RESULTS OF DSO 0423 (STUDY OF INFLIGHT FLUID CHANGES),

PERFORMED ON STS-8

BACKGROUND

The purpose of this investigation was to obtain information under operational Shuttle conditions about body fluid regulation during weightless flight. Endocrine and metabolic changes observed in astronauts after previous space flight series have suggested that the weightless environment presents significant challenges to man's ability to maintain homeostasis. These changes include weight loss; increased aldosterone excretion, and loss of sodium and potassium (Leach, 1979). Bedrest studies (Nixon et al., 1979; Leach et al., 1983) have indicated that increased fluid and electrolyte excretion may begin to occur within a few hours of the attainment of weightlessness. It is necessary to study the early time course of these metabolic changes to determine cause-and-effect relationships. Some of the factors involved in fluid metabolism changes may also be involved in the space adaptation syndrome.

TEST DESCRIPTION

One mission specialist (MS-3 on STS-8) collected all of his urine voids for 4 days before launch,* throughout the 6-day mission and for 3 days after landing. Collection times ranged from 5 hours, 12 minutes to 26 hours; these times are for pools, not single voids. The first inflight pool actually represented more pre-launch (3 h, 22 min) than post-launch time (1 h, 50 min). With three exceptions, each collection was made in a bag containing lithium chloride and boric acid. Boric acid served as a preservative, and postflight assay of lithium concentration in an aliquot of the pool was used to calculate the total pool volume. Since specimens collected inflight could not be frozen immediately, aliquots of preflight specimens were kept at room temperature for the duration of the mission and were compared to specimens frozen immediately. During the mission a representative 25 ml aliquot of each pool was taken in a Sarstedt syringe and left at ambient temperature. The syringes were frozen after being removed from the vehicle. Postflight pools were kept at ambient temperature while being collected, then they were either refrigerated or frozen. The first preflight pool and the second and third pools after landing were collected in disposable urine containers without lithium chloride or boric acid.

Throughout the period of urine collection, records of food and fluid intake were kept. Cardiovascular countermeasures (ingestion of saline solution before landing) were not used by this mission specialist. During the first 5 hours of the flight (until about 0500), the mission specialist experienced episodes of space motion sickness, although he had taken anti-motion sickness medication.

At approximately 1 hour 50 minutes before landing, a blood sample was drawn into heparin and the sample was given to the hematologist about 3 hours after it was drawn. Routine hematology analyses were performed using standard clinical procedures.

Urine samples were analyzed by standard clinical procedures for several hormones, electrolytes and other parameters, and the volume of each pool was determined.

RESULTS

A paired t-test was performed on the data from frozen and room temperature preflight samples. Antidiuretic hormone (ADH) in the room temperature samples was significantly decreased ($p<.05$) while osmolality and creatinine were significantly increased in the room temperature samples. Therefore, the aliquots stored at room temperature were used to compare preflight, inflight and postflight results. Postflight specimens may not be strictly comparable to those from the preflight and inflight periods because they were not kept at room temperature as long as the others were.

Because of the wide variation in amount of time represented by each aliquot analyzed, the amount of each compound or electrolyte measured was divided by the time represented to obtain a urinary excretion rate. This method is more sensitive to change than use of 24-hour pools, but it may not detect transient changes and is more subject to influence by circadian rhythms. Calculations were also done for approximate 24-hour pools; except for the first void after landing and the last postflight specimen, the largest deviation from 24 h was 20 h for the third inflight day.

Inflight

The excretion rate of ADH (Fig. 1) and then cortisol (Fig. 2) increased greatly during the first 24 h of flight but returned to levels only slightly above normal on the second day of the mission. On the sixth day of the mission the excretion rate of aldosterone (Fig. 3) increased and a small peak in excretion rate of cortisol on that day coincided with the aldosterone peak. Epinephrine excretion rate (Fig. 4) was highly variable during the preflight period but became more stable during the flight, with an increase at the time of re-entry. The excretion rate of norepinephrine (Fig. 5) decreased on the first day of the mission but increased on the second day and remained relatively stable until re-entry, when it decreased.

The rate of fluid excretion (urine volume) increased late on the second mission day (Fig. 6) and on a 24-hour basis remained high during the rest of the mission. The excretion rates for some time intervals were as low as preflight rates, however; for at least 3 days there seemed to be a regular-cycle of peaks and valleys. Osmolality (Fig. 7) and specific gravity (Fig. 8) of approximate 24-hour pools were lower inflight than they were preflight, except that they increased on the first inflight day when volume decreased. (Other results for 24-hour pools are presented in Appendixes A and B.) The excretion rates for sodium (Fig. 9), potassium (Fig. 10), chloride (Fig. 11) and phosphate (Fig. 12) varied greatly, even during the preflight period. Sodium and chloride had similar patterns of excretion rate during all phases of the experiment. Preflight rates of excretion varied so much that there was probably no difference between preflight and inflight, at least without taking salt intake into account. There was a large increase in excretion rate of potassium on the first day of flight, at the same time as the main peak in cortisol excretion rate. The phosphate excretion rate, which showed daily peaks and valleys, was generally higher during flight. The excretion rate of calcium (Fig. 13) increased markedly on the second day inflight and remained high until re-entry, and magnesium excretion (Fig. 14) increased slightly on the last day of the flight.

The excretion rate of uric acid (Fig. 15) during flight was probably not significantly different from the preflight rate; the rate varied considerably from one pool to another. The excretion rate of creatinine (Fig. 16) increased from pool to pool from the fourth inflight day until landing.

Recovery

The urinary excretion rate of most parameters decreased on the first day after the mission; only cortisol (Fig. 2) and norepinephrine (Fig. 5) were not excreted at a lower rate. ADH (Fig. 1) and cortisol were the only parameters in which there was no great change in excretion rate during the first 3 days after landing. After the initial decrease, the excretion rate of aldosterone, epinephrine, norepinephrine, urine volume and all of the electrolytes and nitrogenous substances increased during the first few days after landing. Parameters with higher-than-preflight excretion rates for the last pools included ADH, norepinephrine, urine volume, potassium, calcium and uric acid. The level of aldosterone in the last pool was lower than normal.

Hematology

Hemoglobin and platelet and white blood cell numbers were increased inflight and at L+0; ZSR was lower than preflight (Table 1). At L+9, hemoglobin, hematocrit and erythrocyte number were lower than preflight and the number of platelets was greater than preflight.

DISCUSSION

The earliest effect of space flight detected in this study was a transient increase in the excretion rate of ADH, closely followed by a transient increase in the excretion rate of cortisol. ADH is usually produced in response to fluid loss and leads to water retention, and cortisol promotes sodium retention and potassium and water excretion. The usual effect of ADH, retention of fluid, was not seen in the present study, but the effects of cortisol were evident. Excretion of urine increased during at least part of each 24-hour period during the flight, with a pattern that may be attributable to the circadian rhythm of cortisol secretion. Sodium excretion decreased on the day after the peak in cortisol excretion, but it increased later in the flight. Potassium excretion increased at the same time as cortisol excretion on the first day of flight, with smaller peaks on later flight days.

It is possible that ADH was produced in response to fluid shifts caused by acceleration forces during launch. ADH excretion almost doubled in young females subjected to acceleration comparable to Shuttle conditions, and it returned to normal during bedrest (manuscript in preparation). An increase in urinary ADH on the first inflight day of the Skylab 2 mission has been attributed to heat stress (Leach, 1981), and it was not seen in other Skylab crewmen. Another possible cause of the increased ADH excretion seen in the present study is pre-launch dehydration.

Plasma cortisol has also been found to increase after acceleration (Vernikos-Danellis et al., 1978), and in another study urinary cortisol increased after bedrest and after acceleration in male and female subjects ages 35-65 years (manuscript in preparation). All but one crewmember of Skylabs 2, 3 and 4 had increased levels of urinary cortisol on the first day of flight (Leach and Rambaut, 1977).

It is possible that the symptoms of space adaptation syndrome influenced or were influenced by an increased secretion of ADH and cortisol early in the flight. One could postulate that loss of fluid due to vomiting could trigger secretion of ADH. However, since many factors influence the secretion of these hormones, it is not yet possible to determine the reasons for the high excretion rates of ADH and cortisol. The anti-motion sickness medication taken by the mission specialist might also have affected the results.

The only other definite inflight change in hormone excretion occurred on the sixth and last day of the flight, at which time aldosterone excretion rate tripled and cortisol and ADH excretion rates increased by less dramatic amounts. It is difficult to understand why this may have occurred at that time. The excretion rate of fluid, potassium, chloride, calcium and magnesium increased at the same time, but there is no clear indication of metabolic events leading up to these increases, which occurred before re-entry began. The loss of sodium, which might be expected to result in increased aldosterone secretion, was no greater late in the flight than it had been during the preflight period, although it had increased from a low point on the second day of the flight. Skylab results (Leach and Rambaut, 1977) show an increase in angiotensin I on inflight days 5 and 6. Serum sodium and plasma angiotensin I were not determined in the present study. It is possible that the shorter storage time at ambient temperature influenced the analysis of specimens from the last day of flight. Urinary aldosterone increased during the last few days of bedrest lasting a week (manuscript in preparation), but the reason for the increase is unknown.

Increased urinary excretion of fluid did not occur until the second day of the flight, instead of beginning immediately after attainment of weightlessness as has been predicted (Leach, 1979). The apparent delay in diuresis, also seen in other space flight series, has been attributed to pre-launch dehydration and decreased intake of fluid due to motion sickness, factors that may also be operating in this experiment.

Termination of the flight had a dramatic effect on almost all of the parameters measured. Although acceleration is part of the change of environment, the excretion rates of ADH and cortisol did not increase as they did at the beginning of the flight; in fact, they changed the least. The reason for large fluctuations in aldosterone excretion rate after landing is unclear. High levels of urinary aldosterone were found in specimens from two crewmen of Skylab 2 on the fifth day of flight, but they returned to normal on the second and third day after landing.

Sodium and chloride excretion, which decreased on landing to very low levels, decreased on the first day of ambulation after a week of bedrest (manuscript in preparation). Urinary sodium decreased on landing in all of the Skylab crewmen; sodium, potassium, chloride, magnesium, phosphate and uric acid were significantly lower during the first 6 days of recovery than they had been preflight (Leach and Rambaut, 1977).

Postflight (L+0) decreases in urinary sodium, chloride, magnesium and volume have been observed in most of the Shuttle crewmembers (Leach, 1983a and 1983b), and plasma and urinary aldosterone were increased at the same time. Aldosterone generally promotes potassium excretion and sodium retention. Although increased secretion of aldosterone may well be a factor in the conservation of fluid and electrolytes upon landing, it seems unlikely to be the cause of the decrease in excretion rate of all of the electrolytes (as well as several hormones and other compounds) measured in the present investigation and the other Shuttle studies. Such a universal conservation of electrolytes is not seen in bedrest studies.

Increased excretion of calcium and phosphate during flight was also seen in Skylab crewmembers (Leach and Rambaut, 1977) and is an indication of bone loss.

There is some indication from the present results that circadian rhythms in excretion of cortisol, potassium and phosphate are maintained in space, but the time intervals are too far apart to determine whether or not there is a true rhythm.

Hematology results were similar to those of Skylab (Kimzey, 1977).

The results of the STS-8 study indicate that two hormones (ADH and cortisol) involved in fluid and electrolyte regulation are indeed affected by flight conditions soon after launch (within 2 hours, in the case of ADH). It is also evident that rapid changes in fluid and electrolyte metabolism take place upon re-entry, and it is these changes that are reflected in results of L+0 urinalyses.

Since the only subject in this experiment experienced space motion sickness, it is important to repeat the experiment with other astronauts who do not suffer from the space adaptation syndrome, to be certain that the early biochemical changes detected are not related to this syndrome and to determine whether the changes occur in most Space Shuttle astronauts. Analysis of single voids would make it possible to better understand the sequence of events in fluid metabolism adaptation, and measurement of endocrine and electrolyte parameters in blood drawn inflight would complement the results of urinalyses.

ACKNOWLEDGEMENTS

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References

Kimzey, S. L. Hematology and immunology studies. In: Biomedical Results from Skylab (R. S. Johnston and L. F. Dietlein, eds.), NASA SP-377, pp. 249-282, 1977.

Leach, C. S. A review of the consequences of fluid and electrolyte shifts in weightlessness. Acta Astronautica 6:1123-1135, 1979.

Leach, C. S. An overview of the endocrine and metabolic changes in manned space flight. Acta Astronautica 8:977-986.

Leach, C. S. Biochemistry and endocrinology. In: Summary Test Flight Medical Report, NASA, in press, 1983.

Leach, C. S. Biochemistry and endocrinology results. In: STS-5 through STS-8 Medical Operations Report, NASA, in press, 1984.

Leach, C. S., P. C. Johnson and W. N. Suki. Current concepts of space flight induced changes in hormonal control of fluid and electrolyte metabolism. The Physiologist 26 (Suppl.):S-24-S-27, 1983.

Leach, C. S. and P. C. Rambaut. Biochemical responses of the Skylab crewmen: An overview. In: Biomedical Results from Skylab (R. S. Johnston and L. F. Dietlein, eds.), NASA SP-377, pp. 204-216, 1977.

Nixon, J. V., R. G. Murray, C. Bryant, R. L. Johnson, Jr., J. H. Mitchell, O. B. Holland, C. Gomez-Sanchez, P. Vergne-Marini and C. G. Blomqvist. Early cardiovascular adaptation to simulated zero gravity. J. Appl. Physiol.: Respirat. Environ. Exercise Physiol. 46:541-548, 1979.

Vernikos-Danellis, J., M. F. Dallman, P. Forsham, A. L. Goodwin and C. S. Leach. Hormonal indices of tolerance to $+G_z$ acceleration in female subjects. Aviat. Space Environ. Med. 49:886-889, 1978.

Table 1

STS-8 DSO 0423
Hematology

	RBC $x10^{12}/l$	Retic. % of RBC	Hb g/dl	Hct l/l	ZSR ml/ml	Platelets $x10^9/l$	WBC $x10^9/l$
PREFLIGHT							
F-30	5.08	1.0	14.4	0.44	0.52	192	4.4
F-11	5.18	0.8	15.0	0.46	0.52	179	4.8
F-3 PM	5.34	0.6	15.2	0.46	0.51	198	5.8
*INFLIGHT							
	5.17	0.7	16.3	0.44	0.48	232	6.0
POSTFLIGHT							
L+0	5.18	0.7	16.4	0.45	0.50	244	10.8
L+9	4.99	0.8	14.2	0.43	0.51	236	4.8

* Sample drawn 05:2300, mission elapsed time, approximately 1°50' prior to landing. Approximately 3 hours elapsed before sample was assayed.

APPENDIX A

URINE ENDOCRINE RESULTS FOR APPROXIMATE 24-HOUR POOLS

Start Date or Mission Day	Start Time	Stop Date or Mission Day	Stop Time	Time Represented by Pool	Volume ml	Cortisol µg/TV	Aldo µg/TV	ADH ng/TV	Epi µg/TV	Norepi µg/TV
					Preflight					
8-25	2130	8-26	2115	23°45'	1040	38.7	12.8	129.0	5.0	100.7
8-26	2115	8-28	2200	48°45'*	1150	31.1	4.8	72.4	17.1	113.1
8-28	2200	8-29	2310	25°10'	960	37.6	5.1	68.7	9.5	93.0
					Inflight					
3°22'	Pre-Launch	00	1900	22°22'	769	282.5	4.9	594.1	15.2	50.1
00	1900	01	2029	25°29'	1747	68.1	4.6	95.9	16.7	118.2
01	2029	02	1629	20°08'	1682	62.6	2.4	76.5	13.0	69.2
02	1629	03	1802	25°33'	2134	63.3	6.4	92.2	15.1	115.4
03	1802	04	1742	23°40'	1262	49.8	6.0	79.0	12.8	83.3
04	1742	05	1638	22°56'	2526	80.2	12.4	107.2	13.2	130.5
05	1638	05	2331	6°53'	891	7.7	2.5	30.3	13.7	41.1
					Postflight					
9-5	0050	9-5	2050	20°00'	425	24.8	12.1	66.4	8.8	72.9
9-5	2050	9-6	2250	26°00'	965	26.5	21.4	131.3	8.1	149.7
9-6	2250	9-7	2200	23°10'	1765	39.3	13.6	89.3	6.5	141.5
9-7	2200	9-8	0500	7°00'	1340	25.9	0.5	56.3	3.6	117.0

*Measurements given are those for half of this pool, a period of 24°23'.

APPENDIX B

URINE BIOCHEMISTRY RESULTS FOR APPROXIMATE 24-HOUR POOLS

Start Date or Mission Day	Start Time	Stop Date or Mission Day	Stop Time	Time Represented by Pool	Specific Gravity	Osmo mosm/l	Na meq/TV	K meq/TV	Cl meq/TV	Ca meq/TV	Mg meq/TV	IPO4 mg/TV	Uric Acid mg/TV	Creat mg/TV
Preflight														
8-25	2130	8-26	2115	23°45'	1.023	800	110	83	110	6.9	9.5	915	728	1986
8-26	2115	8-28	2200	48°45'*	1.022	695	143	78	141	5.3	9.2	687	364	1182
8-28	2200	8-29	2310	25°10'	1.022	803	12	80	119	5.4	8.8	843	458	1915
Inflight														
3°22'	Pre-Launch	00	1900	22°22'	1.027	923	98	101	82	4.0	7.1	1078	499	1607
00	1900	01	2029	25°29'	1.015	406	41	38	38	11.1	9.3	790	498	2114
01	2029	02	1629	20°08'	1.016	423	88	37	74	10.4	6.3	1071	519	1721
02	1629	03	1802	25°33'	1.013	423	103	51	94	11.7	8.6	1291	531	2095
03	1802	04	1742	23°40'	1.020	722	149	62	140	12.3	9.0	1216	437	1968
04	1742	05	1638	22°56'	1.014	444	143	75	153	12.4	9.7	1180	388	2159
05	1638	05	2331	6°53'	1.010	360	35	21	43	3.7	3.1	285	178	704
Postflight														
9-5	0050	9-5	2050	20°00'	1.020	606	4	26	3	2.4	2.6	417	119	905
9-5	2050	9-6	2250	26°00'	1.020	597	9	59	14	8.0	7.1	849	502	2017
9-6	2250	9-7	2200	23°10'	1.016	540	93	98	108	9.6	7.3	981	660	1872
9-7	2200	9-8	0500	7°00'	1.006	226	40	32	36	2.5	2.1	241	188	482

*Measurements given are those for half of this pool, a period of 24°23'.

TV = total volume

NASA-S-83-02676

Figure 2

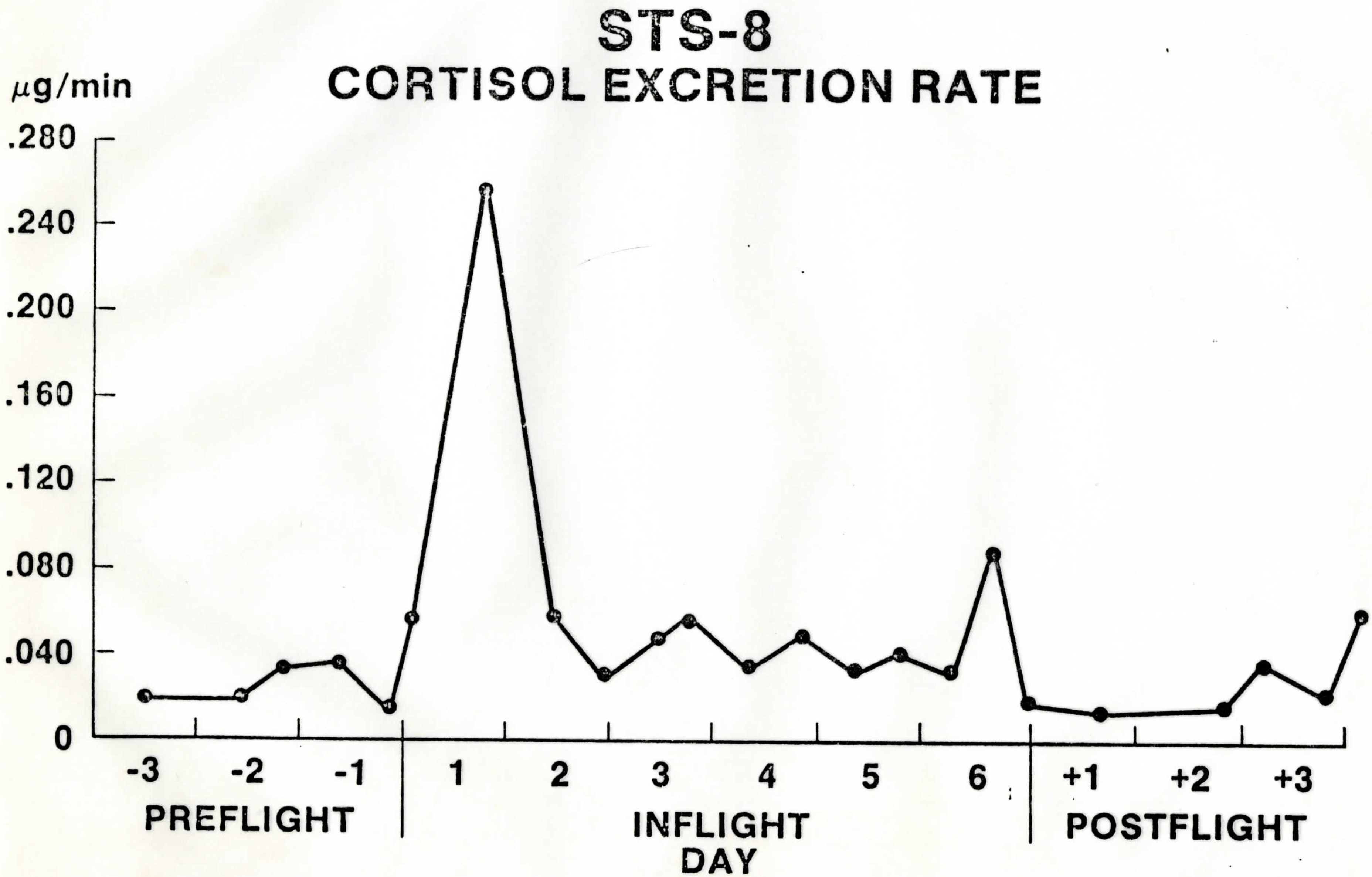

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Figure 3

STS-8
ALDOSTERONE EXCRETION RATE

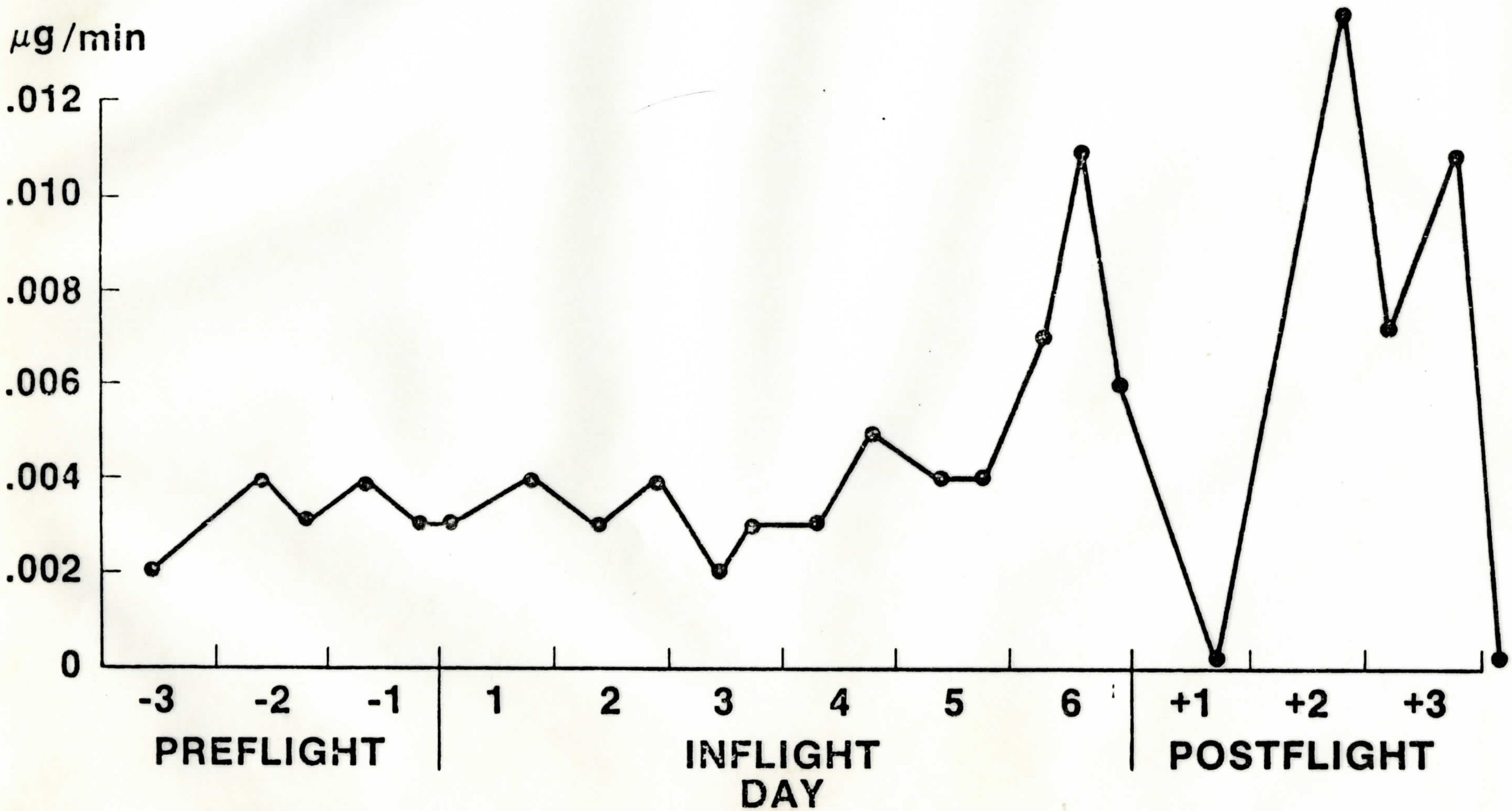

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Figure 4

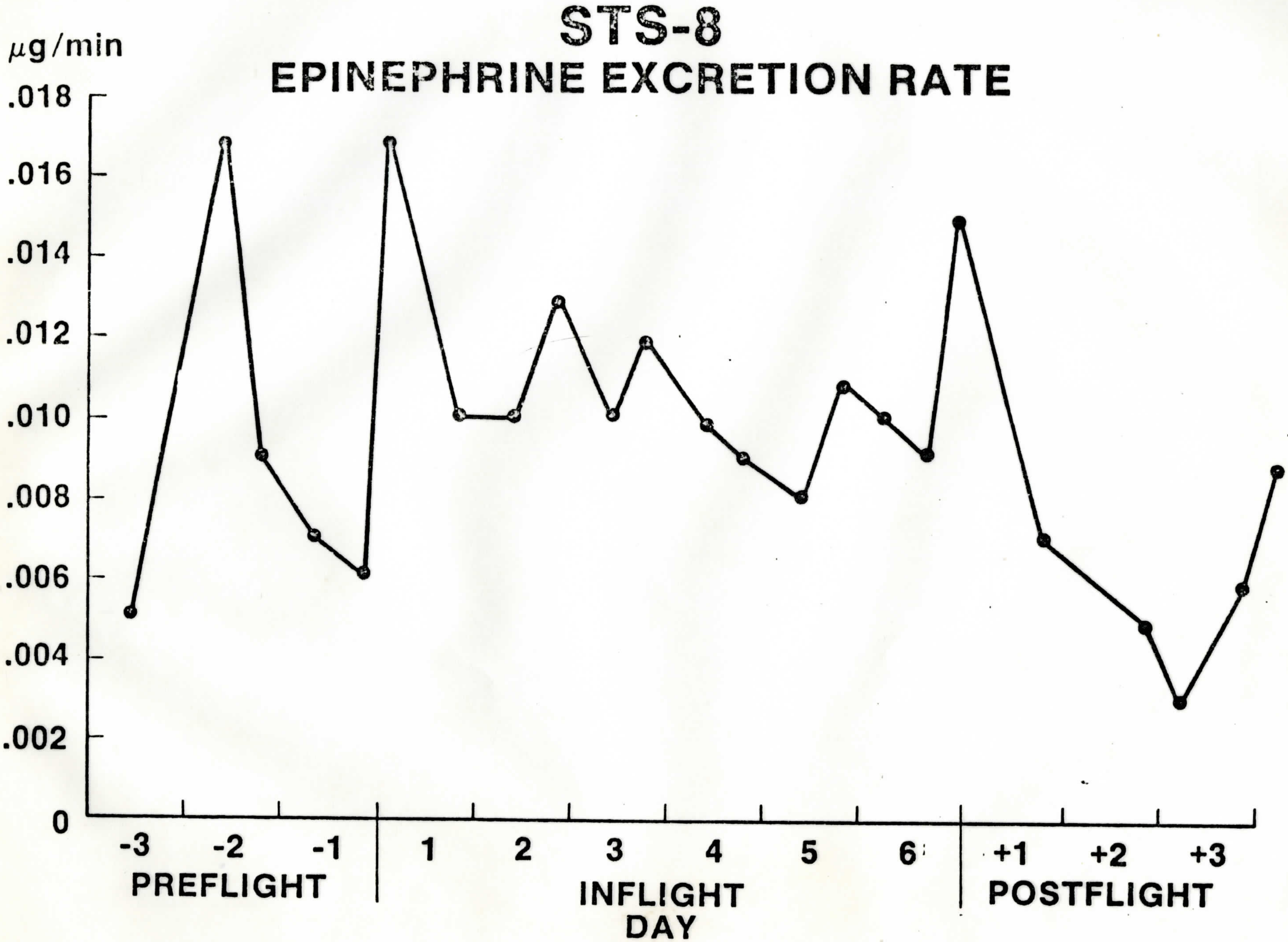

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Figure 5

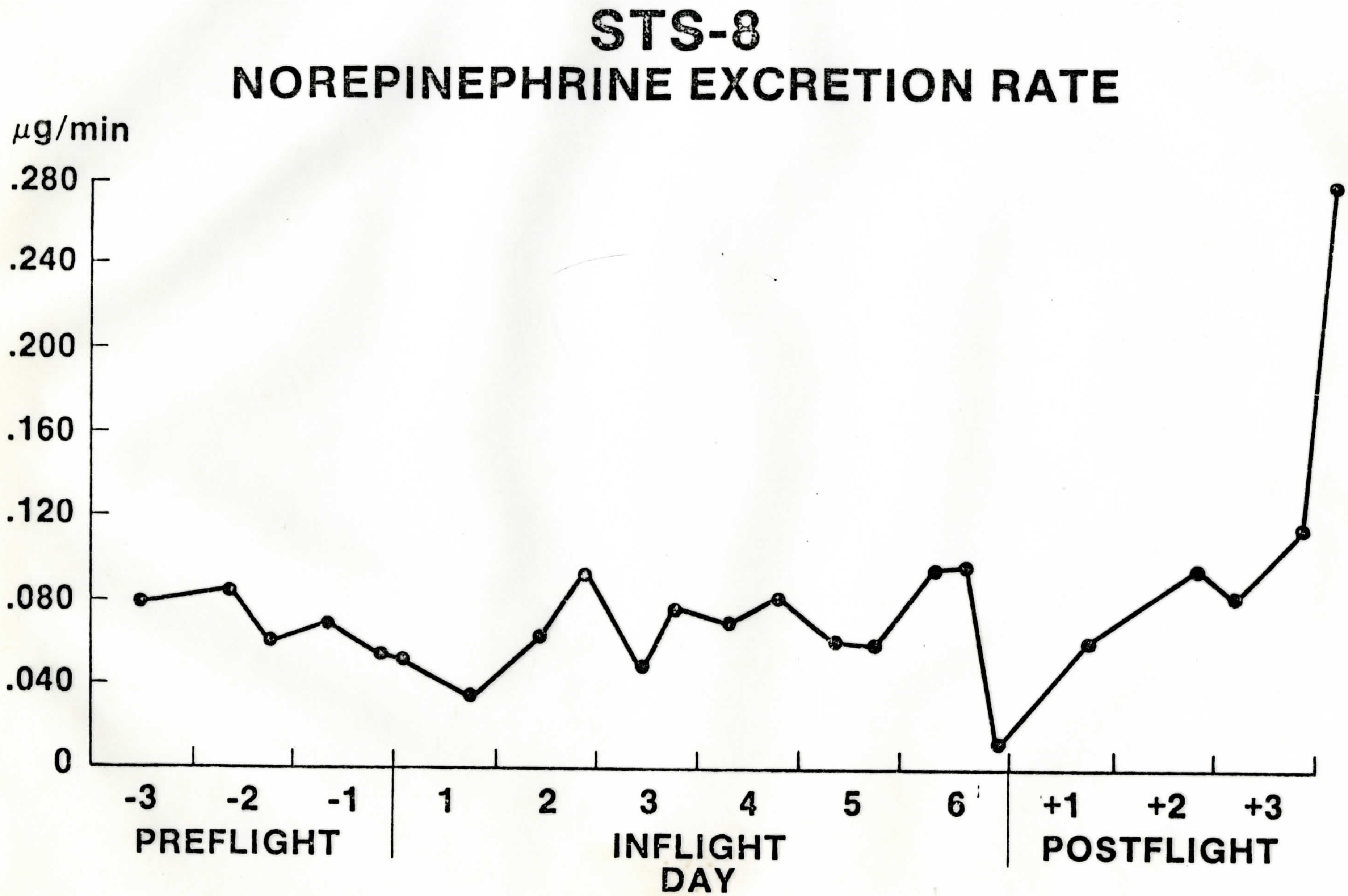

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Figure 6

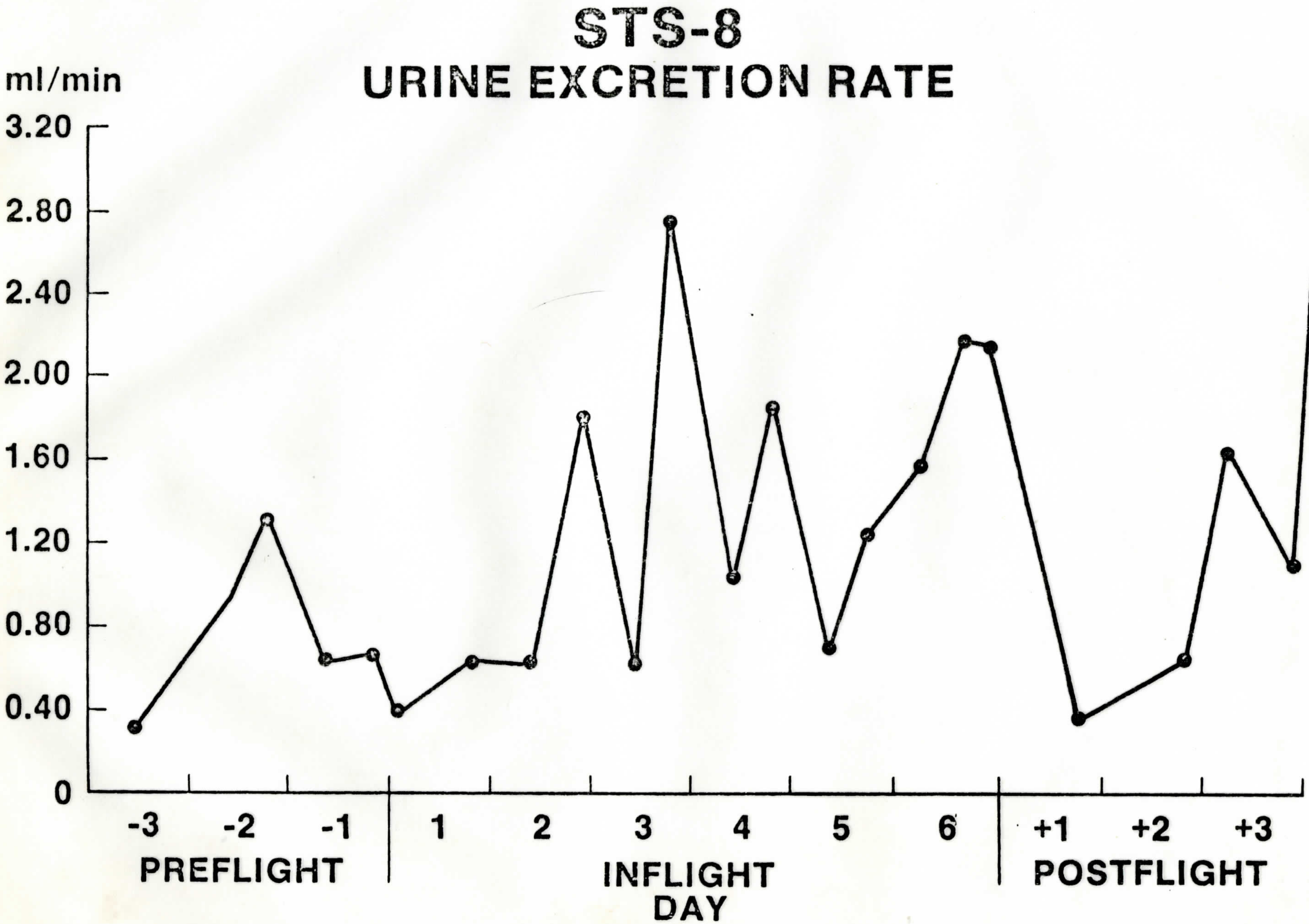

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Figure 9

STS-8
SODIUM EXCRETION RATE

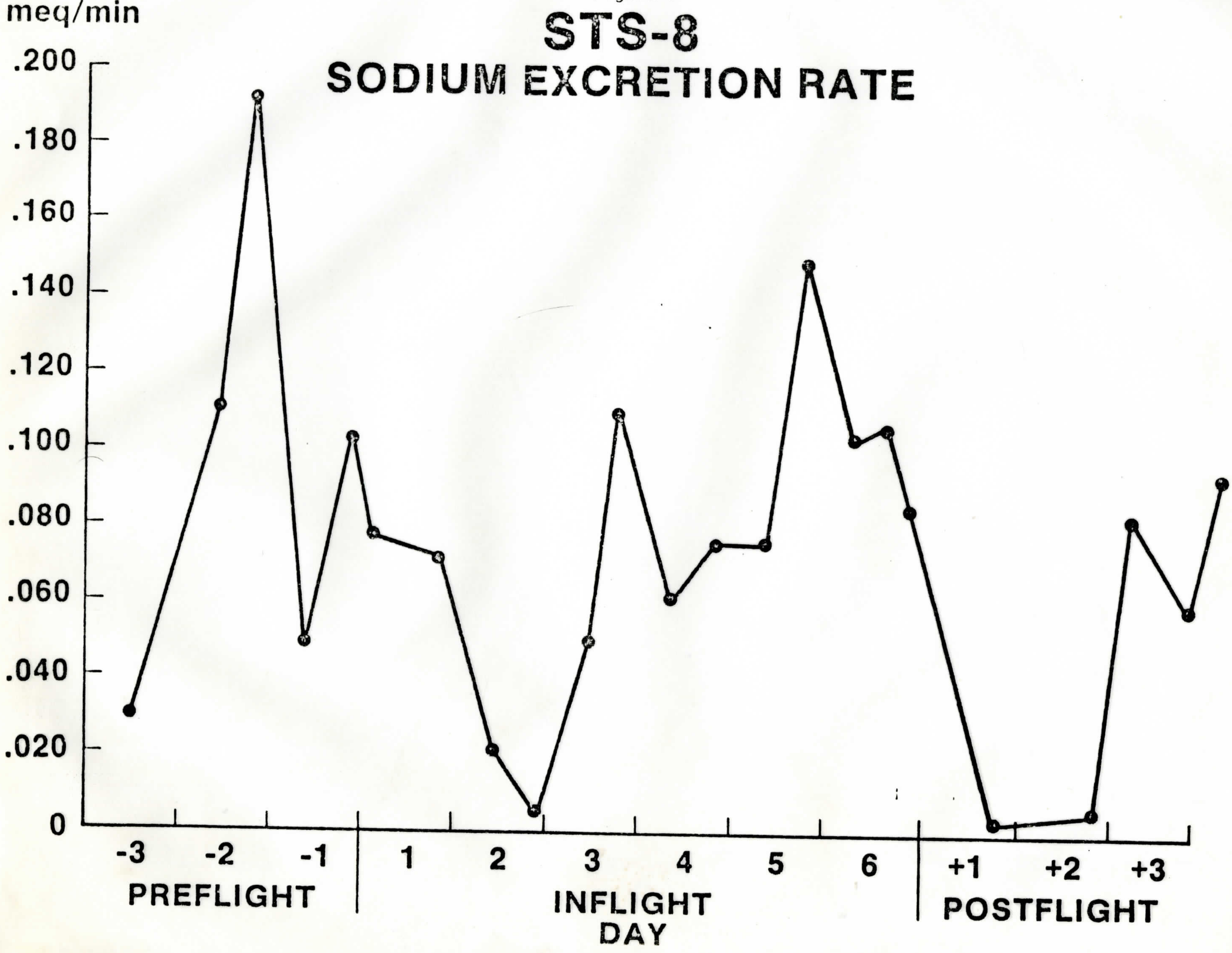

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Figure 10

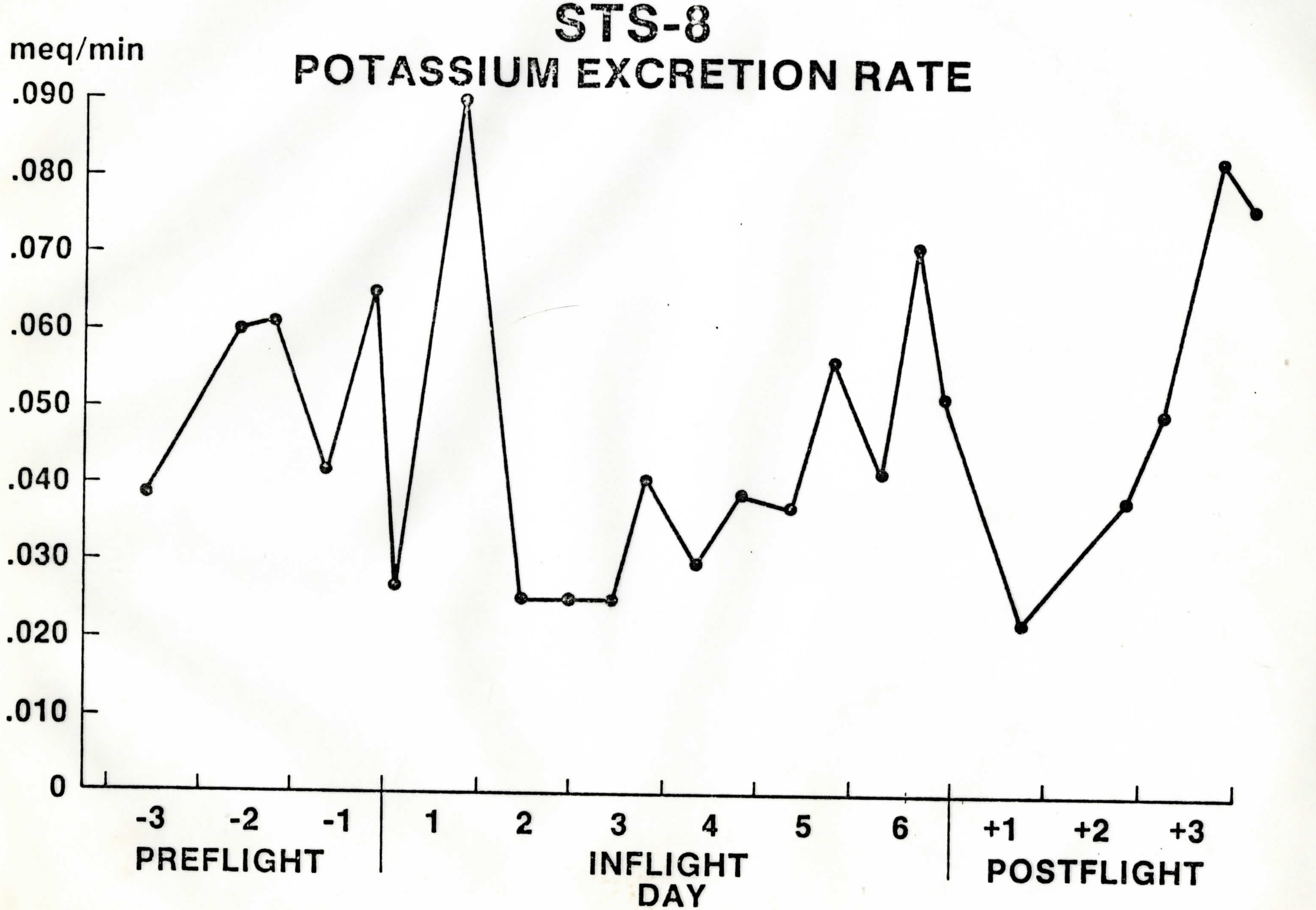

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Figure 11

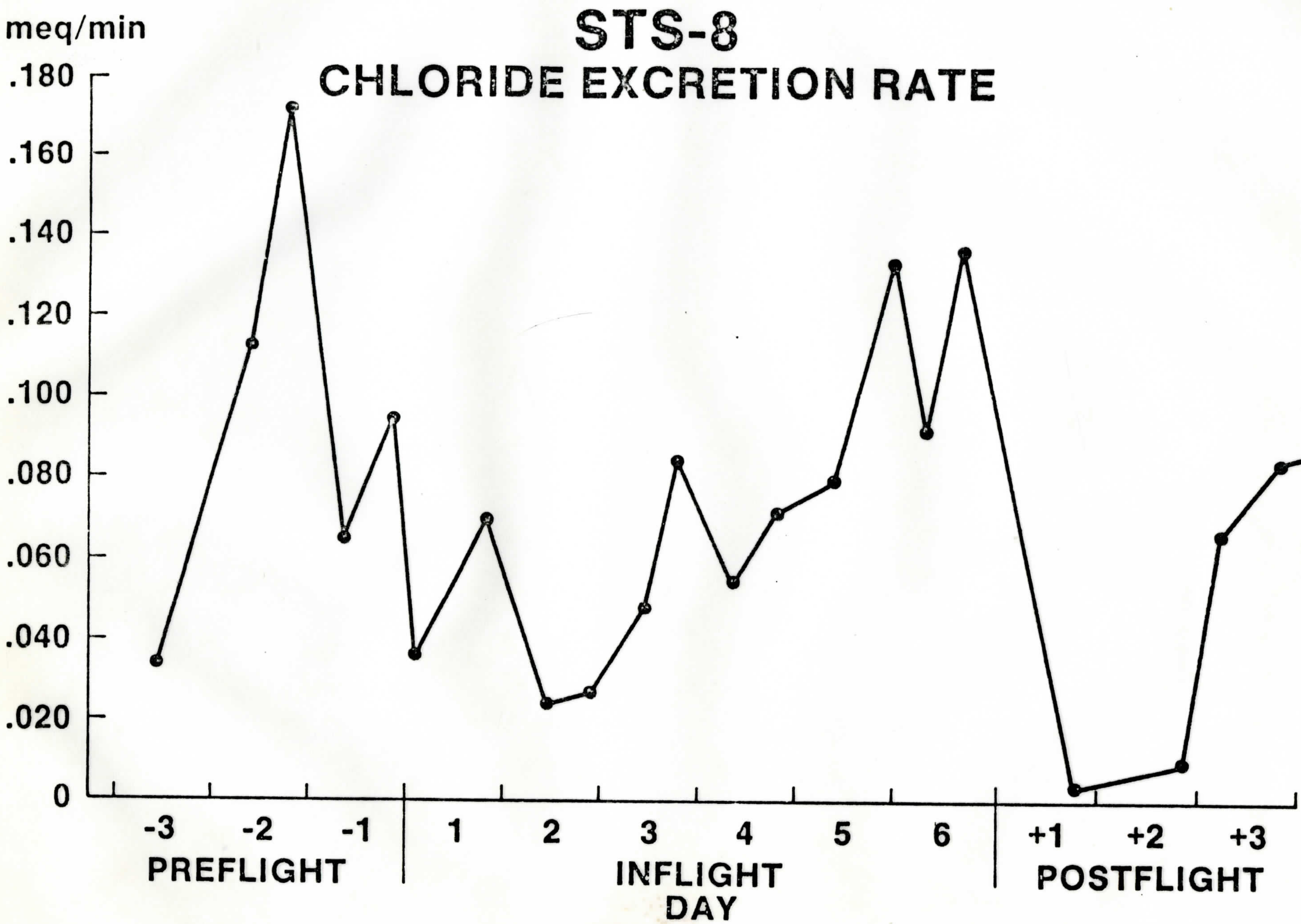

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Figure 12

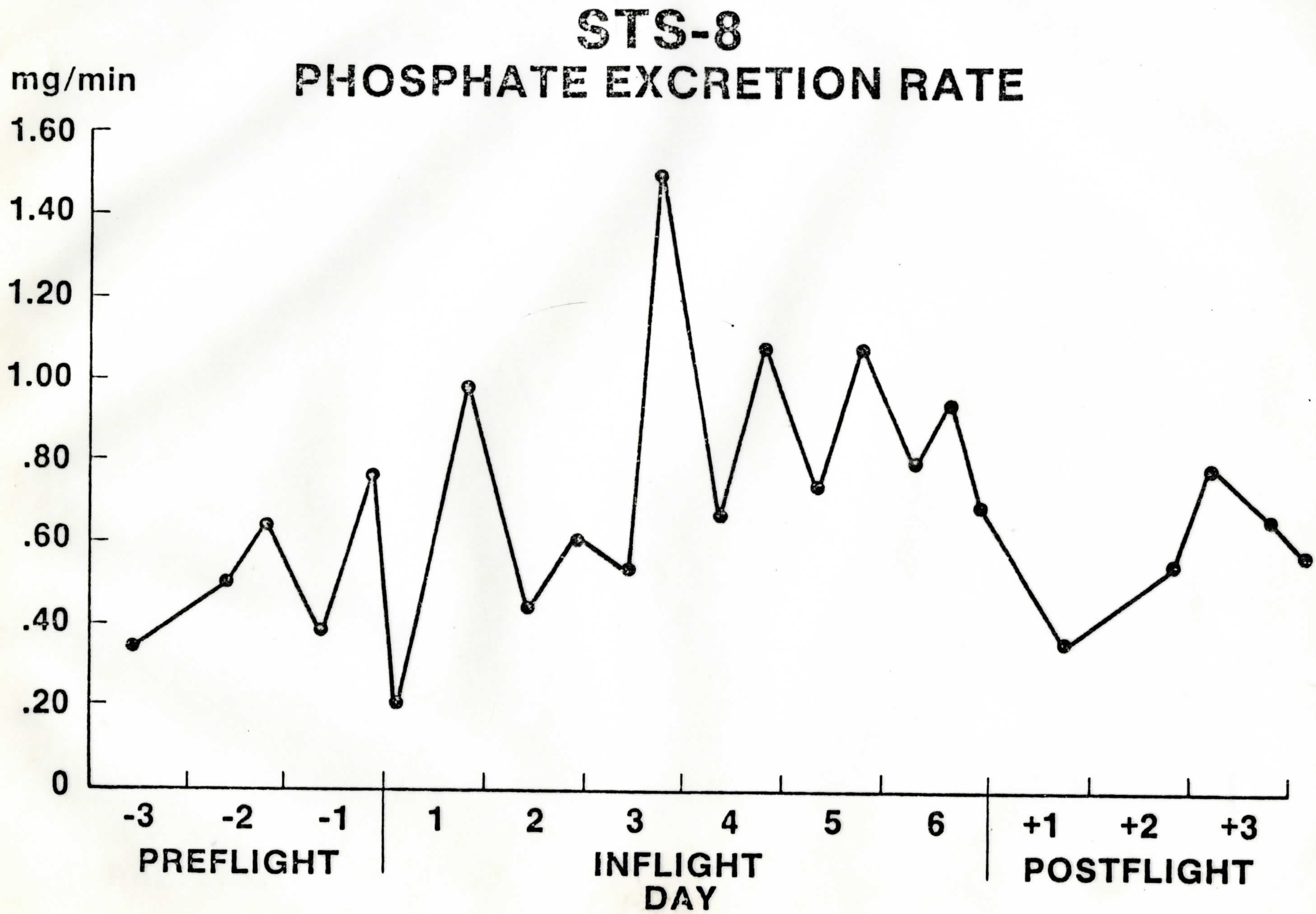

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Figure 14

STS-8
MAGNESIUM EXCRETION RATE

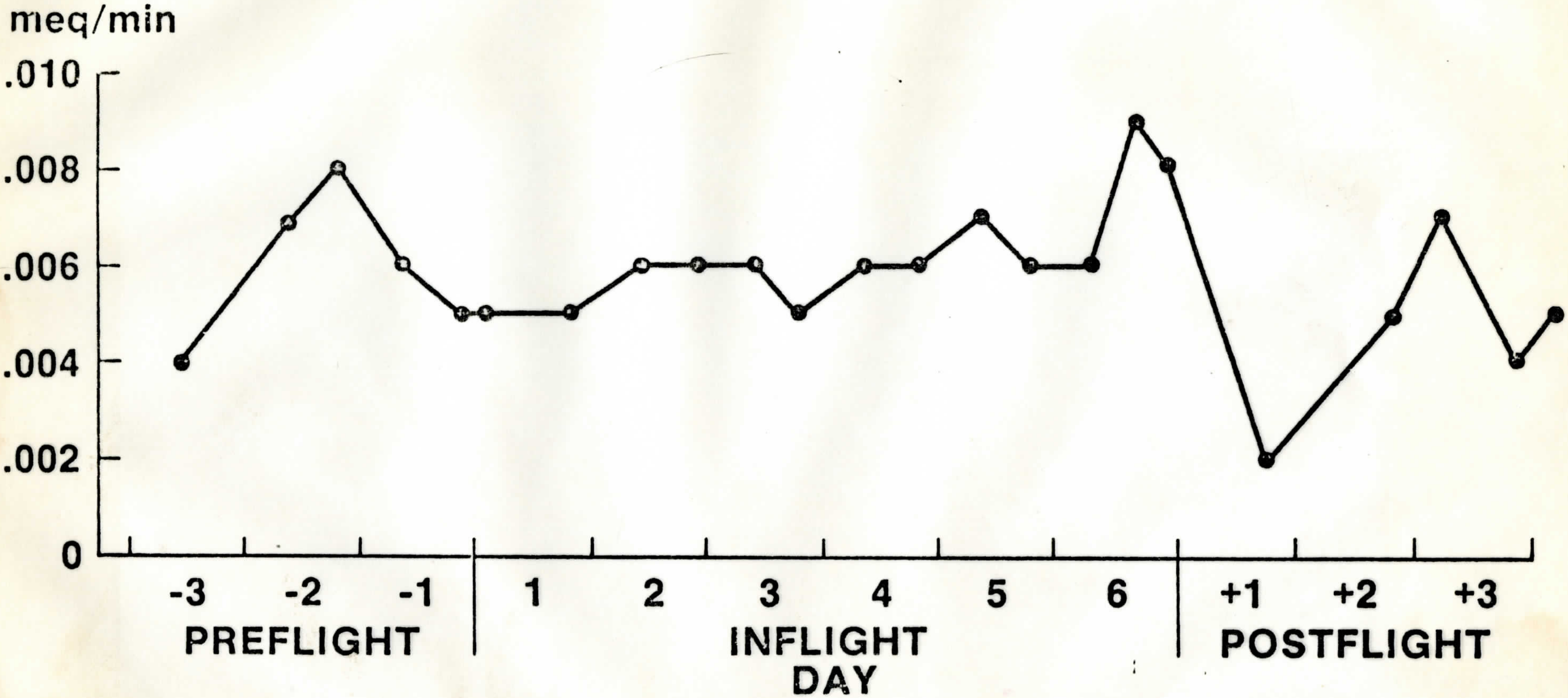

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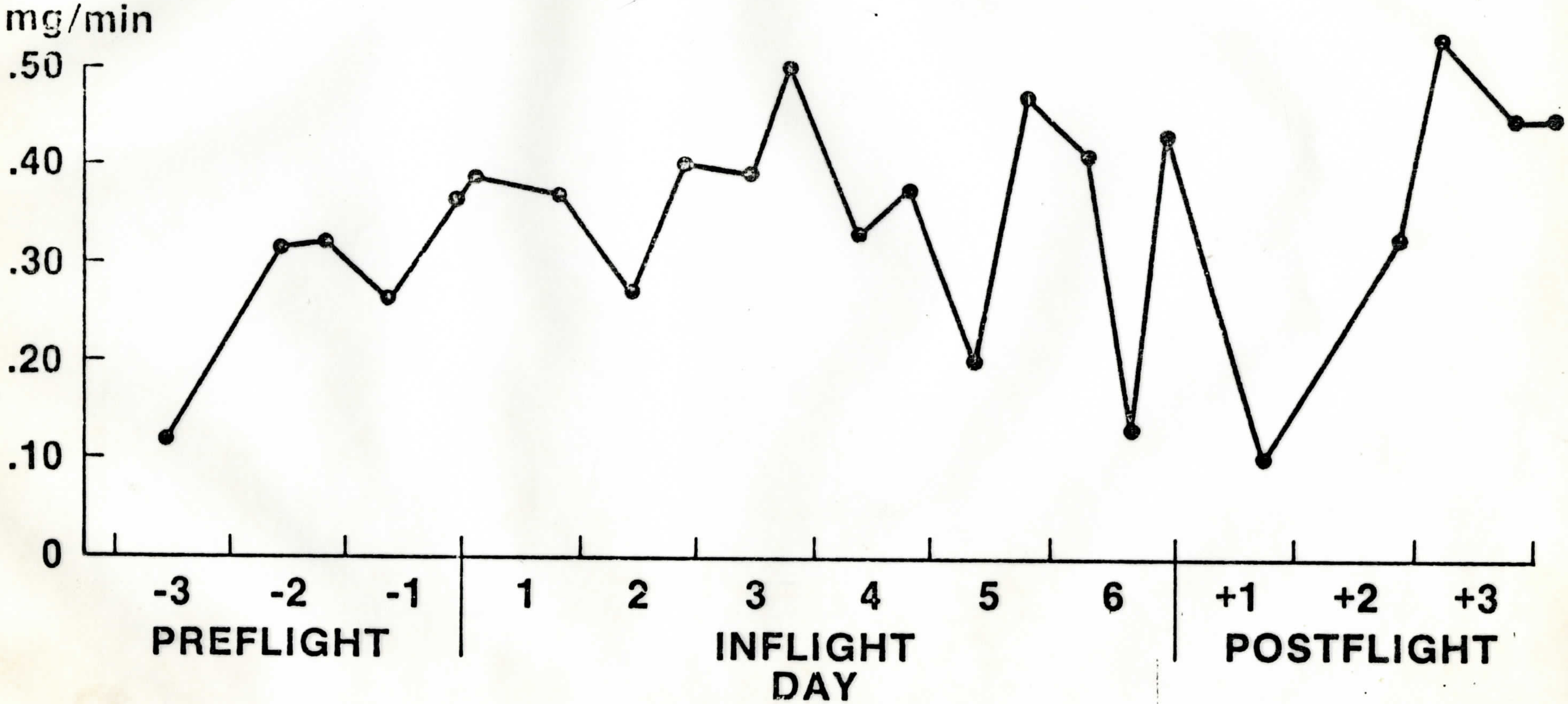
Figure 15

STS-8
URIC ACID EXCRETION RATE



Thornton Fluid Intake

MD1 150 ml } 16+5.1 oz = 21.1 oz = 623 ml
16 oz }

MD2 20 oz } 40 oz = 1181 ml
20 oz

MD3 170 g ≅ 170 ml = 5.7 oz } 85.7 oz = 2531 ml
20 oz
10 oz
20 oz
10 oz
20 oz

MD4 22 oz } 65.8 oz = 1943 ml
20 oz
112 g ≅ 112 ml = 3.8 oz
20 oz

MD5 18 oz } 79 oz = 2333 ml
20 oz
25 oz
16 oz

MD6 13 oz } 53.5 oz = 1580 ml
21 oz
19.5 oz

MD7 14.5 } 142.5 oz = 4208 ml
60+
Postflt. 8
16
12
6
26 at ~2400

~~1 gal = 32 X 4 oz = 128 oz = 3.78 l = 3785 ml~~

$oz \times \frac{gal}{oz} \times \frac{l}{gal} \times \frac{ml}{l}$

$\frac{1}{128} \times \frac{1000}{1} \times \frac{3.78 \cdot 1000}{128}$

1 oz = 29.6 ml

1 ml = .034 oz

Rev. 2.51

S-8 MS-3 Fluid intake by Mission Day

(unless otherwise noted.

MD	Bag start	stop	
1		01:55	~150 ml - H_2O
	01:55	19:00	2 X 8 oz Or. J. (:05: + :10:)
2	19:00	01:09:10	10 oz H_2O (:20:40) 10 oz OJ (:22:)
	01:09:10	01:20:29	10 oz. H_2O (1:10:30) 10 oz Or. J.
3	01:20:29	02:09:09	B - 2 X 10 oz H_2O 10 oz Citrus Dr. medium sized (orange.)
	02:09:09	02:16:29	L 20 oz. H_2O 10 " Citrus Dr.
			D 20 oz H_2O
4	02:16:29	03:06:50	B 10 oz Citrus Dr. 10 oz H_2O Cereal Rehydration
	03:06:50	03:18:02	L - { 2 X 10 oz H_2O. ~~Standard liquids~~ (?) (Fruit cocktail) } D - (Std.) liquids + 10 oz H_2O
5	03:18:02	04:07:49	B - Std. Bkfst less less scr. eggs. + 20 oz. H_2O
	04:07:49	04:17:42	L - Rehydrated (Strawb-) " (Shrimp) 10 oz H_2O 10 oz Gr. Fruit
			D - (Std Dinner + Liquid (?)) 3 oz + 3 oz

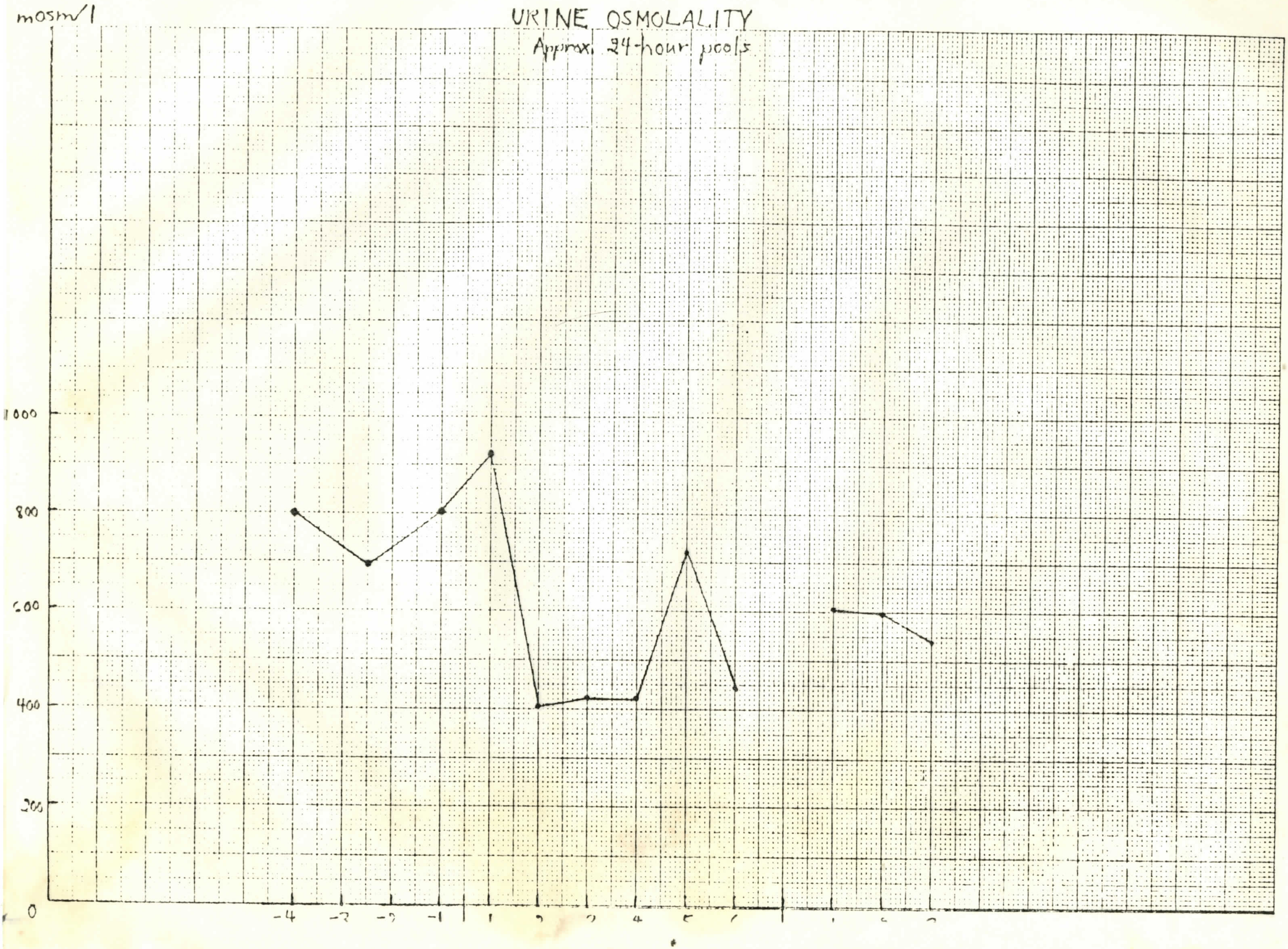
16

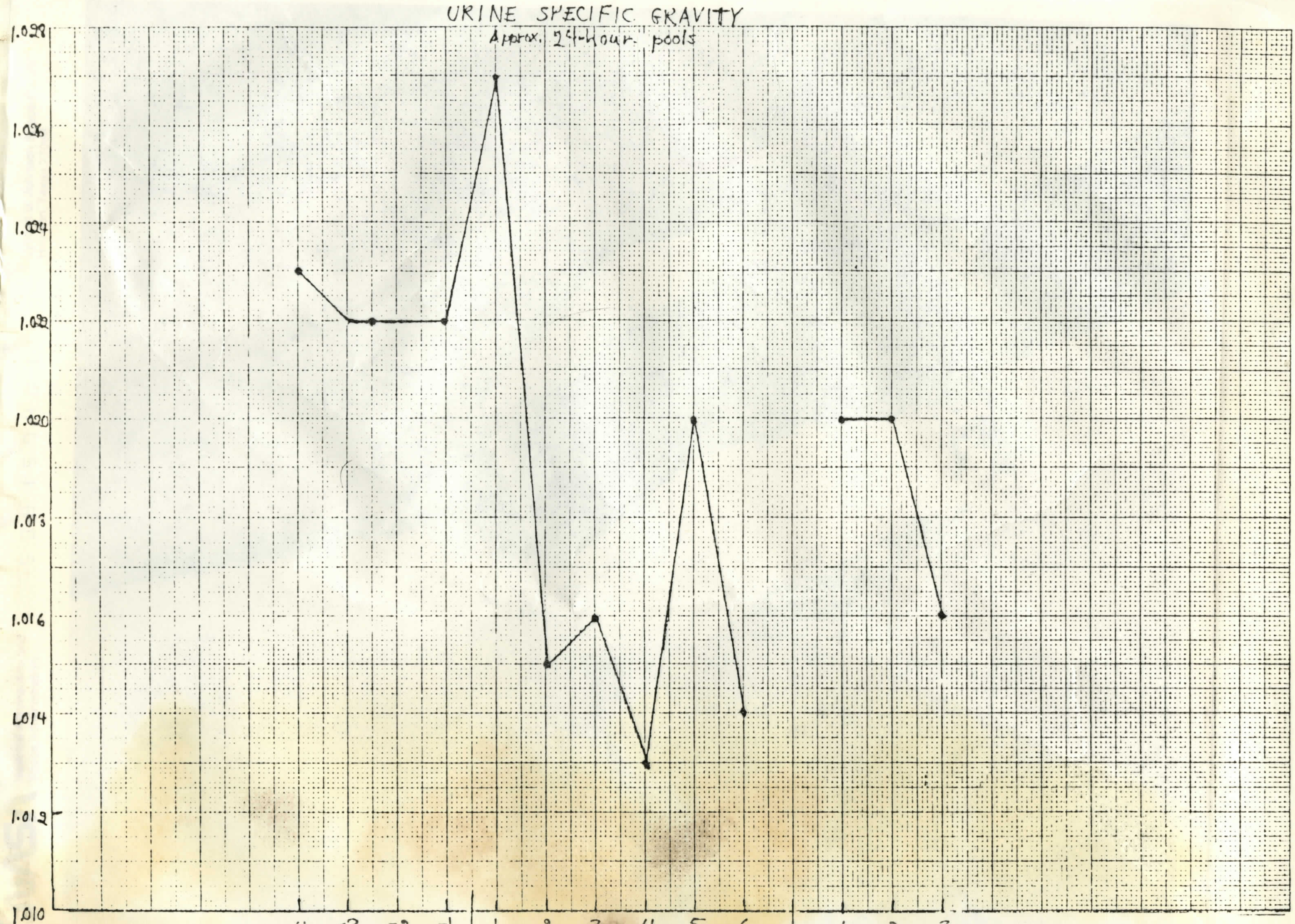
20

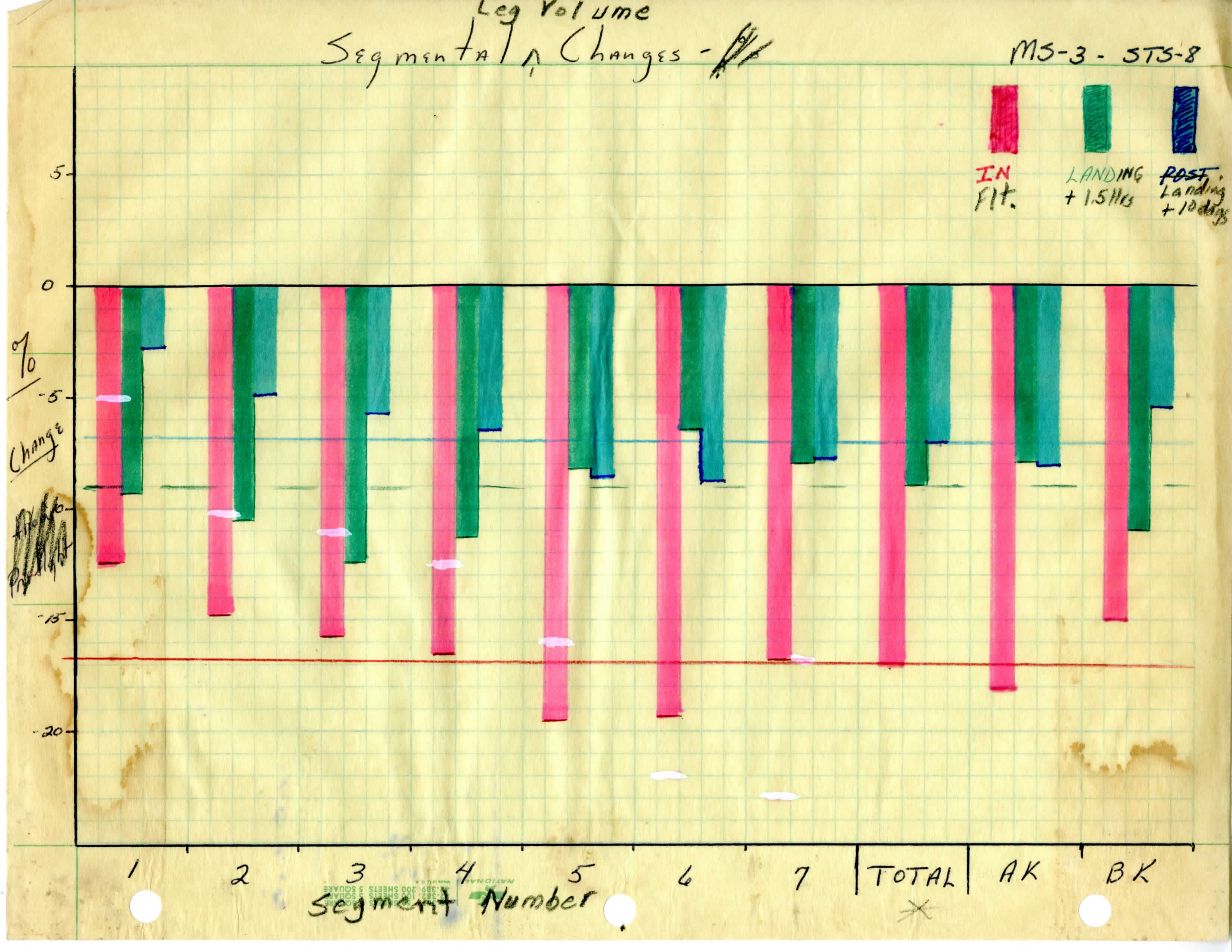
80

3

3


URINE OSMOLALITY
Approx. 24-hour pools
mosm/l
1000
800
600
400
200
0
-4
-3
-2
-1
1
2
3
4
5
6
1
2
3


URINE SPECIFIC GRAVITY
Approx. 24-hour pools
1.028
1.026
1.024
1.022
1.020
1.018
1.016
1.014
1.012
1.010


Leg Volume
Segmental Changes
MS-3 - STS-8
IN Flt.
LANDING + 1.5 Hrs
POST Landing + 10 days
5
0
-5
-10
-15
-20
% Change
1
2
3
4
5
6
7
TOTAL
AK
BK
Segment Number