normal limits for all subjects during the course of the study and no differences between immersion and bed rest were noted.

There was a characteristic pattern for catecholamine excretion during both immersion and bed rest, especially norepinephrine, in which output fell from an initial level to a low point on T-6. The output then rose to or above the initial level at the end of the testing period.

Kidney function tests (phenolsulfonphthalein excretion), performed as a cautionary measure prior to and following silicone immersion, were within normal limits on all subjects and no evidence of kidney damage was detected.

Nose, throat, and urine cultures were taken on all subjects prior to the study and all were within normal limits. None of these subjects had clinical evidence of respiratory disease.

Urine and blood samples were examined periodically by Dow Corning for silicone absorption during immersion; results are summarized in Table XVI. Specimens were also analyzed for Subjects BI, BB, and RM prior to bed rest to obtain further control data. In some instances, silicone levels in the urine and blood samples were found to be high. It is felt that these readings,

TABLE XVI

ANALYSIS OF BLOOD AND URINE FOR SILICONE

Subject	Sample	Date of determination					
		Immersion			Bed rest		
		B	T-5	BR	B	T-5	BR
BB	Urine	0 to 3	66	0 to 3	0 to 3	0 to 3	0 to 3
	Blood	0 to 3	0 to 3	0 to 3	0 to 6	27	9
LB	Urine	0 to 3	0 to 3	0 to 3			
	Blood	0 to 3	9	6			
EH	Urine	0 to 3	*	9			
	Blood	0 to 3	6	9			
JH	Urine	0 to 3	6	0 to 3			
	Blood	0 to 3	0 to 3	0 to 3			
BI	Urine	0 to 3	21	0 to 3	0 to 3	0 to 3	0 to 3
	Blood	0 to 3	0 to 3	0 to 3	6	9	*
GK	Urine	0 to 3	0 to 3	0 to 3			
	Blood	0 to 3	60	12			
LL	Urine	0 to 3	0 to 3	0 to 3			
	Blood	0 to 3	0 to 3	0 to 3			
RM	Urine	0 to 3	6	0 to 3	0 to 3	0 to 3	0 to 3
	Blood	0 to 3	0 to 3	0 to 3	0 to 3	12	9
BS	Urine	0 to 3	0 to 3	0 to 3			
	Blood	0 to 3	24	0 to 3			
LS	Urine	0 to 3	*	18			
	Blood	6	0 to 3	6			
WW	Urine	0 to 3	12	0 to 3			
	Blood	0 to 3	12	0 to 3			

Notes:

(1) Entries in parts per million of silicone

(2) *Sample lost

and their erratic occurrence, resulted from contamination of the urine and blood during collection and were not caused by absorption in the body.

Except for Subjects GK and RM, the skin problems that developed during immersion were trivial. Periodic brushing resulted in the maintenance of normal skin condition or the regression of minor rashes in the majority of subjects. However, daily cultures were made of the silicone fluid in each tank and samples were analyzed for water content and contamination. An effort to relate these measures to the development of skin problems was inconclusive.

Daily cultures of the silicone in each tank were obtained before, during, and after each test period. These data include the bacteria isolated, colony counts, and fungus cultures. The predominant organisms isolated were Staphylococcus epidermidis (coagulase negative), Escherichia coli, Diptheroids, Micrococcus species, Pseudomonas aeruginosa, Enterococci, and Klebsiella-Aerobacter Sp. Bacteria occasionally cultured were Achromobacter species, Bacillus species, and Herellea species.

Elevations in tank cultures and the development of skin problems were not related in a notable way. The following is a brief description of the skin problems encountered during the study.

(1) Subject BB developed a rash on T-6 when the colony count in his tank was 1 300 microorganisms/ml; however, on T-10 when his rash was regressing, the colony count was 9 000 microorganisms/ml. At this time, itching of his skin was noted.

(2) Subject LB developed a skin rash on T-6 with no significant elevation of colony count.

(3) Subject EH developed a skin problem on his feet with the colony count well within normal limits; also, the cultures of his skin did not correlate with the tank culture.

(4) Subject JH developed a rash on T-2. The colony count did not rise until T-4, when it was 1 600 microorganisms/ml. On this date (T-4), he developed erythema on his feet. On T-6, he developed a rash and the tank had a high colony count. Resolution which followed continued despite elevated bacterial levels.

(5) Subject BI developed a rash on T-5. The following day, the colony count rose to 500 microorganisms/ml; however, his rash improved despite elevated bacterial counts.

(6) Subject GK developed a rash on T-4 when the tank colony count was at 1 000 microorganisms/ml. Skin and tank cultures did not correlate as to the type of flora.

(7) Subject LL developed a rash, but the tank colony counts remained well within normal limits.

(8) Subject RM developed itching on his legs on T-7 and a rash appeared the following day. Cultures of the fluid in his tank at this time revealed no microorganisms.

(9) Subject BS developed a lesion on his ankle on T-4. On the preceding 2 days, elevated colony counts were obtained from his tank. The bacterial flora of the skin lesion and the tank fluid were similar. During the period of lesion resolution, the tank bacterial flora remained low.

(10) Subject LS developed a rash on his thighs and perineum on T-5, one day before the count rose to 1 600 microorganisms/ml. Three days later, T-8, the rash became worse despite low tank colony counts.

(11) Subject WW developed a rash on T-4, which was preceded by elevated colony counts for 2 days. On the day the rash developed, the counts were low and remained within normal limits during the remainder of immersion, despite the appearance of other skin problems.

Silicone specimens, taken from each tank before immersion, on T-5, and during baseline-recovery periods, were analyzed for water content and other contaminants. During baseline periods when the tanks were unoccupied, water content varied from 144 to 290 ppm.* During immersion, the water content varied from 163 to 283 ppm. There was a trend toward the appearance of minor skin problems (Subjects BB, LB, JH, BI, GK, BS, LS, and WW) at the time water content approached 210 ppm or higher, although this was not a consistent finding. Subjects RM, BS, and WW developed rashes when the water content was lower (179 to 196 ppm). Some of the subjects (LB, EH, JH, LL, and LS) showed actual improvement despite elevation of

* 290 ppm corresponds to a water content of approximately 0.162 liters in 570 liters.

water content. The more pronounced skin problems occurred in Subjects GK and RM, but the water content of the silicone fluid in which they were immersed varied. The water content was high (253 ppm) when Subject GK developed skin problems and relatively low (179 to 192 ppm) when the rash appeared on Subject RM. Analysis of the silicone for contamination revealed that the plastic tanks were the probable source of an impurity. Because of the very low concentration of the contaminant (less than 100 ppm), it was felt that the contaminant presented no danger to the subjects and the study was continued. It is unlikely that the contaminant contributed significantly to the skin problems seen during the study. The majority of subjects showed improvement of their skin while immersed. If the contaminant was the primary source of skin irritation, it would seem that the skin problems would remain, or become progressively more pronounced with the continuation of immersion. Because this did not occur, it is also probable that the contaminant was not the cause of skin problems.

During the entire program, no reaction was observed when the silicone was injected intracutaneously into rabbits.

Monitoring Tests

Table XVII summarizes fluid intakes and outputs during the testing period for each subject and experimental condition. Comparison of fluid intakes show that 7 of the 10 subjects completing the experiment had average daily intakes that were higher during bed rest than during immersion. An average, taken across all 10 subjects, shows that the average daily intake was 1 594 ml during bed rest and 1 461 ml during immersion. Comparison of urine outputs show that 9 of the 10 subjects had average daily outputs that were higher during immersion than during bed rest. The average daily urine output during immersion was 1 859 ml as compared with 1 530 ml during bed rest. Subject WW, the tenth subject, averaged 133 ml more urine per day during bed rest than while immersed. Daily urine volumes, averaged across 10 subjects, are summarized graphically in fig. 5.

Comparison of the immersion and bed rest environments in terms of input and output data shows that 9 of the 10 subjects evidenced a higher urine output than fluid intake during immersion. Output exceeded input by an

TABLE XVII

FLUID INTAKE AND OUTPUT

Subject	Medium	Total intake	Total output	Average daily intake	Δ Intake immersion minus bed rest	Average daily output	Δ Output immersion minus bed rest	Δ Daily intake minus output
BB	Immersion	15 470	22 080	1 547	-258	2 208	+424	-661
	Bed rest	18 050	17 845	1 805		1 785		+21
LB	Immersion	10 735[a]	14 060	1 193	-156	1 406	+161	-213
	Bed rest	12 140[a]	12 450	1 349		1 245		+104
EH	Immersion	16 595[a]	22 360	1 844	+134	2 236	+939	-392
	Bed rest	17 100	12 970	1 710		1 297		+413
JH	Immersion	13 510	16 700	1 351	+47	1 670	+410	-319
	Bed rest	13 040	12 600	1 304		1 260		+ 44
BI	Immersion	25 680	25 335	2 568	+755	2 534	+648	+ 34
	Bed rest	18 130	18 860	1 813		1 886		- 73
LL	Immersion	12 110	17 200	1 211	-507	1 720	+ 75	-509
	Bed rest	17 185	16 450	1 719		1 645		+ 73
RM	Immersion	10 200	10 400[b]	1 457	-384	1 486	+210	- 29
	Bed rest	12 870	8 935[b]	1 839		1 276		+563
BS	Immersion	10 840	18 550	1 084	-144	1 855	+360	-771
	Bed rest	12 280	14 950	1 228		1 495		-261
LS	Immersion	9 200[a]	14 935	1 022	-196	1 494	+197	-472
	Bed rest	12 180	12 970	1 218		1 297		- 79
WW	Immersion	13 300	19 850	1 330	-621	1 985	-133	-655
	Bed rest	19 510	21 175	1 951		2 118		-167
Average	Immersion			1 461	-133	1 859	+329	-399
	Bed rest			1 594		1 530		+ 64

Notes:

(1) Entries are in ml

(2) [a] Based on 9 days of immersion or bed rest

(3) [b] Based on 7 days of immersion or bed rest

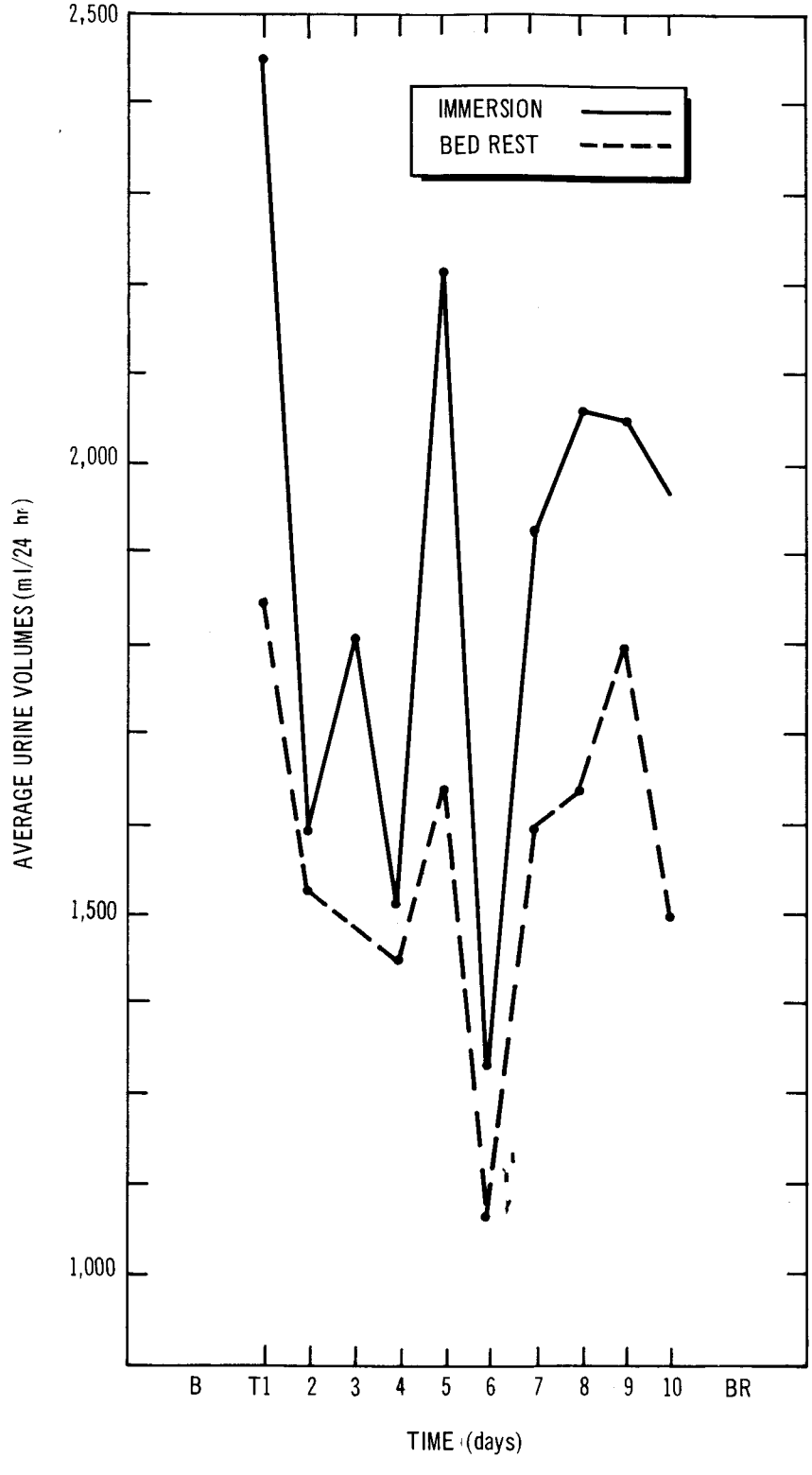


Figure 5. Daily Urine Volumes

average of 399 ml/man/day. During bed rest, 6 of the 10 subjects had a higher input than output, while the remaining subjects had a higher output than input. It is concluded, therefore, that the immersion analog of null gravity produced an elevated urine flow, as evidenced by comparison of urine outputs in the two environments and by higher urine outputs than fluid intakes during immersion.

In the formation of urine, the volume of water and the amount and kind of solute passing through the kidney are closely interdependent. For the purpose of defining the physiological relationship between the two analogs, a number of graphic and numeric analyses were made. First, osmotic urine/plasma ratios, osmolar clearance, and rate of urine flow were computed and plotted for each subject against time. Fig. 6 shows a typical plot (Subject WW during immersion). The highest concentration of urine achieved by the human kidney is approximately 1 400 mOsm/liter. The solute concentration of plasma is approximately 300 mOsm/liter. Analysis of the osmotic U/P ratios yielded one ratio of less than unity (Subject BI on T-6 of immersion). All other ratios were greater than unity and none of the ratios reached the osmolal ceiling of 4.6. These ratios were slightly higher during bed rest than during immersion. Of the 10 subjects, 6 had a larger ratio at bed rest than they did during immersion. The remaining subjects showed the reverse relationship. Urine flow rates for each subject, calculated from 24-hour urine outputs, averaged 1.29 ml/min/day during immersion, and 1.05 ml/min/day during bed rest. Osmolar clearance was higher during immersion than during bed rest. Table XVIII summarizes these relationships for each subject and experimental condition. Free-water clearance, the difference between the osmolar clearance and the rate of urine flow, is negative for both environments. Because urine flow is smaller than the osmolar clearance, it is concluded that neither analog produced a free-water diuresis; that the tubular reabsorption of water was consistently in the direction of water salvage (relative to the isosmotic parameter); and that subjects during immersion evidenced a slightly higher osmotic diuresis than they did at bed rest.

In the second analysis, daily and accumulative electrolyte concentrations were plotted against time. Fig. 7 shows a typical plot (Subject EH). During

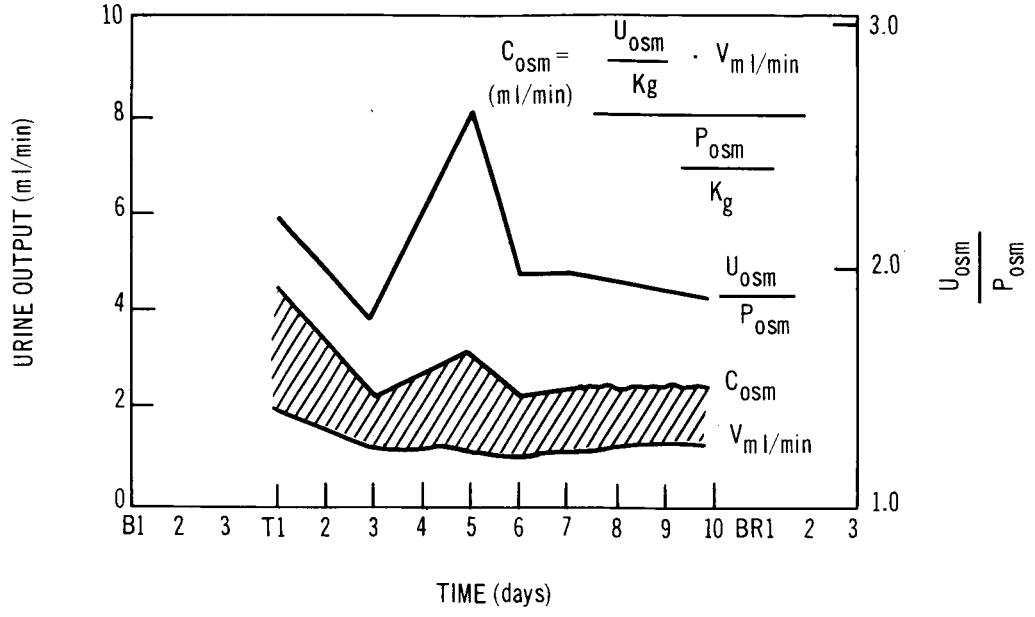


Figure 6. Relation Between Urine Output and Time

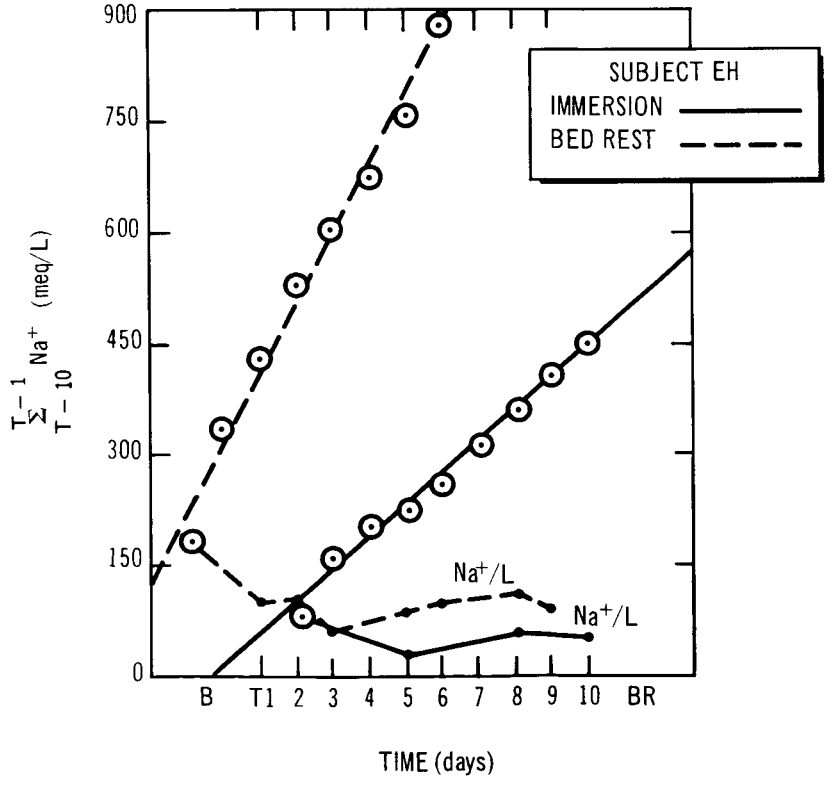


Figure 7. Daily and Accumulative Sodium Concentration

TABLE XVIII

AVERAGE OSMOTIC U/P, OSMOLAR CLEARANCE AND URINE VOLUME

Subject	Medium					
	Immersion			Bed rest		
	Osmotic U/P	C_{osm}	Urine volume	Osmotic U/P	C_{osm}	Urine volume
BB	1.63	2.55	1.61	1.75	2.07	1.18
LB	2.13	1.92	0.93	2.53	2.08	0.81
EH	2.03	3.10	1.70	2.51	2.24	0.91
JH	1.82	1.92	1.16	2.75	2.31	0.88
BI	1.31	2.37	1.79	1.48	1.80	1.28
LL	2.22	2.24	1.01	2.05	2.10	1.05
RM	2.37	2.12	0.93	2.33	2.27	0.98
BS	2.05	2.96	1.42	2.14	2.05	0.93
LS	2.38	2.27	1.00	2.24	2.05	0.94
WW	2.08	2.80	1.35	1.57	2.24	1.50
Average	2.00	2.43	1.29	2.14	2.12	1.05

Notes:

(1) Entries are in ml/min for C_{osm} and volume

(2) Entries for osmotic U/P are nondimensional

immersion and bed rest, sodium and potassium levels remained within normal limits (see Table XV). There was, however, a trend toward increased sodium, potassium, and chloride excretion at the onset of immersion and bed rest. Most subjects showed urinary chloride values below normal on several dates. The two environments produced no outstanding difference in the daily concentration of the electrolytes in the urine. However, accumulative electrolyte concentrations maintained by each subject was different for the two environments. Numerical descriptions of the daily concentration of sodium and potassium, calcium, and chloride for each subject and experimental condition are shown in Table XIX. When the slopes of the

TABLE XIX

NUMERICAL DESCRIPTION OF DAILY CONCENTRATION IN URINE OF SODIUM, POTASSIUM, CALCIUM, AND CHLORIDE

Subject	Medium	Na^+			K^+			Ca^{++}			Cl^-		
		Y	Y/10	Δ Immersion bed rest	Y	Y/10	Δ Immersion bed rest	Y	Y/10	Δ Immersion bed rest	Y	Y/10	Δ Immersion bed rest
BB	Immersion	510	51	- 6	405	41	- 2	32	3	-1	600	60	- 3
	Bed rest	570	57		425	43		40	4		625	63	
LB	Immersion	695	70	-23	550	55	+ 4	74	7	0	820	82	-18
	Bed rest	930	93		510	51		65	7		1000	100	
EH	Immersion	385	39	-44	380	38	-22	39	4	-3	540	54	-43
	Bed rest	830	83		595	60		66	7		970	97	
JH	Immersion	610	61	- 1	430	43	-12	69	7	-3	650	65	- 5
	Bed rest	615	62		550	55		98	10		700	70	
BI	Immersion	275	28	-10	220	22	- 6	49	5	-1	370	37	- 1
	Bed rest	375	38		280	28		58	6		375	38	
LL	Immersion	650	65	-31	510	51	- 2	57	6	+1	735	74	- 5
	Bed rest	955	96		530	53		51	5		790	79	
RM	Immersion	615	62	-12	410	41	+ 5	78	8	-2	725	73	-14
	Bed rest	740	74		355	36		104	10		865	87	
BS	Immersion	540	54	-23	445	45	- 6	55	6	0	770	77	-12
	Bed rest	765	77		505	51		62	6		890	89	
LS	Immersion	665	67	-13	515	52	- 3	58	6	+1	815	82	- 4
	Bed rest	800	80		545	55		47	5		855	86	
WW	Immersion	615	62	+13	520	52	+27	58	6	0	780	78	+28
	Bed rest	485	49		250	25		60	6		500	50	
Average	Immersion	556	56	-15	439	44	- 2	57	6	-1	681	68	- 8
	Bed rest	706	71		454	45		65	7		757	76	

Note:

(1) Entries are in $\sum_{T-10}^{T-1}$ of the electrolyte in meq/L

concentration lines were compared, the average concentration of urinary electrolytes tended to be higher during bed rest than during immersion. Of the 10 subjects, 9 had a higher concentration of urinary sodium and chloride during bed rest than during immersion. During bed rest, 7 subjects had a higher potassium concentration than they did during immersion. Cumulative calcium concentration showed little or no difference in slope. Daily urine osmolality, averaged across 10 subjects, tended to be higher (fig. 8) when the subjects were at bed rest (see Table XV). It might be concluded that there was a higher solute output in the urine of these subjects; however, as can be seen in fig. 9, this was not the case. The figure shows that the average daily solute load of the 10 subjects was higher during immersion than during bed rest.

It is concluded that the conditions of bed rest caused the subjects to produce a slightly more concentrated urine than the subjects did during immersion, both with respect to individual electrolytes and to solute load concentration. During immersion, the subjects excreted a larger 24-hour solute load and had a higher osmolar clearance than they had during bed rest. The larger daily urine outputs during immersion made this possible. A possible conclusion, the dietary solute intake for both groups being the same, is that the fluid compartments had contracted slightly more during immersion than at bed rest and fewer electrolytes were required to maintain the new volume. This would allow for a daily excretion of excess electrolytes and water, and would explain both the higher diuresis and lower concentration seen during immersion. This possibility is partially supported by larger declines in plasma and extracellular fluid volume found at T-5 during immersion than during bed rest. Another possibility is that a breakdown of tissue was faster during immersion and this process released excess water and electrolytes. There is, however, no evidence for this because neither the pattern of electrolyte excretion nor work capacity changed in significant ways.

The relative increase in urinary catecholamines seen after T-6 may reflect the decreased sensitivity of the cardiovascular system secondary to decreased levels of renin-angiotensin. Monitoring data indicate that none of the subjects were significantly stressed, either physically or psychologically, during immersion or bed rest. If the level of epinephrine reflects emotional

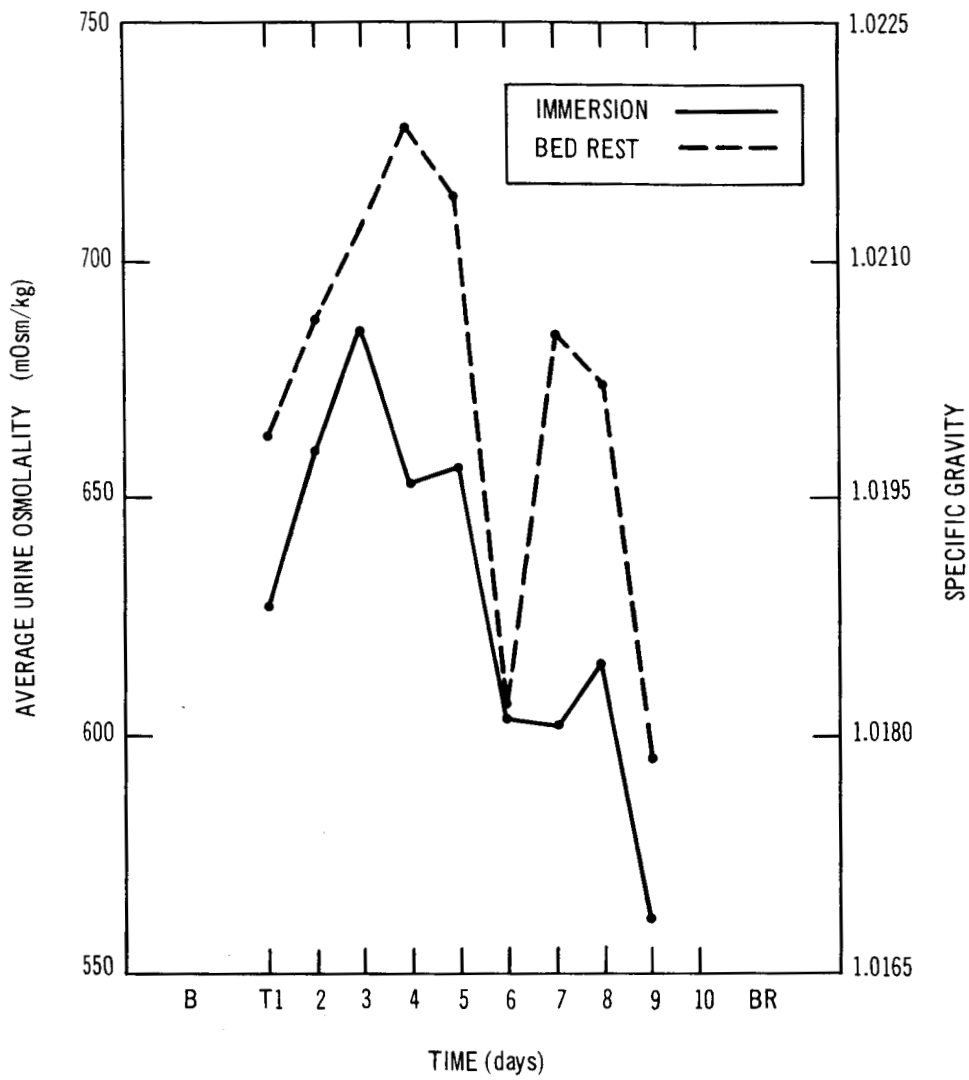


Figure 8. Daily Urine Osmolality

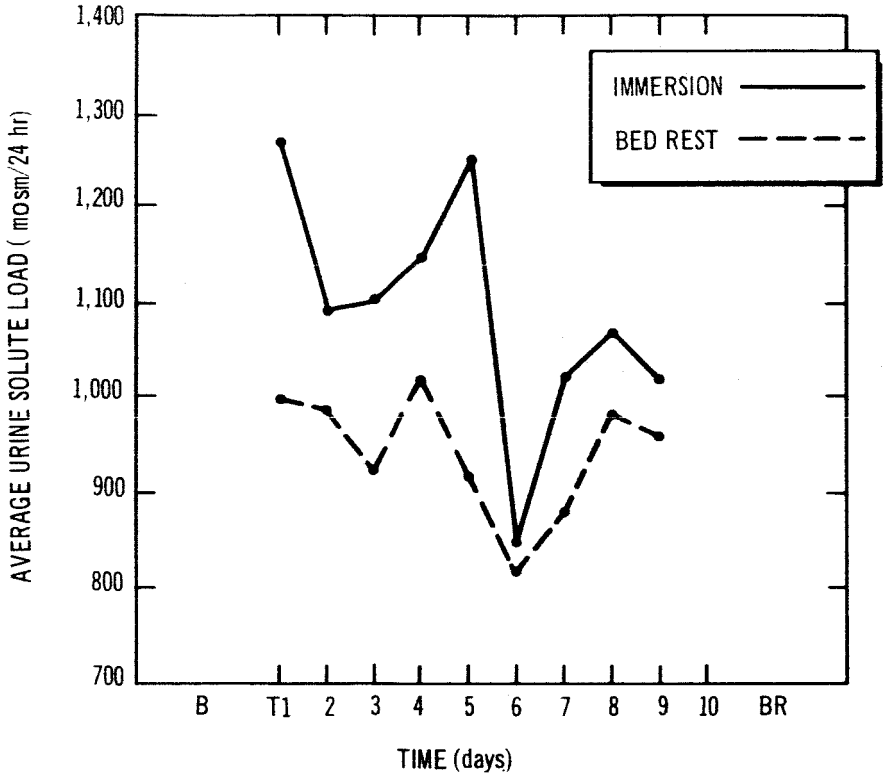


Figure 9. Daily Urine Solute Load

factors, and norepinephrine reflects physiological activity, it would seem that this activity reached its lowest point on T-6. From this date to T-10, activity increased and the subjects were anticipating the end of the study. The pattern of catecholamine excretion in both groups is shown in Table XV.

Blood pressure readings, made three times per day, revealed no marked change. Pulse pressures remained relatively constant throughout the testing period. Systolic and diastolic pressures taken at 0200 hours were slightly lower than those taken at 1030 and 1700 hours. Heart rate showed a similar diurnal variation. Heart rates varied between 50 and 70 beats/min, with some individual variation. Respiratory rates remained relatively constant at 14 to 18 breaths/min. Oral temperatures ranged from 97° to 98.6°F.

Daily physical examinations were made of each subject. During immersion test periods, Subjects GK and RM developed skin problems that necessitated their removal from the silicone fluid. Their cases are reported here in detail.

On T-4, Subject GK developed maceration and erythema of both feet, especially the left, on the dorsal aspects and between the toes. Several areas of confluent tiny vesicles were present on both feet. The subject also developed scattered erythema on both ankles, calves, and thighs. An area of an old healed injury (infected contusion) on the lateral malleolus of his left ankle opened and became erythematous. The dorso-lateral aspect of his left foot was mildly tender to palpation and was mildly swollen and warm. Scattered and confluent erythema developed on both axillary areas and the lateral aspects of his chest. The subject felt well and was not toxic. He was removed from the silicone and placed at bed rest. He was isolated from the other subjects and started on Pan Alba, 250 mgm Q6H. The cultures isolated were as follows:

(1) Left foot -- Klebsiella-Aerobacter Sp., Pseudomonas aeruginosa, Staphylococcus epidermidis, and Enterococci.

(2) Left axilla -- Klebsiella-Aerobacter Sp., Pseudomonas aeruginosa, and Staphylococcus epidermidis (coagulase negative).

(3) Feces -- No pathogens, ova, or parasites

(4) Throat -- Hemophilus parainfluenza, Neisseria species, alpha hemolytic Streptococci, and gamma hemolytic Streptococci.

(5) Blood -- No growth after 10 days

On T-5, the swelling of the feet had regressed. The erythema of the lateral chest walls had improved considerably, although a fine maculo-papular rash remained. There were scattered maculo-papular areas (0.5 to 2 mm in size), several with central pustules, on his left foot and ankle. The vesicles on his feet were essentially unchanged. He was afebrile, nontoxic, and felt well. On T-6 the skin lesions had improved. Neo-polycin ointment applications were begun. On T-7 the skin lesions were much improved. The dorsal aspects of his feet were dry. There were cracks in the skin between several toes. Erythema was most prominent at the base of the toes. The rash on his chest was gone. On T-8 the subject was ambulated. By T-10 the erythema was more prominent on the right foot, the skin of both feet was

dry, and the superficial epidermis over the involved areas was beginning to desquamate. Erythema of the feet was more prominent when the subject was erect. By BR-2 the skin was soft with no further cracking. Physical examination on BR-3 showed the subject to be within normal limits except for flaky skin on his knees and feet and three areas of resolving rash on his feet. Neopolycin ointment was continued after the subject's dismissal from the ward. No emotional or other medical problems developed during emmersion.

On T-2, a routine nose and throat culture was obtained from Subject RM which isolated Hemophilus parainfluenza (few), Neisseria species, Staphylococcus epidermidis (coagulase negative), alpha hemolytic Streptococci, and gamma hemolytic Streptococci. On T-3, minimal scaling of the skin on the bridge of the subject's nose and lower forehead developed. Examination revealed mild erythema and a macular rash of these areas. A culture was obtained and isolated Staphylococcus epidermidis (coagulase negative). Periodic bathing of his face and forehead with pHisoHex was instituted and by the afternoon of T-3 the skin of his nose and forehead appeared to be improved. Mild-to-moderate injection of the subject's conjunctivae was also noted on T-3; this condition improved the following day. On T-4 there was no rash on his nose, cheeks, or forehead, although the skin was dry and midly erythematous. Bathing of these areas with pHisoHex was continued, followed by applications of Lubriderm lotion. The subject was depressed and expressed a dislike for silicone fluid immersion. On T-5 a slight erythema was observed on his nose and under his eyes, but there was no rash. On T-7 an extreme itching of his legs developed with a questionable, slight scattered rash. On the morning of T-8, an erythematous macular rash, including a few scattered clear vesicles, developed primarily around or involving, the hair follicles. The areas involved were the anterior aspects of his feet, ankles, and legs. Itching of his entire body had beem present for 24 hours, but was more pronounced on his feet, legs, and perineum. He was removed from silicone on T-8. The cultures isolated were as follows:

(1) Right tibial area -- Klebsiella-Aerobacter Sp.

(2) Left tibial area -- Enterococci (few), Klebsiella-Aerobacter Sp., and Pseudonomas aeruginosa.

Periodic bathing of his entire body with pHisoHex soap was instituted. Mycolog ointment was applied to his feet and legs every 6 hours. On T-8 itching of thighs, perineum, and chest was present, but no other rash on his lower extremities had developed. By T-9 the rash on his legs appeared worse and had become confluent in some areas; it appeared to be a contact dermatitis starting around hair follicles. He was ambulated and took a shower using pHisoHex soap. The skin of the involved area itched slightly and was sore to the touch; it felt as though it were "sun-burned." On T-10 the rash showed improvement but was still prominent, especially around the hair follicles. The rash appeared to be more papular. The seborrhea of his head was improving. He was nontoxic, afebrile, and had no other signs or symptoms. He was examined by a consulting dermatologist on T-10.

By BR-1, the rash on the subject's feet and legs was much improved and he had no further itching. On BR-2, the rash showed continued improvement and appeared macular and only slightly erythematous. He had no seborrhea of his scalp, eyelids, face, or neck. Physical examination of the subject on BR-3 was negative except for a mild follicular distribution of maculo-papular rash over the anterior tibial areas. He had no seborrhea.

All subjects were observed for 6 months following this study. During that period, none of the subjects developed abnormal symptoms, signs, or skin problems. They have participated in subsequent projects with no adverse effects.

DISCUSSION

Although the osmotic diuresis found during immersion could be accounted for by changes in renal blood flow, by elimination of hydrostatic pressure within the cardiovascular system, or by negative pressure breathing factors, a question remains as to the effects of silicone temperature on sweating and insensible perspiration. Could it be that the temperature regulation of the fluid produced an environment in which sweating and diffusion of water through the skin was decreased, that the fluid normally lost through the skin was lost in urine? There are no indications that extrarenal water losses were decreased during immersion. The constant care required of the filtration units to ensure effective separation of water from the silicone indicated that there was water loss through the skin.

By analyzing the filtering system, it is possible to obtain an estimate of magnitude of this water loss. Diatomaceous earth is capable of absorbing its own weight in water. Approximately 1 lb of earth was added each day to each filtration unit. This amount of earth could have absorbed 454 ml of water/day. At least this amount was absorbed because water began to appear in the silicone without a daily addition of diatomaceous earth. It is concluded that approximately this amount of water was lost through the skin during immersion.

Another method of arriving at an estimate of this water loss is to assume that insensible water loss dissipates approximately 25% of metabolic heat. Oxygen consumption at rest (from Table VIII) was approximately 300 ml/min, which is equivalent to 2 160 kcal/day. Therefore, 540 kcal of metabolic heat was dissipated through insensible water loss. Because all of this heat was dissipated by vaporization of water, 896 ml of water/day had to be lost to dissipate the 540 kcal of heat. Calculation of water losses through the lungs showed this to be 366 ml/day. If the insensible loss from the lungs is subtracted from the total loss predicted from metabolic data, approximately 530 ml of water is removed through the skin. The difference in water loss through the skin, as estimated by the two methods, is 76 ml.

One further consideration is that the water loss as a result of sweat was higher at bed rest than during immersion. Analysis of the filtering system indicates that subjects did not sweat during immersion. During bed rest there were wider temperature variations; however, the ambient environment was comfortable and activity was curtailed. Monitoring data indicate that sweating of the magnitude of 500 ml/day did not occur.

It is concluded that the fluid normally lost through the skin was not lost in urine; the elevated urine flow during immersion must be accounted for in terms of renal, hydrostatic, and respiratory factors.

An attempt was made to qualitatively follow the variation in extracellular fluid during the testing periods. This was done by plotting urine output for each subject against time, together with the excretion of the extracellular chloride ion and the intracellular potassium ion. If the concentration of chloride is maintained at a constant value in the extracellular fluid, a gain or loss of this ion would show a corresponding change in this volume. However, it is realized that, even with a constant intake of water and chloride, urine volume would not necessarily correlate with chloride excretion because of the variability in extrarenal water loss. In this undertaking, chloride is compared with potassium, which is present in extracellular fluid in relatively small and constant concentrations and is less affected by fluid shifts. If the rate of chloride excretion is increased, there should be a corresponding increase in the excretion of water from extracellular fluid and the extracellular fluid compartment should contract. If, on the other hand, the rate of chloride excretion is decreasing, then water should be saved and the extracellular fluid compartment should expand. If variation could be shown it might help to explain the variability encountered in all of the Douglas studies where extracellular fluid volumes have been measured.

Gamble (ref. 9) states, "Water expenditure, in the removal of waste substances in urine and of heat by vaporization of water, is at the expense of extracellular fluid. Since water intake is intermittent and expenditure is continuous and of a variable degree, adjustment of interstitual-fluid volume is constantly required."

However, there is no physiological reason why this compartment should be adjusted every day to a normal level. Though adjustments are continuous, rigidity of this compartment and its plasma and interstitial components is not required. It seems likely, therefore, that variation may be found.

Figures 10 through 29 show the daily variation in urine volume, potassium ions, and chloride ions for each subject and condition of the experiment. In most cases the variations of insensible water loss and dietary intake were not large enough to obscure the relation of chloride excretion and urine output. No attempt has been made to quantify the relation. These figures show large, slowly varying changes in extracellular fluid which occur over a period of several days.

A fair correlation can be detected in fig. 30 between declines in plasma volume and urinary norepinephrine and incidences of presyncopal symptoms on the tilt table. Although no causal relation has been shown between chronic contraction of bood volume, deficient sympathetic response and orthostatic intolerance, it seems logical to assume that one exists.

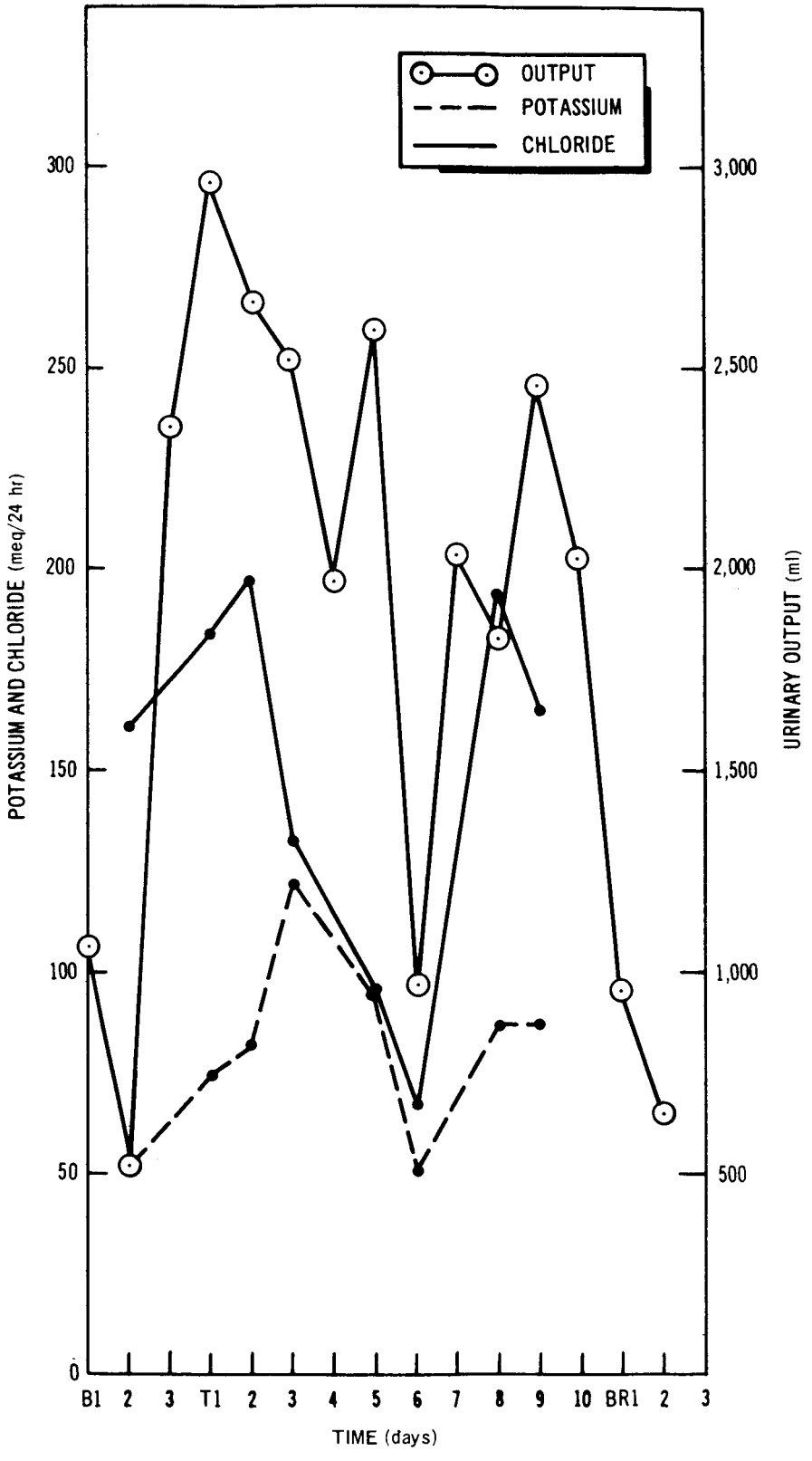


Figure 10. Subject BB, Immersion

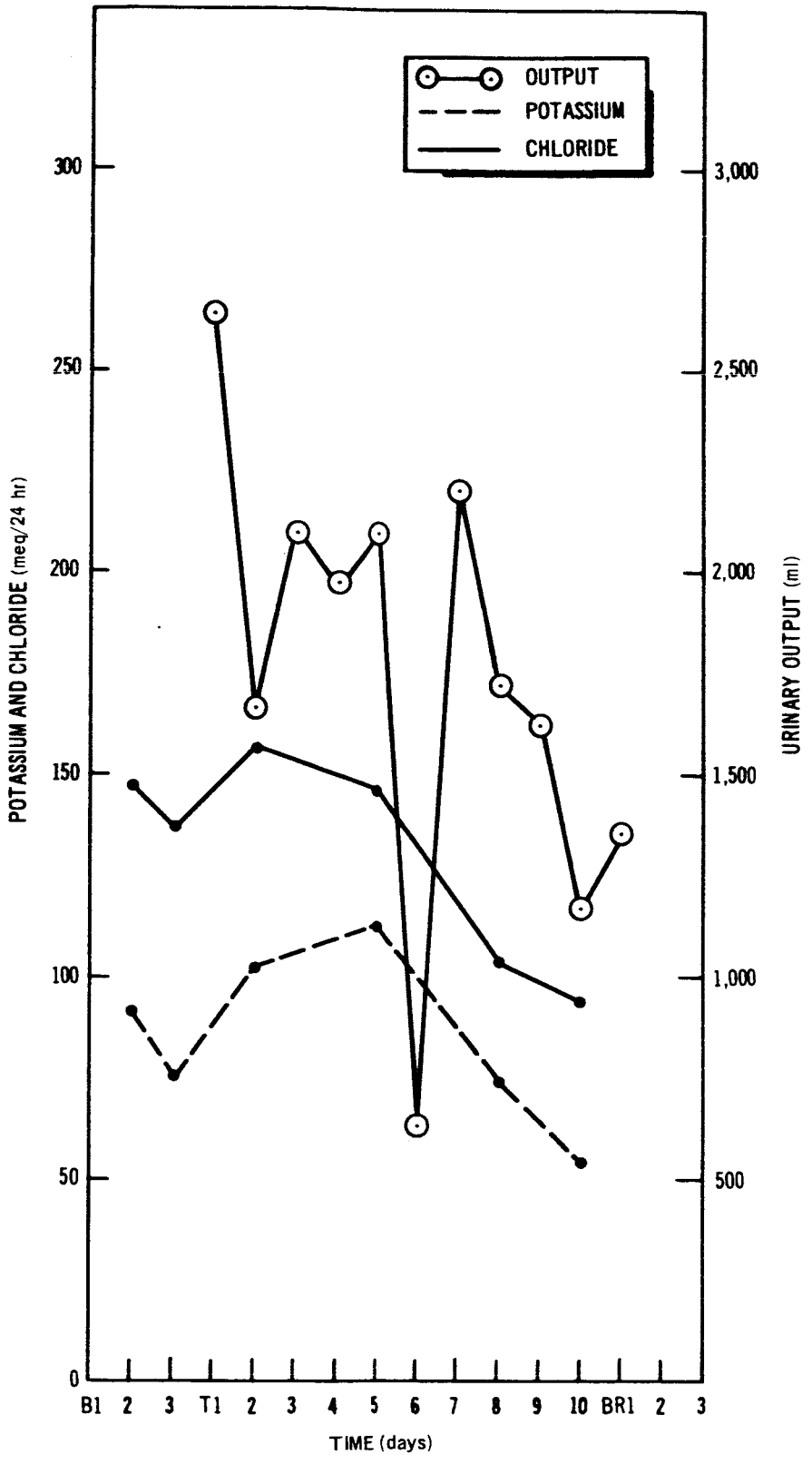


Figure 11. Subject BB, Bed Rest

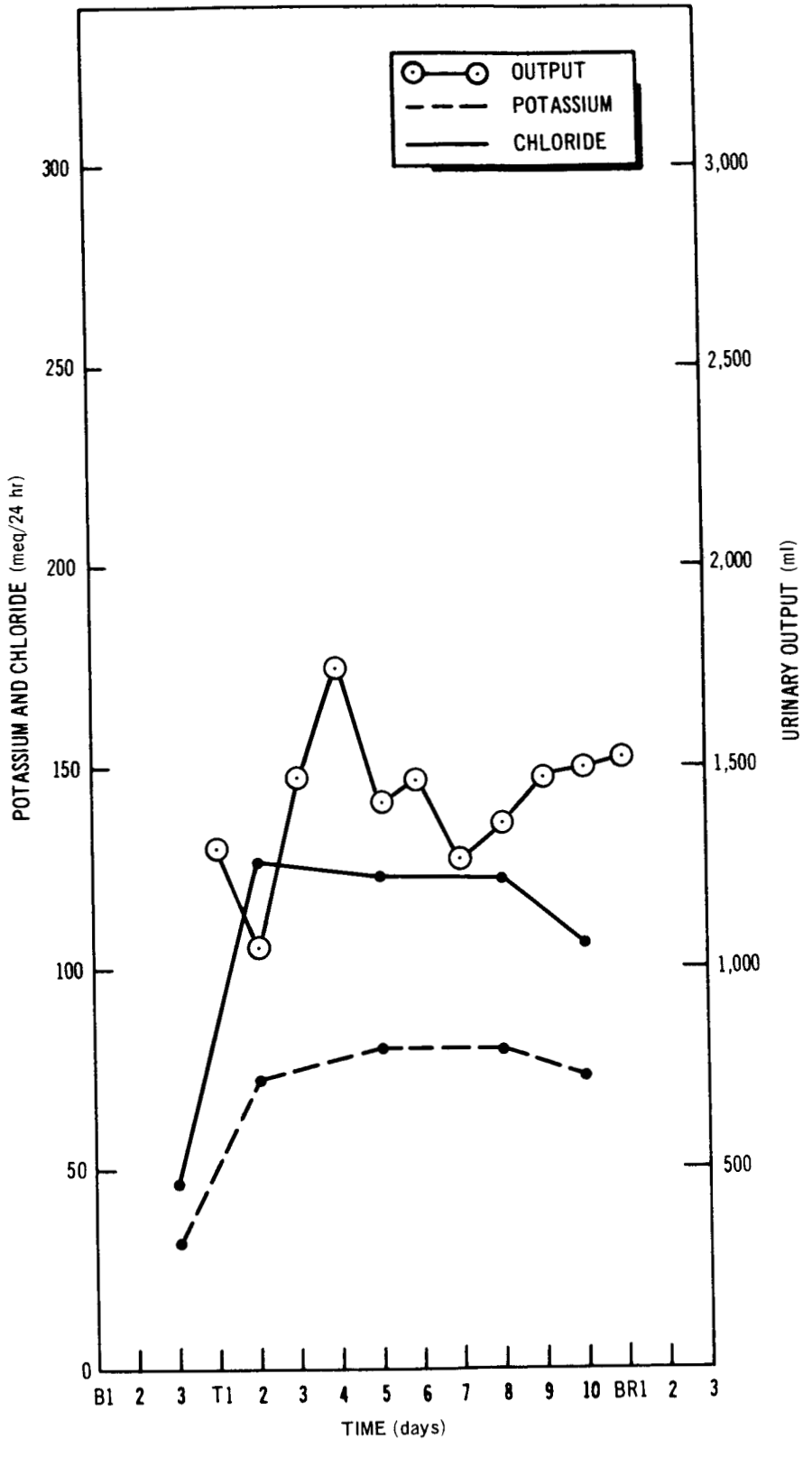


Figure 12. Subject LB, Immersion

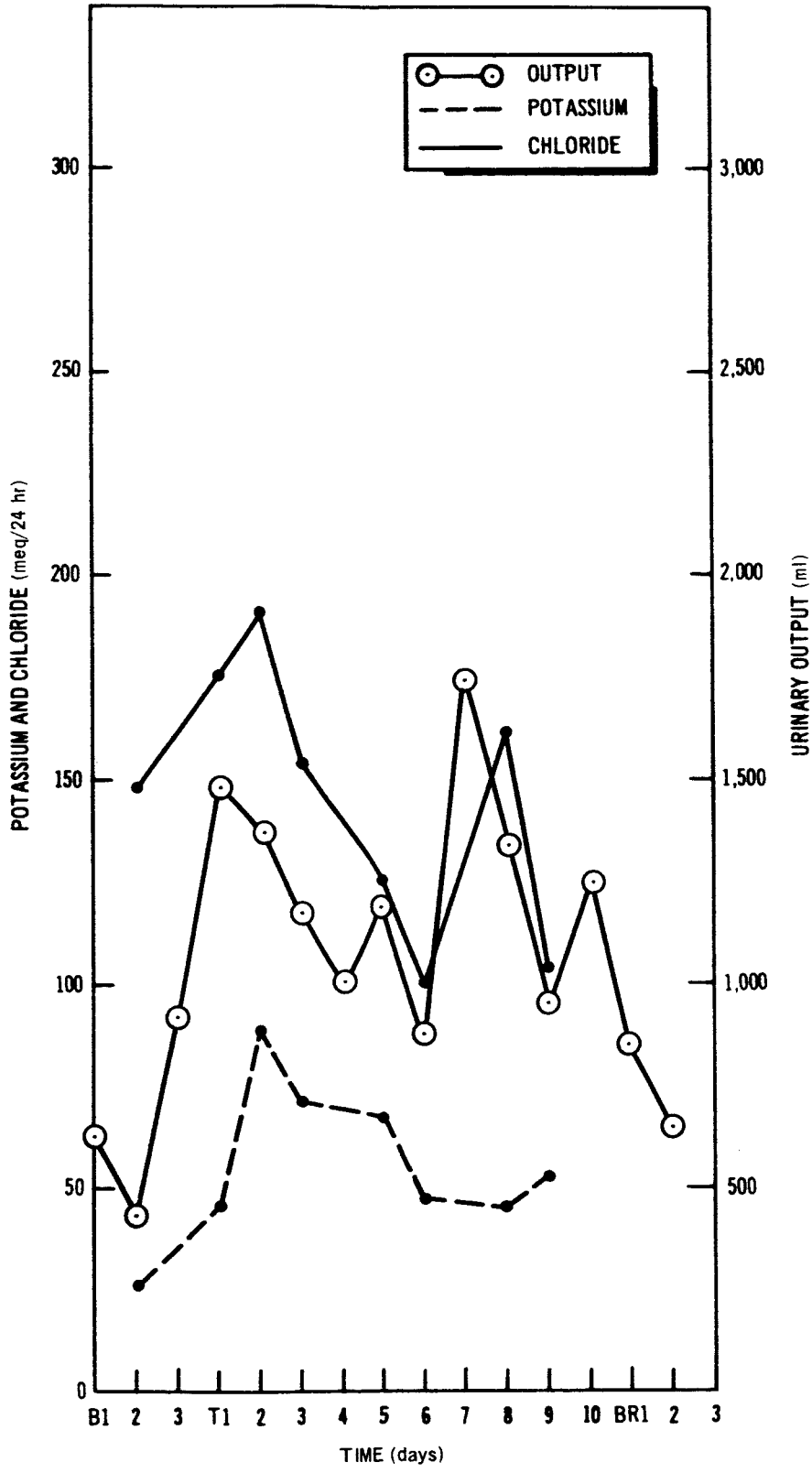


Figure 13. Subject LB, Bed Rest

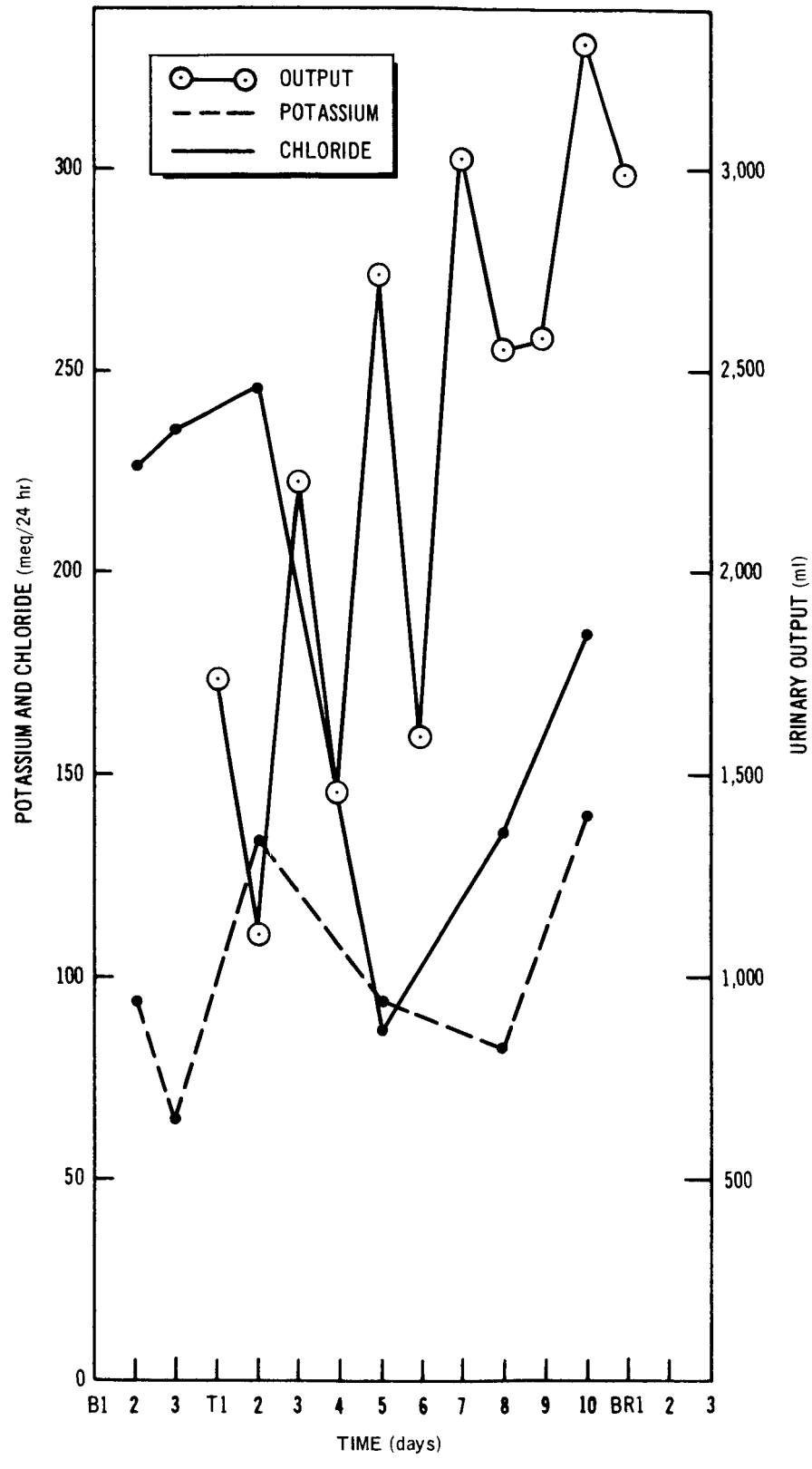


Figure 14. Subject EH, Immersion

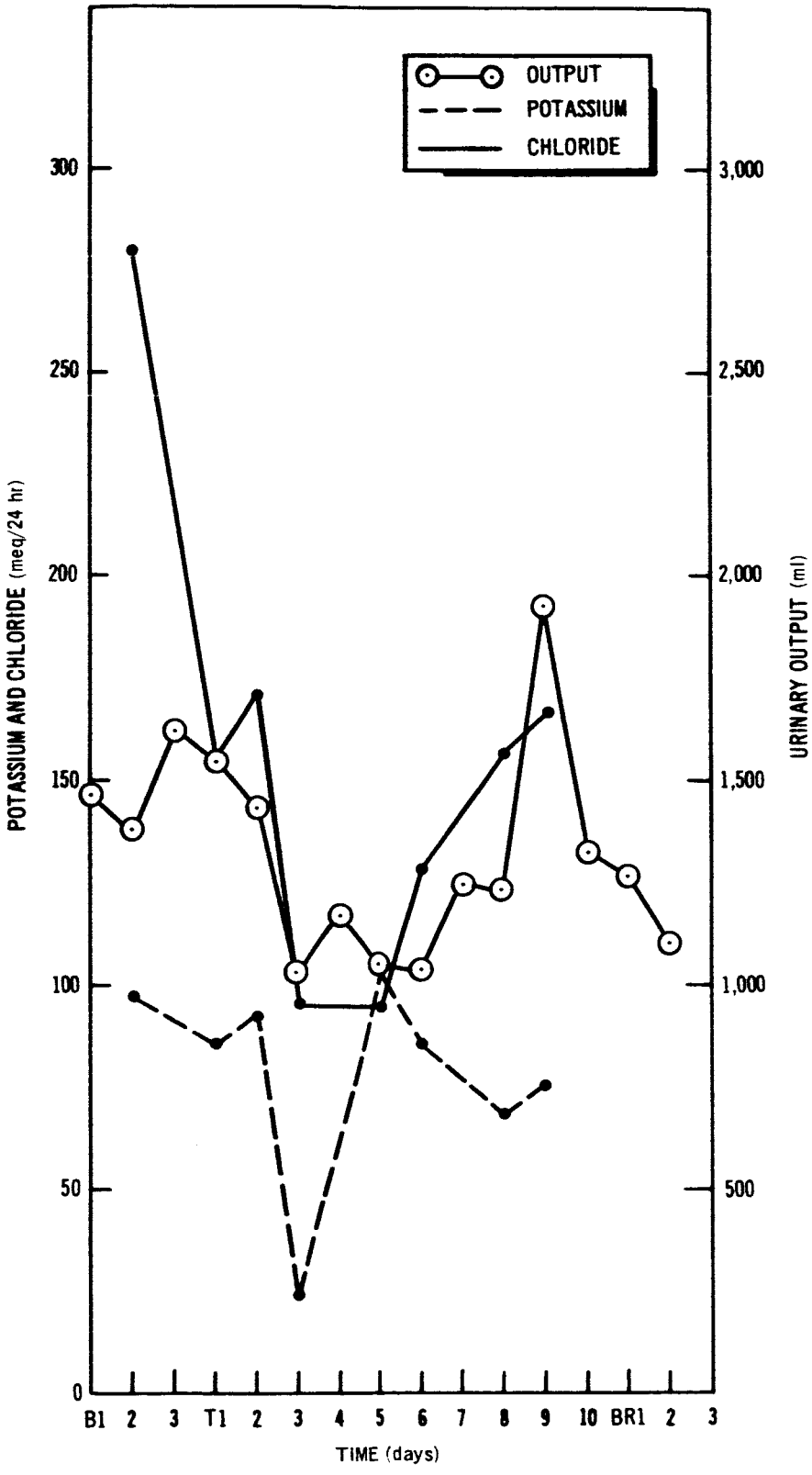


Figure 15. Subject EH, Bed Rest

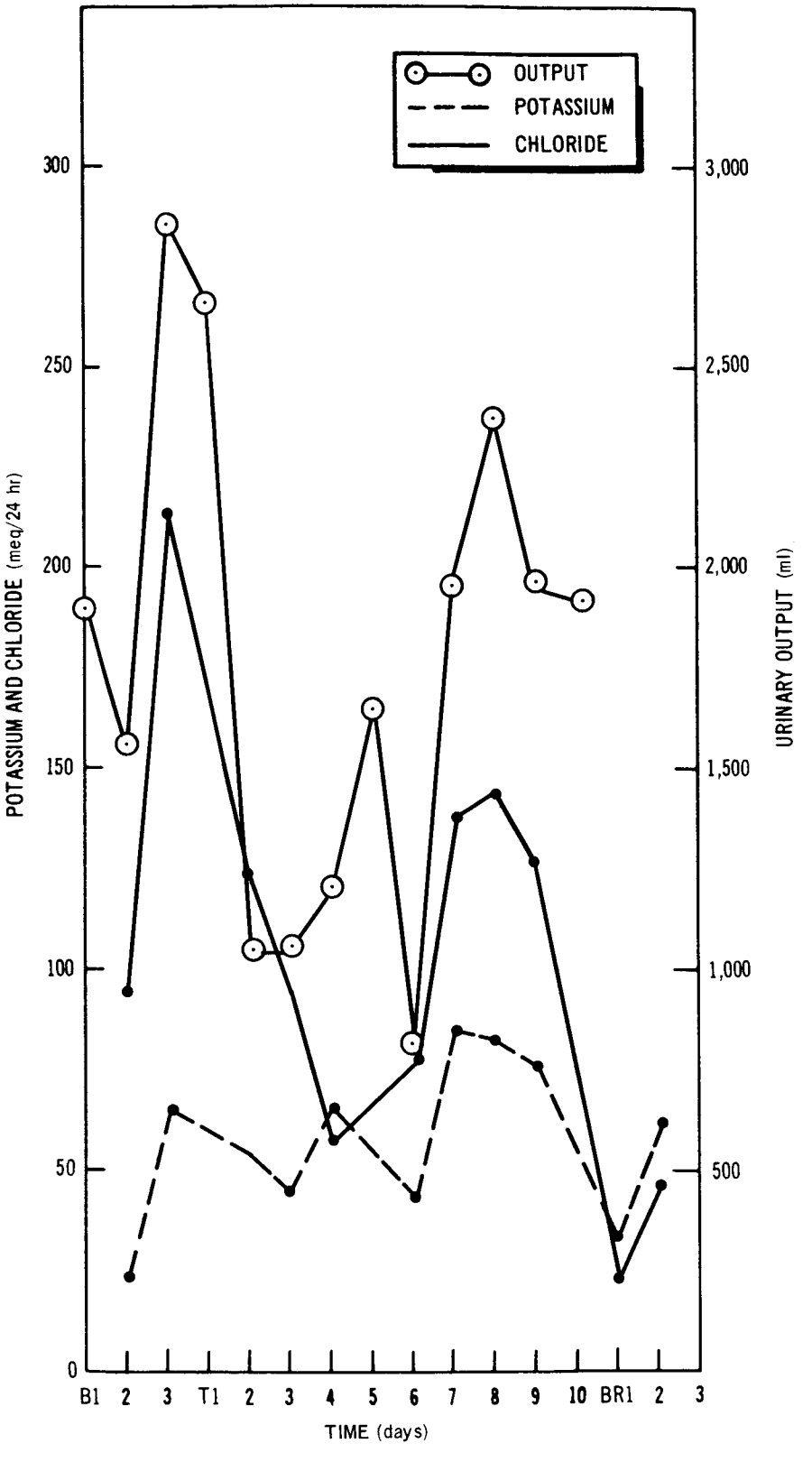


Figure 16. Subject JH, Immersion

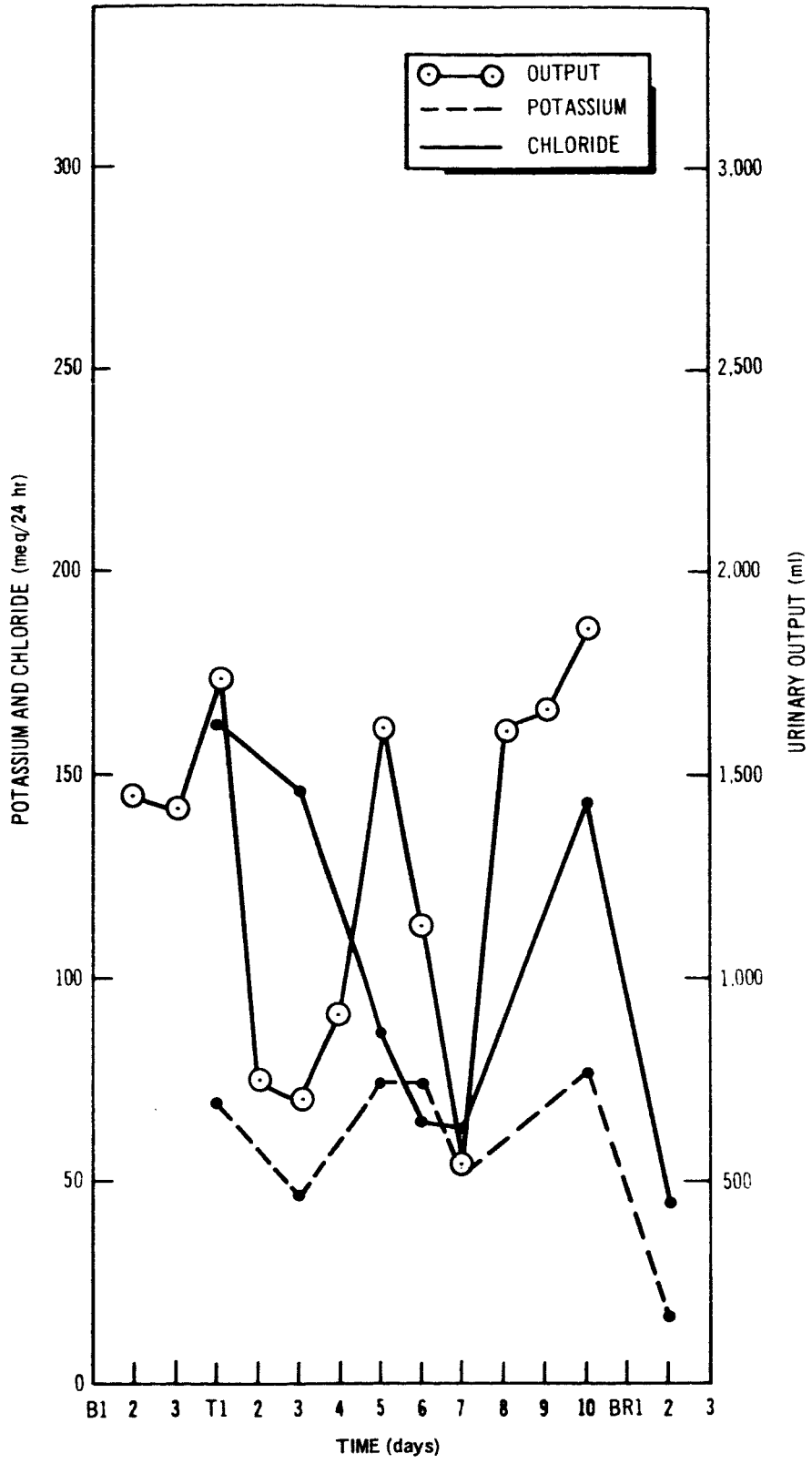


Figure 17. Subject JH, Bed Rest

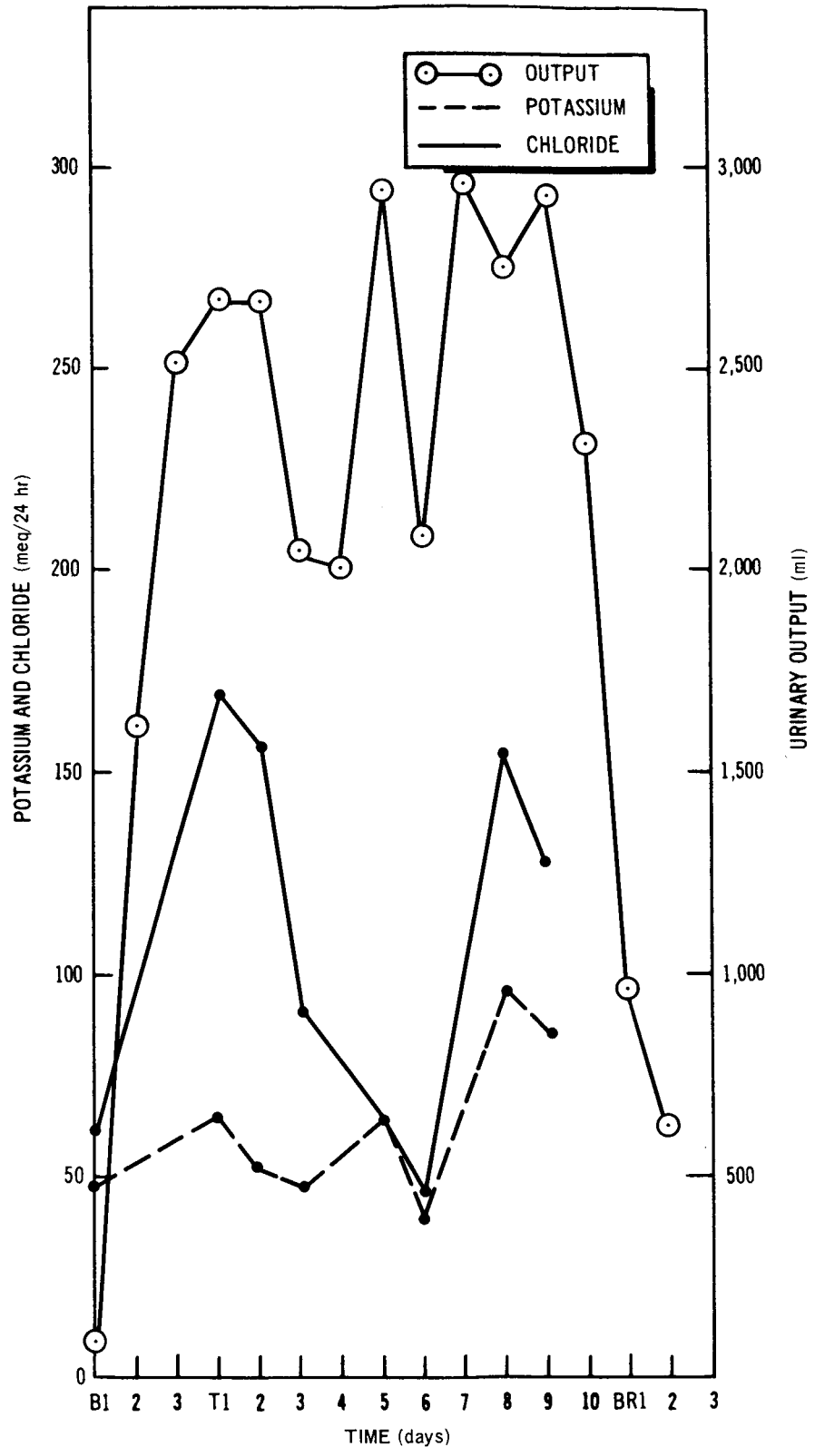


Figure 18. Subject BI, Immersion

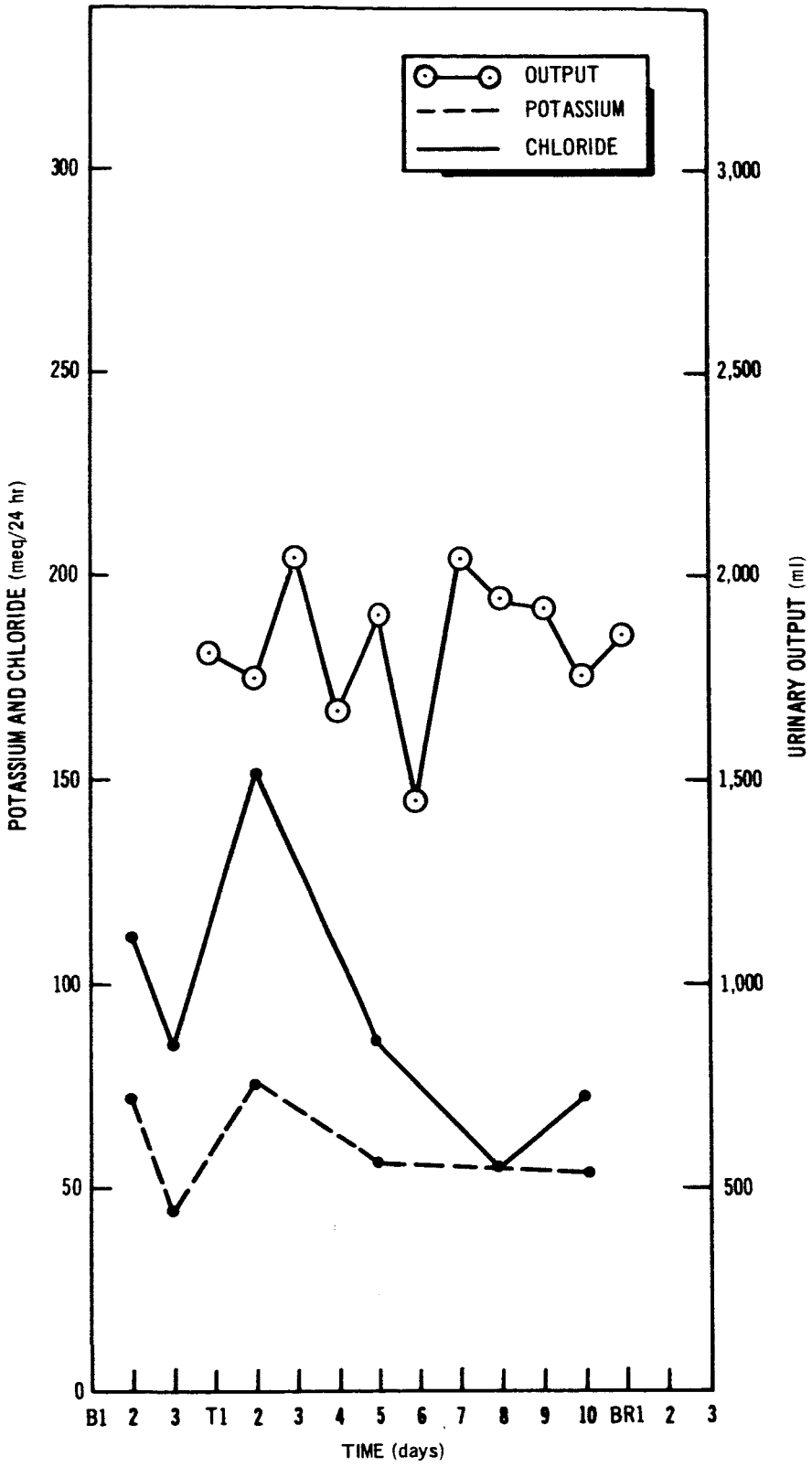


Figure 19. Subject BI, Bed Rest

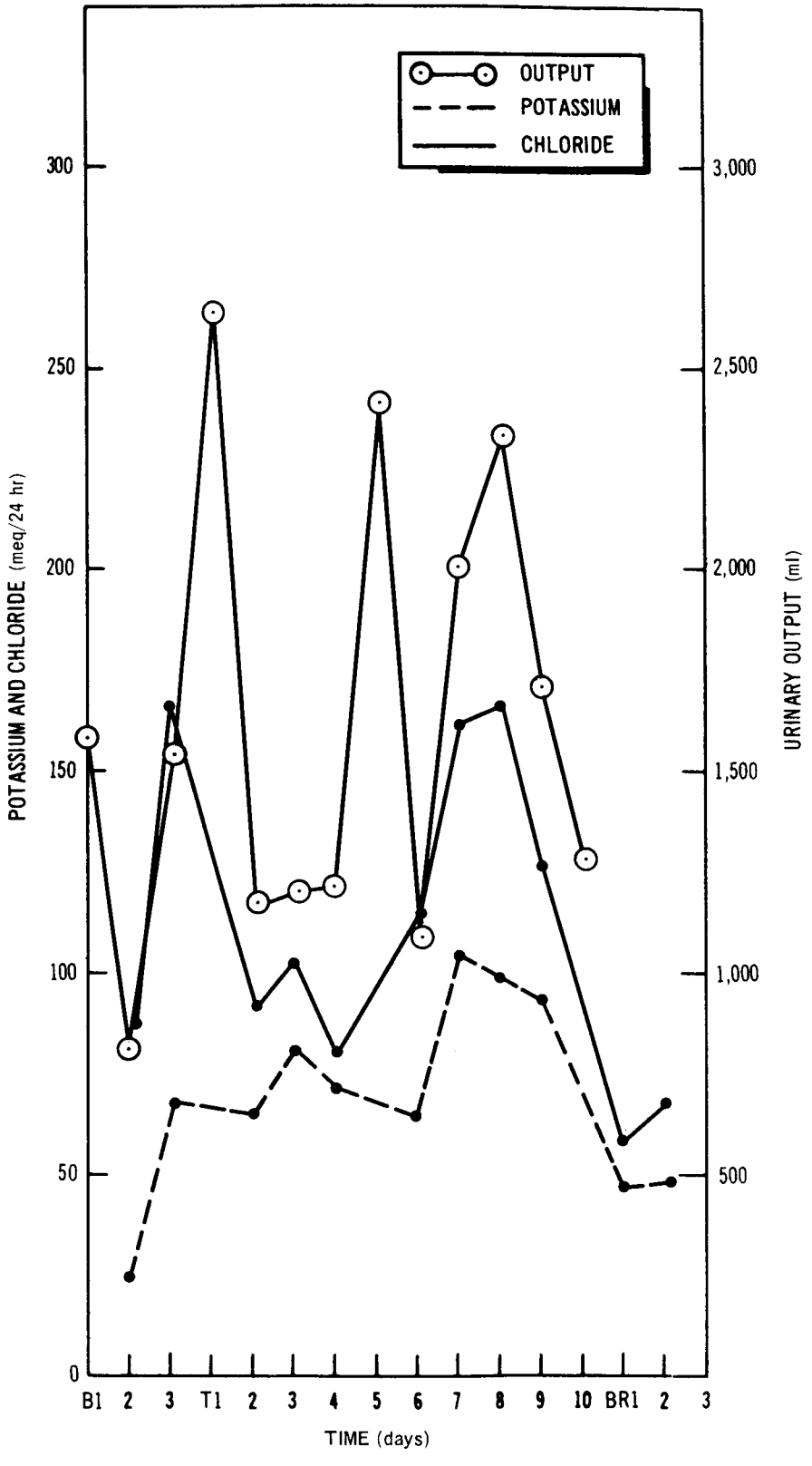


Figure 20. Subject LL, Immersion

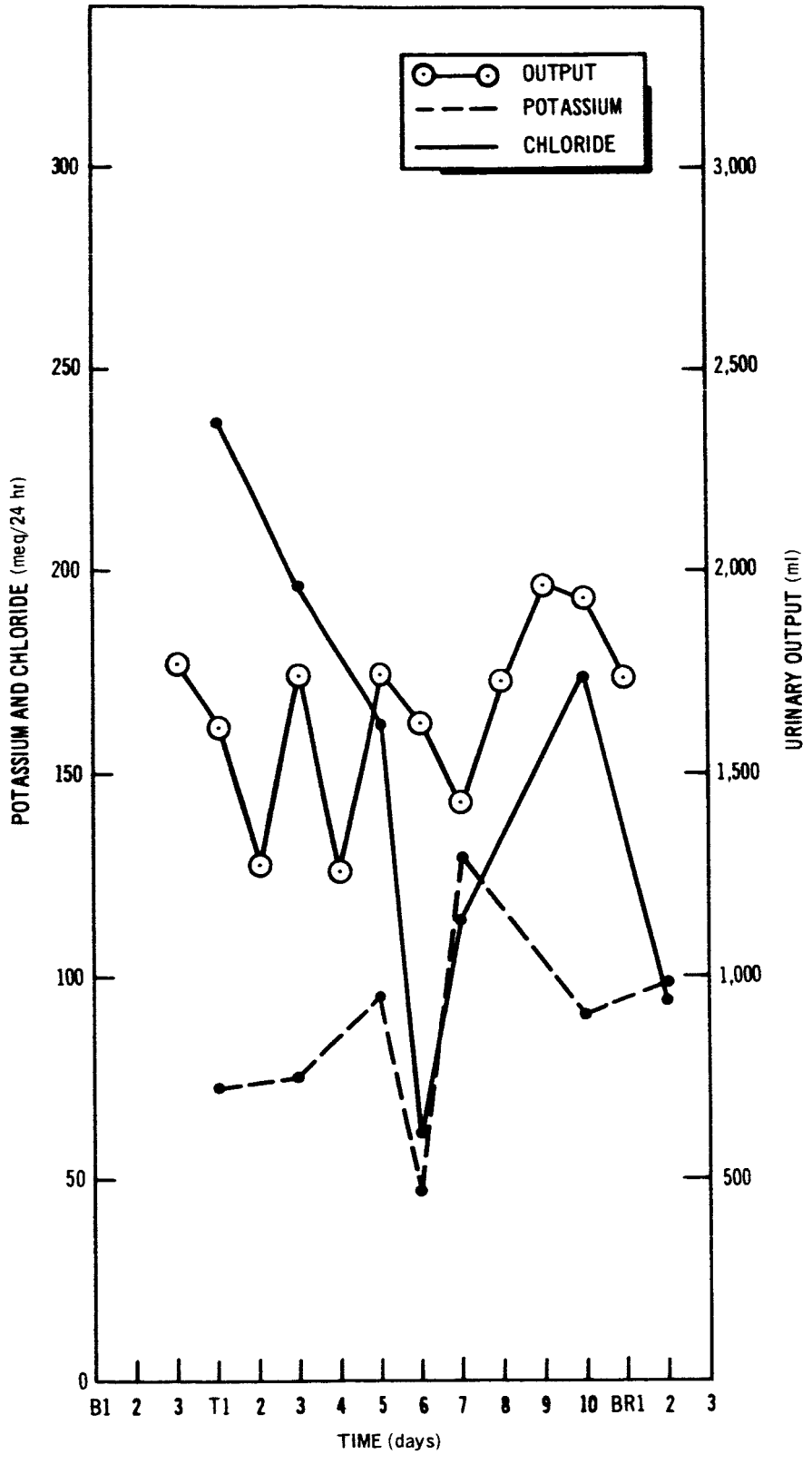


Figure 21. Subject LL, Bed Rest

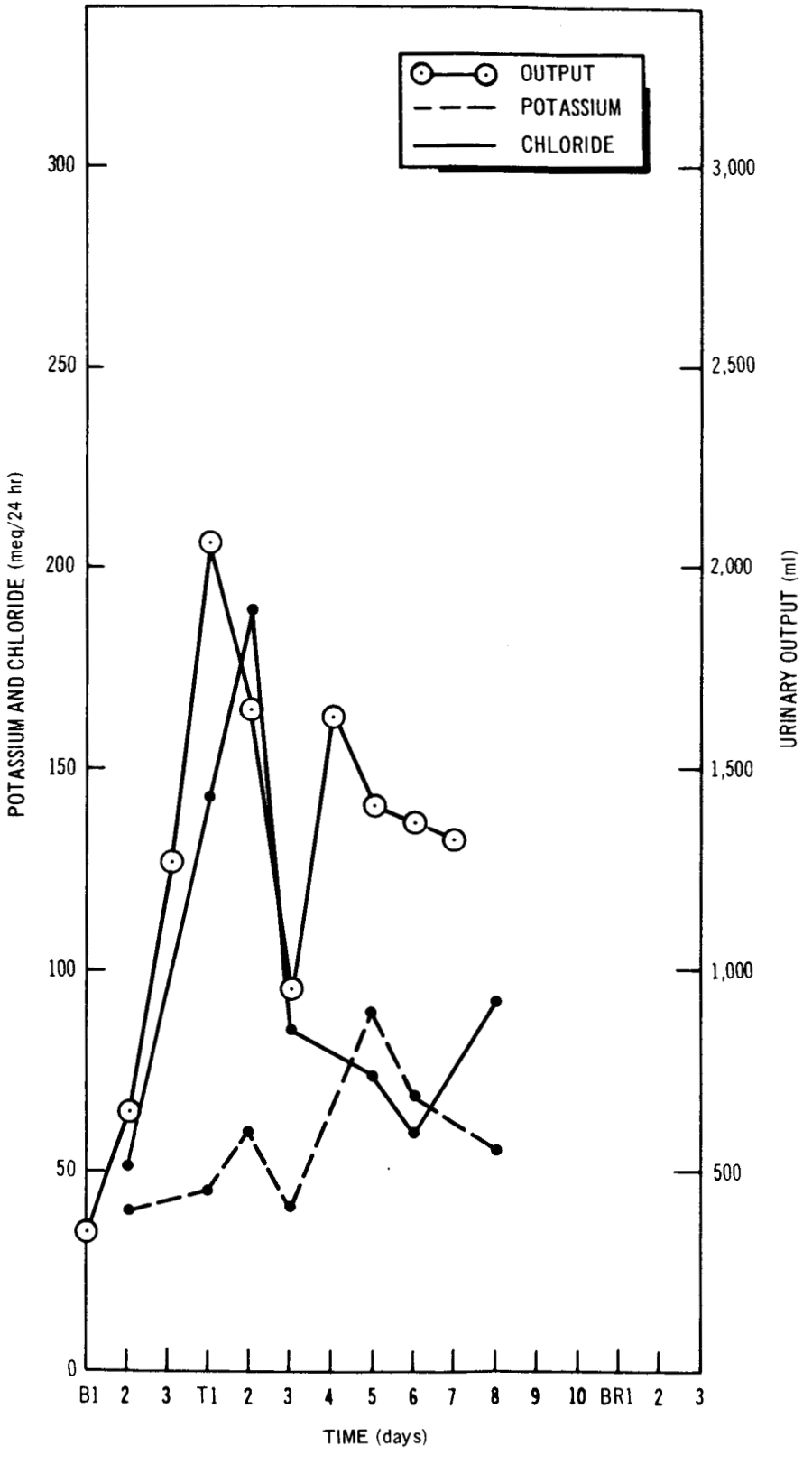


Figure 22. Subject RM, Immersion

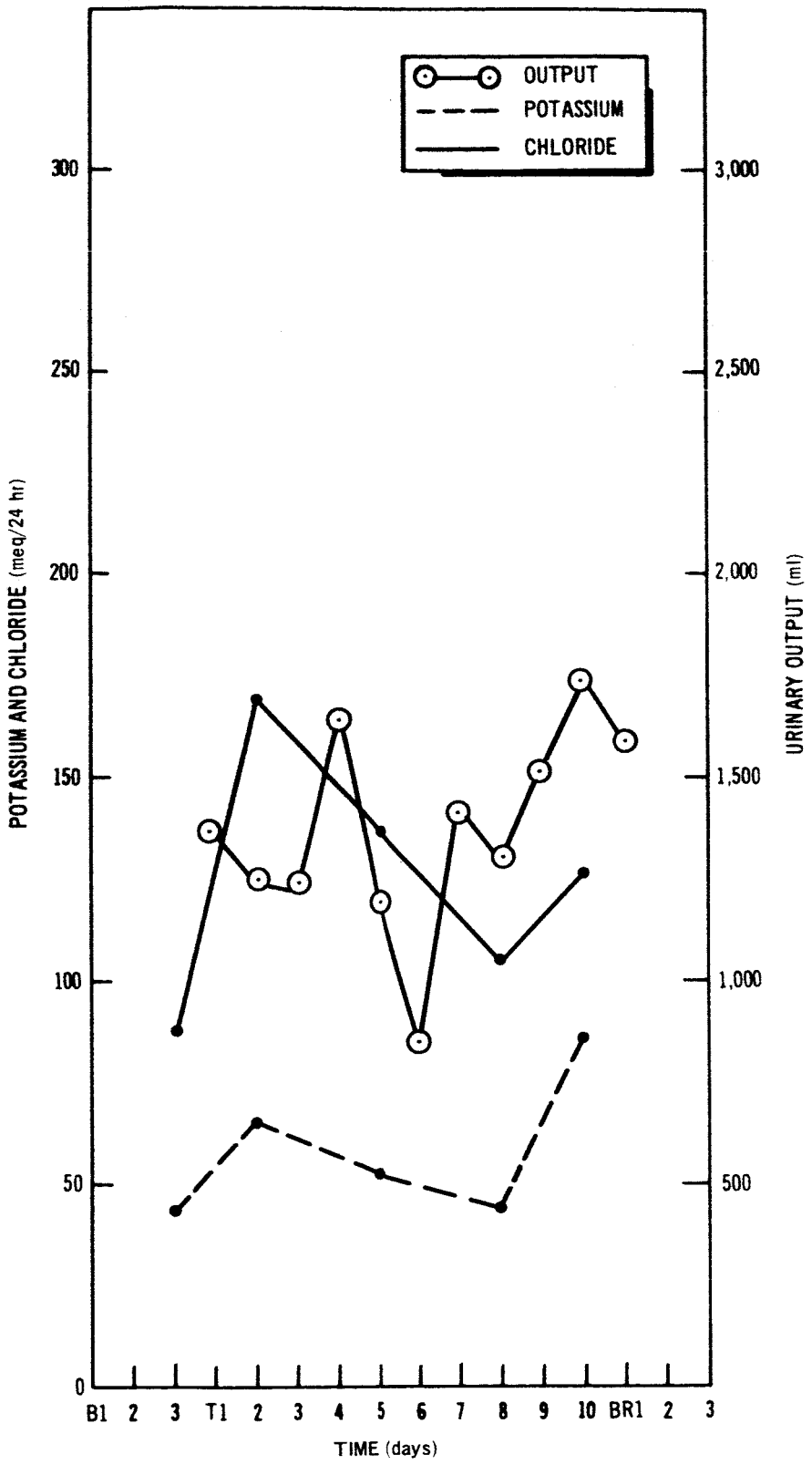


Figure 23. Subject RM, Bed Rest

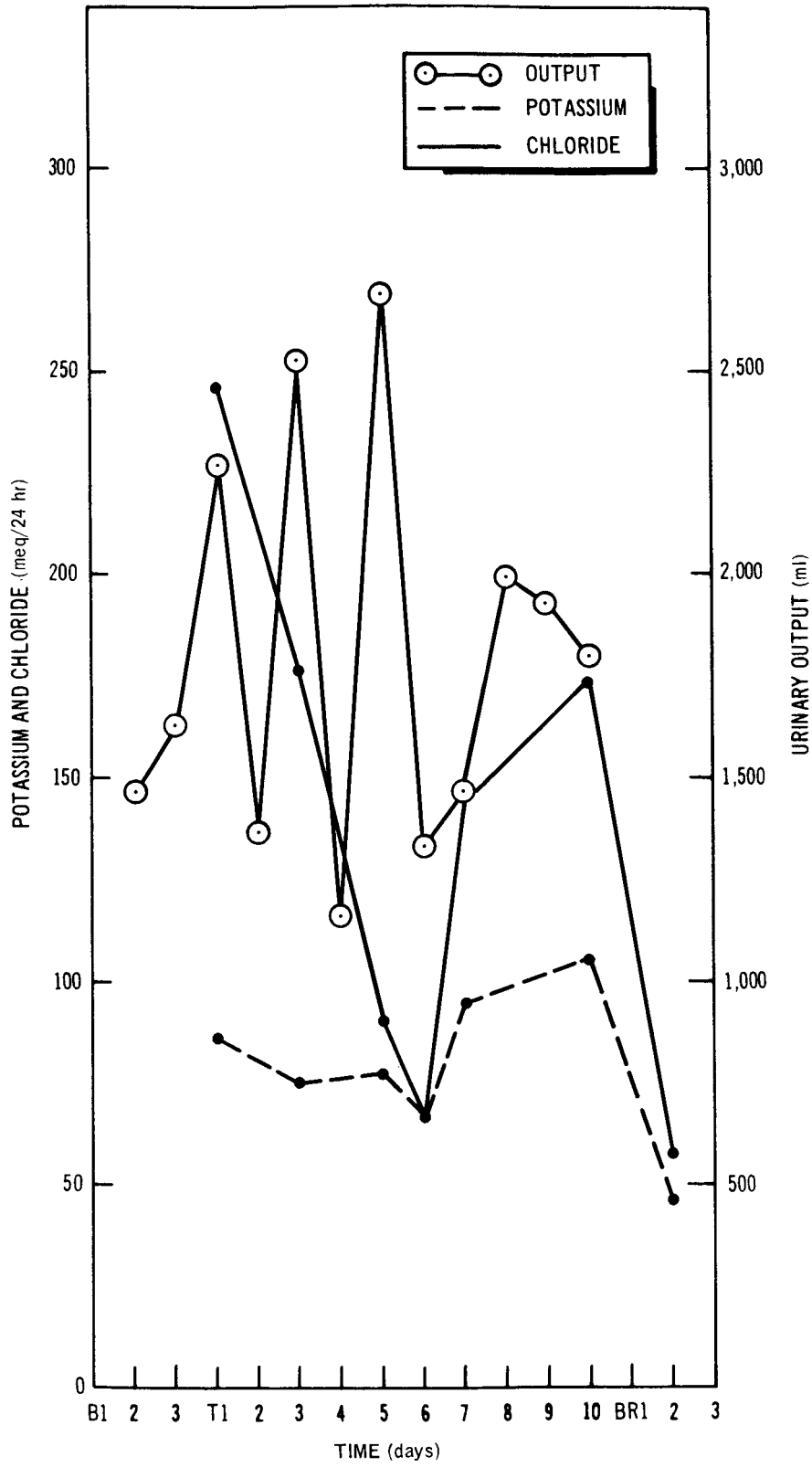


Figure 24. Subject BS, Immersion

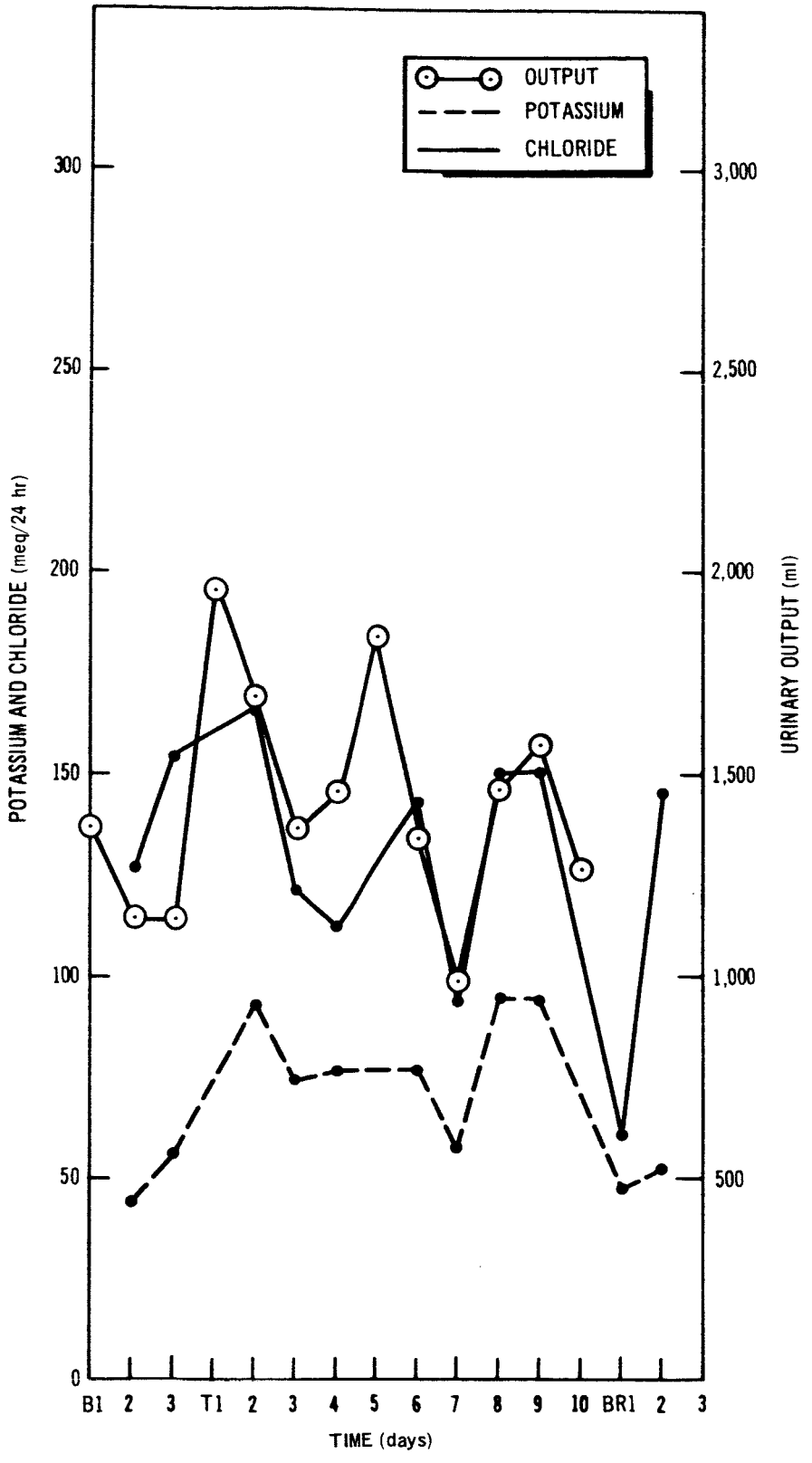


Figure 25. Subject BS, Bed Rest

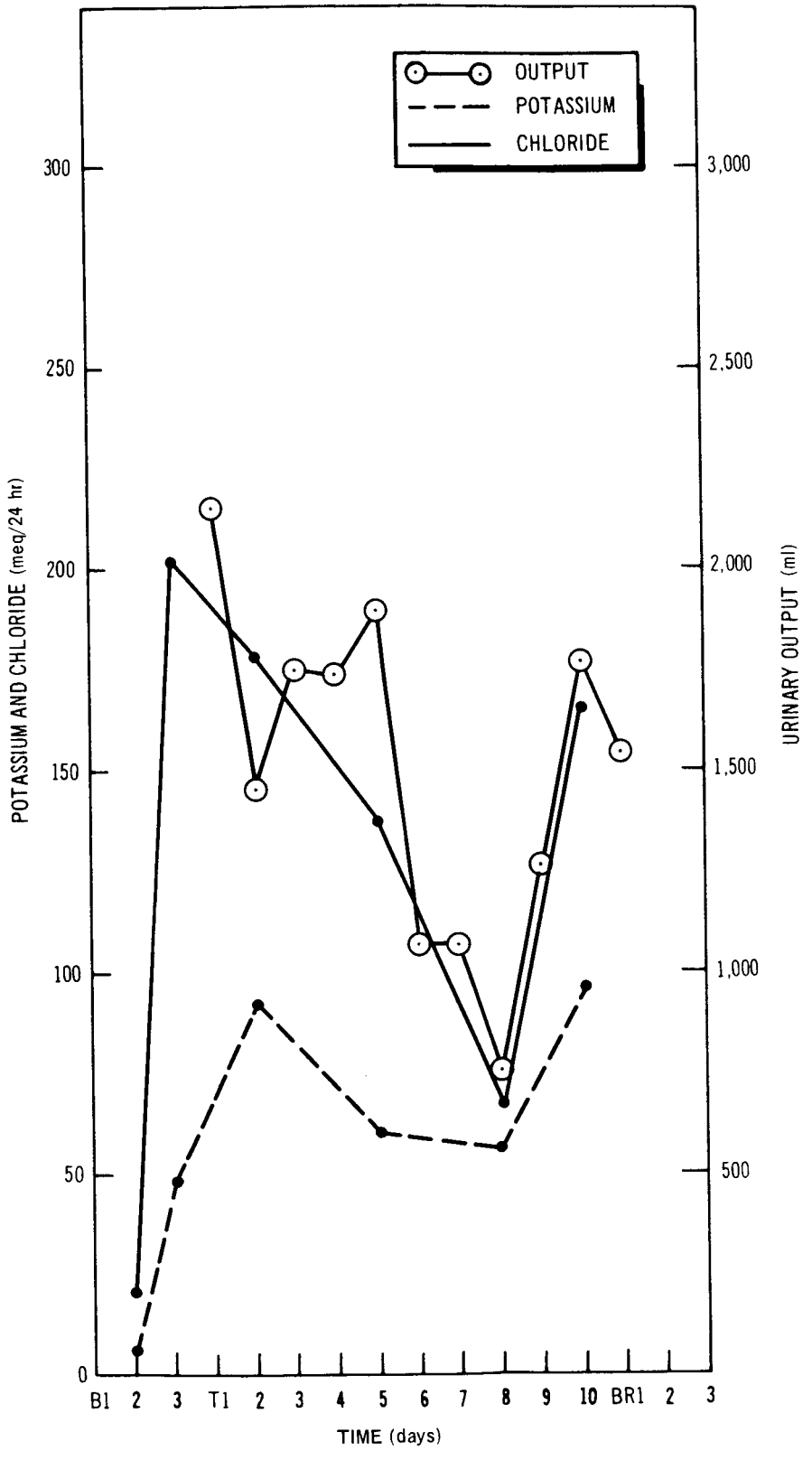


Figure 26. Subject LS, Immersion

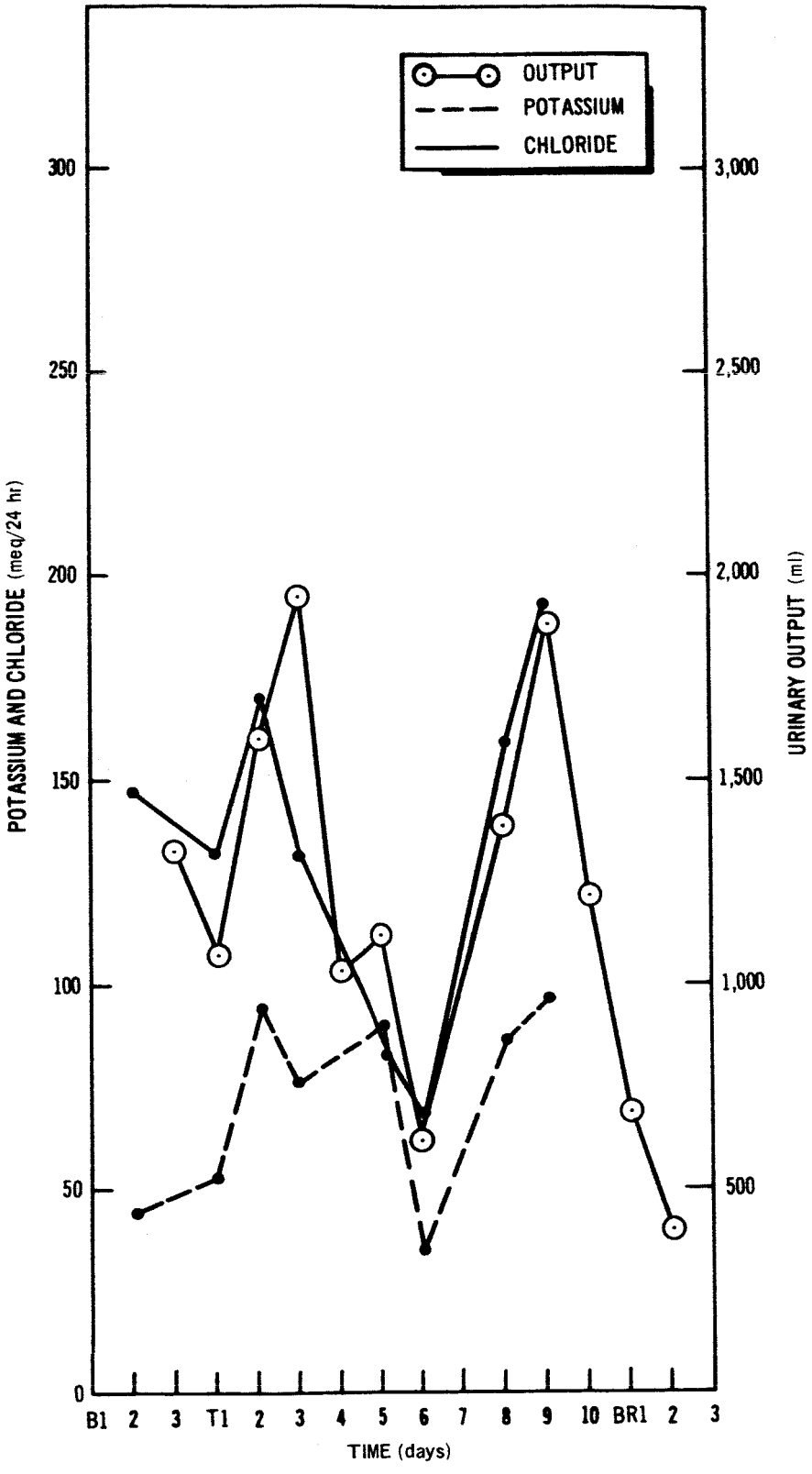


Figure 27. Subject LS, Bed Rest

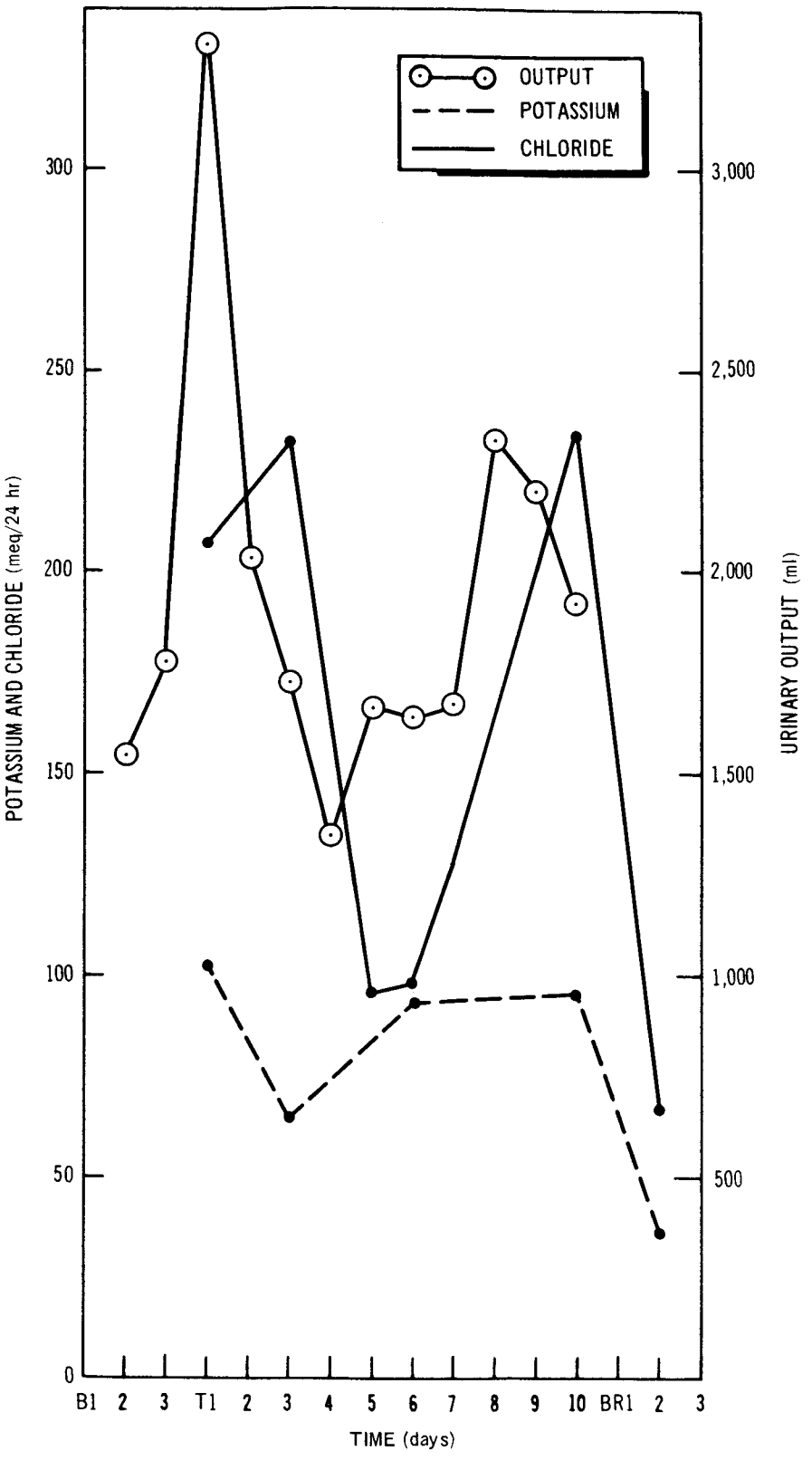


Figure 28. Subject WW, Immersion

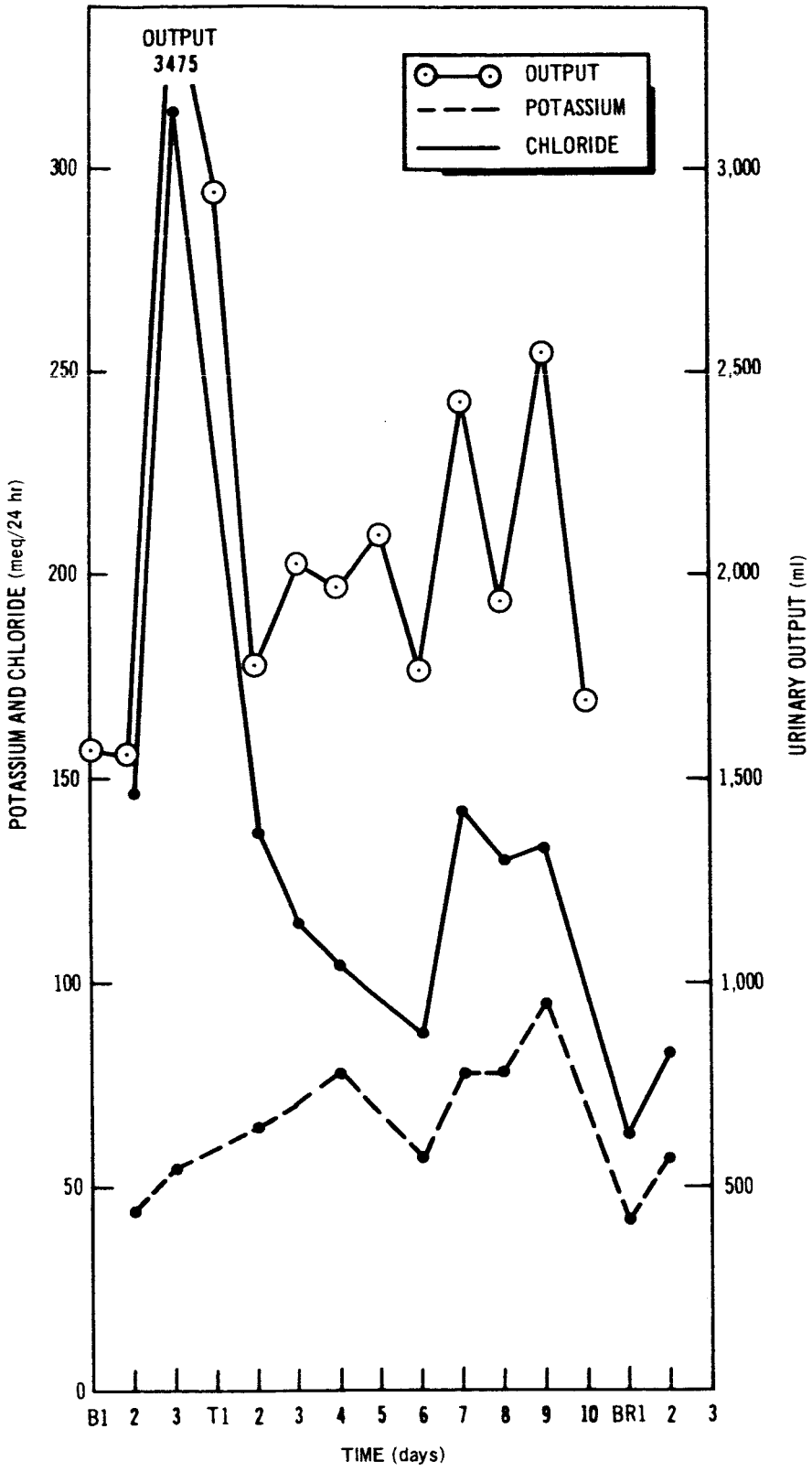


Figure 29. Subject WW, Bed Rest

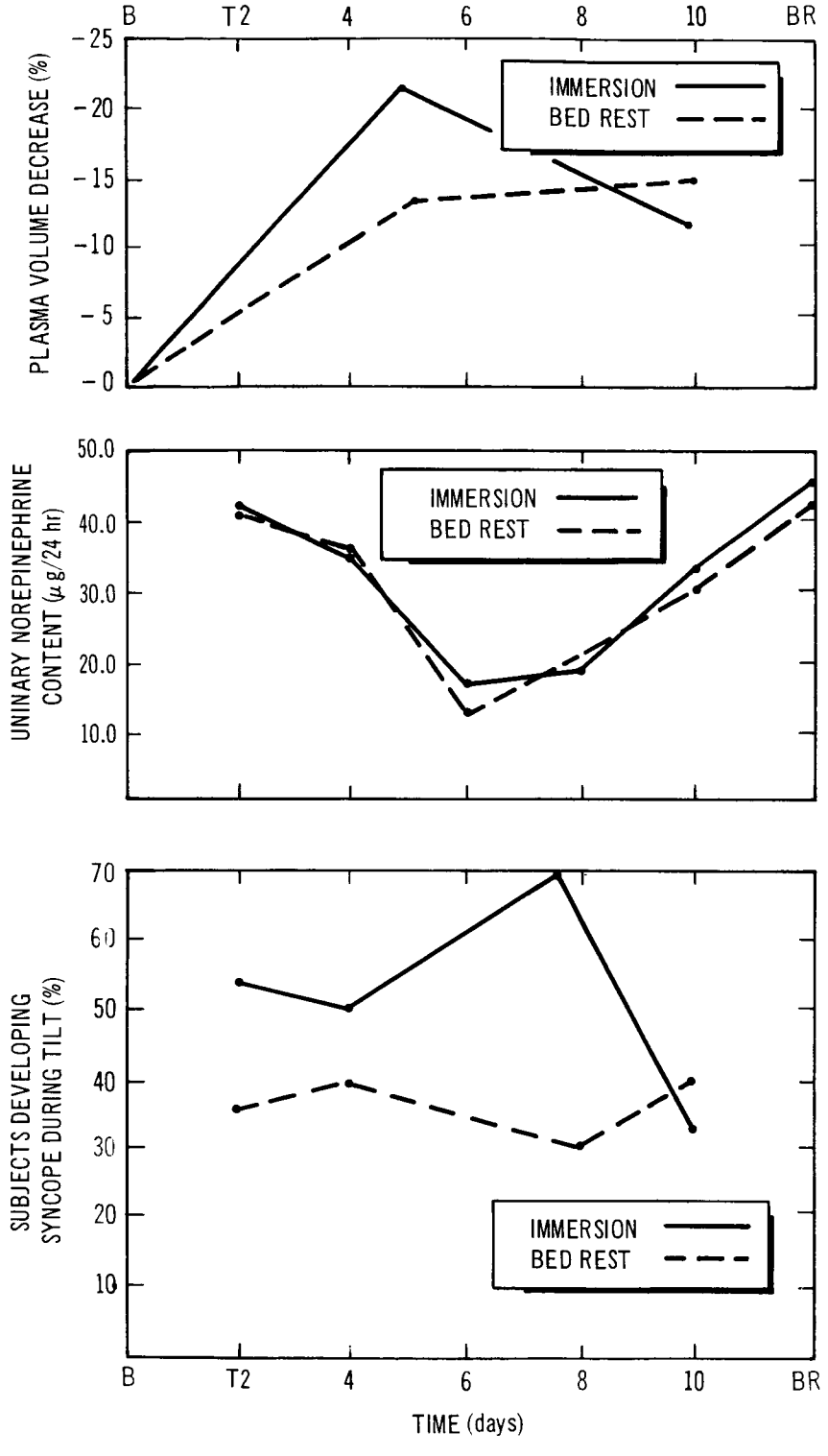


Figure 30. Relation Between Plasma Volume, Norepinephrine, and Orthostatic Tolerance

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