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SUBJECT

Skylab Water Balance Analysis

This report contains a complete water balance analysis of the Skylab crewmen during the entire preflight, inflight and postflight phases. It is part of a larger effort to document-time trends in the Skylab water, mass and energy balances as well as the components of these balances. Previous transmittals have been submitted covering evaporative water loss analysis and energy balance. A knowledge of inflight changes in total body water, which is included in this document, is essential for a complete understanding of the dynamics of fluid shifts within the body, renal function, electrolyte and hormonal regulation in response to extended periods of weightlessness. The results of this effort represents an integration of many important Skylab biomedical experiments including those associated with the mass measuring device, body fluid assay. biochemical response, food and nutrition, and mineral balance. They will be useful in analyzing these and other experiments such as LBNP and exercise response, in comparing weightlessness with bed rest, and in providing validation data for the simulation of weightlessness using mathematical models. The report will satisfy in part the following tasks of the statement of work for the extended contract: Task 2.6, Task 2.7, and Task 2.8.

/db
Attachment

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SKYLAB WATER BALANCE ANALYSIS

CONTRACT NAS9-14523

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INTRODUCTION

This report contains the results of a water balance analysis of the Skylab crew. The analysis was originally intended to provide estimates of evaporative water loss using a whole-body mass input/output balance equation, but has been extended to include water, body tissue, and energy balances. Results of the evaporative water loss and a preliminary energy balance analysis have been previously transmitted.

This integrative approach to describing water, mass and metabolic responses to weightlessness has utilized the results of several major Skylab medical experiments including those associated with the mass measuring device, body fluid assay, biochemical responses, food and nutrition and mineral balance. The software necessary for this analysis effort consists of several specially designed subsystems: a) an extensive data base of daily fluid and mass inputs and outputs for each of the nine subjects on each day of preflight, inflight and postflight, b) metabolic balance algorithms for computing daily and average flight phase values of all components of water, mass and energy balances, c) an integrating algorithm to compute relative changes in total body composition; d) statistical algorithms for computing mean, standard deviations and errors for each parameter by pooling results for each subject, each flight or groups of flights and a limited correlation analysis algorithm for determining sources of errors in the balance method, and e) a plotting package that generates microfilm time-trend plots of any input or derived variable for any subject or groups of subjects over any time interval. The input data of this analysis consists of over 12,000 independent measurements representing nearly 900 man-days of continuous data collection. All results may be plotted as continuous daily values which provides a convenient format for displaying, scanning, comparing and interpreting the data.

An effort has been made in the analysis to provide not only overall balances for water, mass and energy, but also to partition these balances into its components of input and output. Thus, a partitional water balance is presented in this report that graphically depicts the changes due to water intake (free drinking water + food water + metabolic water) and water output (urine + fecal water + evaporative water loss). Similarly, the mass balance separates out the changes in total body mass that are due to water and dry tissue; changes in body tissue are further divided into those due to protein and fat. The energy balance analysis determines the net available energy to the individual crewman during any period by accounting for energy input (calories in food and calories available by catabolism of body fat and protein) and energy losses (calories in urine and feces and calories stored by body tissue anabolism).

In addition to computing these partitional balances, a unique feature of the analysis provides the capability of integrating these balances to produce a visual description of the total change of a particular body component (i.e., body water, fat, protein, mass, dry tissue) during the course of the mission.

Previous measurements during space flight missions were performed only prior to and following the flight. Even on Skylab, measurements of total body water, protein, fat, etc. could not be performed inflight. Thus, the dynamic behavior of changes in body composition could not be directly obtained. However, this information can be salvaged from the unusually extensive collection of metabolic balance data if certain techniques are used to reduce errors inherent in the balance method. The present study attempts to extract this valuable information from the Skylab data.

METHOD OF COMPUTATION

The purpose of this section is to outline the exact methods which were used to prepare the tables and illustrations in this report. These processed data consist of complete water balances including evaporative water loss, and changes in total body water, protein, fat and total dry tissue over long intervals of each mission.

Water Balance

The daily change in total body water (i.e., daily water balance), ΔTBW, is given by the algebraic sum of all liquid quantities entering or excreted from the body according to the following relationship: (Conselazio, et al, 1963)

$$\Delta\text{TBW} = \text{water intake (food + drink)} + \text{metabolic } H_2O - \text{water excreted (urine + feces)} - \text{evaporative water loss (skin + respiratory)} \quad (1)$$

Water intake and water excreted were measured on a daily basis during the Skylab missions and metabolic water could be estimated from the known fat, protein, and carbohydrates consumed. However, it is not possible to compute a daily water balance from this formulation inasmuch as daily evaporative water loss, a significantly large quantity, was not measured. An alternative water balance equation can be derived which does not depend on either evaporative water loss or any other liquid quantity consumed or excreted. This will be done by first writing a complete gravimetric (mass) balance.

Gravimetric Balance

The daily change in body mass, ΔBWgt, is found by summing up the total masses (liquids + solids) of all input and output quantities:

$$\Delta\text{BWgt} = \text{dry weight of food} + \text{water intake (food + drink)} - \text{dry weight of excreta (urine + feces)} - \text{water excreted (urine + feces)} - \text{evaporative water loss (skin + respiratory)} - \text{weight of metabolic } CO_2 + \text{weight of metabolic } O_2 - \text{dry skin losses} \quad (2)$$

Subtracting Equation (2) from Equation (1) we get,

$$\Delta TBW = \Delta BWgt - \text{dry weight of food} + \text{dry weight of excreta (urine + feces)} + \text{metabolic } H_2O + \text{metabolic } CO_2 - \text{metabolic } O_2 + \text{dry skin losses} \quad (3)$$

The dry skin losses in these equations refer to sweat solids, sebaceous residues, desquamated epithelium, nail and hair clippings, etc. The metabolic H_2O, CO_2 and O_2 refers to those insensible quantities produced or consumed by metabolism of food stuffs as well as the catabolism of body tissue (primarily body fat and protein).

All of the quantities on the right side of Equation (3) were measured directly except for the metabolic H_2O, CO_2 and O_2, which was estimated from the foodstuffs, and the dry skin losses which were estimated from infrequent total body water measurements. The procedure used to compute these indirectly measured quantities are given below:

<u>Net Insensible Metabolic Losses (IML)</u>

We define the net insensible metabolic losses (IML) as:

$$\begin{aligned} IML &= \text{metabolic } H_2O + \text{metabolic } CO_2 - \text{metabolic } O_2 \\ &= (H_2O + CO_2 - O_2)_{met} \\ &= IML(\text{foodstuff}) + IML(\text{body tissue}) \end{aligned} \quad (4)$$

IML associated with foodstuffs was determined indirectly from the daily amounts of carbohydrate (CHO), fat (FAT), and protein (PRO) in the ingested diet according to the stoichiometric relationships given by McHattie (1960) for reduction of food to carbon dioxide, water and urinary nitrogen:

$$H_2O(met) = EFF\ (0.555\ CHO + 1.071\ FAT + 0.413\ PRO) \quad (5)$$

$$CO_2(met) = EFF\ (0.829\ CHO + 1.427\ FAT + 0.775\ PRO)\ \rho_{CO_2} \quad (6)$$

$$O_2(met) = EFF\ (0.829\ CHO + 2.019\ FAT + 0.967\ PRO)\ \rho_{O_2} \quad (7)$$

The densities, ρ, of CO_2 and O_2 were taken as 1.977 and 1.429 g/l, respectively. EFF is an efficiency factor to allow for incomplete digestion across the gastrointestinal tract. A value of EFF was obtained for each Skylab crewman based on a solids balance of food and feces according to the relationship:

$$EFF = \frac{\text{Total mission dry food - total mission dry feces}}{\text{Total mission dry food}} \tag{8}$$

An average value of EFF = 0.962 $\pm$ .005 (sd) was obtained and the individual crew values used in this study are given in Table I.

Combining Equations (5 - 7) according to Equation (4) we obtain:

$$\text{IML(foodstuff)} = \text{EFF (1.009 CHO + 1.007 FAT + 0.563 PRO)} \tag{9}$$ *

Body protein (Δ Protein Loss) and body fat (Δ Fat Loss) catabolism occurred during the course of the Skylab mission. It would be expected that these quantities would contribute to the net insensible metabolic losses in a similar manner as equivalent amounts of foodstuffs; i.e.

$$\text{IML(body tissue)} = 1.007 \ (\Delta \text{ Fat Loss}) + 0.563 \ (\Delta \text{ Protein Loss}) \tag{10}$$

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*NOTE: Carbohydrates and fats are metabolized completely to water and carbon dioxide,

$$\text{CHO or FAT} + O_2 = H_2O + CO_2$$

or

$$\text{CHO or FAT} = H_2O + CO_2 - O_2 = \text{IML(CHO or FAT)}$$

so that the IML is nearly identical to the weight of the original CHO or FAT metabolized. Protein, however, is incompletely metabolized to H_2O and CO_2, the remainder being converted to urea which is excreted from the body:

$$\text{PRO} = H_2O + CO_2 - O_2 + \text{urea}$$

Thus,

$$\text{IML(PRO)} = \text{PRO - urea} = 0.563 \text{ PRO}$$

It was not possible to accurately estimate the metabolic losses associated with body tissue metabolism on a daily basis. However, this term was included in the estimate for dry skin loss

Dry Skin Losses

One of the purposes of this study was to obtain not only estimates of daily water balance, but to sum up these daily balances to compute the total body water changes over large time intervals (up to several months). Errors in the estimates of daily water balance would, therefore, be cumulative over time.

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*Note - continued

Therefore, only a fraction of the protein metabolized contributes to the net insensible metabolic loss. Summing these terms we get:

$$\begin{aligned} IML(foodstuff) &= IML(CHO) + IML(FAT) + IML(PRO) \\ &= CHO + FAT + 0.563PRO \end{aligned}$$

which is very close to the formulation given in Equation (9) with the exception of the digestive efficiency factor which has been omitted in this note for simplicity.

The metabolized protein can also be found from urinary N instead of diet protein:

$$PRO = 6.25 \times \text{urinary N}$$

and

$$IML(PRO) = 0.563 \times 6.25 \times \text{urinary N}$$

where 6.25 is a factor accounting for the fact that the amount of nitrogen contained in a typical protein molecule represents on the average 16% (or 1/6.25 x 100%) of total protein weight. In this study this latter formulation was not used because it was decided that dietary protein was known with better overall accuracy than urinary N.

It has previously been estimated that dry skin losses amount to at least 12-20 gm/day (Roth, 1968; Webb, 1964). The difficult to measure insensible metabolic losses due to body tissue catabolism on Skylab represents an additional 20 - 40 gm/day (Rambaut, 1975) error in the water balance if these factors are not taken into account. From Equation (3) it can be seen that failure to take skin and body tissue losses into account could underestimate daily water balance by at least 30 - 60 gm/day and produce errors at the end of a one-month period of 1 - 2 liters in total body water calculations. Thus, it was imperative to attempt an estimate of these quantities. This was done as follows:

Rewriting Equation (3),

$$\Delta \text{TBW} = \Delta \text{BWgt} - \text{dry weight of food} + \text{dry weight of excreta} + \text{IML(foodstuff)} + \text{IML(body tissue)} + \text{dry skin losses} \quad (11)$$

Define ΔTBW(balance) as the right side of Equation (11) excluding the last two terms:

$$\Delta \text{TBW} = \Delta \text{TBW(balance)} + \text{IML(body tissue)} + \text{dry skin losses} \quad (12)$$

In other words ΔTBW (balance) is the water balance typically obtained from directly measured quantities not including corrections for skin and body tissue losses. The left side of Equation (12) represents the true change in total body water as measured, in the case of the Skylab crew, by tritium dilution techniques before and after a period of several weeks or months. Therefore, if we designate this direct measurement of total body water change by ΔTBW(direct) and we let a general correction factor, CF, apply to the non-measured quantities, then:

$$\text{CF} = \text{IML(body tissue)} + \text{dry skin loss} \quad (13)$$

and Equation (11) can be solved for CF as follows:

$$\text{CF} = \overline{\Delta \text{TBW}}\text{(direct)} - \overline{\Delta \text{TBW}}\text{(balance)} \quad (14)$$

where

$$\overline{\Delta \text{TBW}}\text{(balance)} = \overline{\Delta \text{BWgt}} - \overline{\text{dry weight of food}} + \overline{\text{dry weight of excreta}} + \overline{\text{IML}}\text{(foodstuff)} \quad (15)$$

During the Skylab experiments total body water measurements were obtained at the beginning and end of each flight phase: preflight, inflight, and postflight. (In the case of flight SL-3, the measurement at the start of inflight was omitted.) The value ΔTBW(direct) was taken as the difference between any two consecutive tritium dilution measurements and the value ΔTBW(balance) was computed from the uncorrected balance Equation (15) using the total quantities consumed, excreted, or changed during this same time interval. The bar above the terms in Equations (14) and (15) indicates that these are average daily quantities during that particular period between TBW measurements.

Thus, in the majority of cases, it was possible to compute a separate correction factor for each flight phase of each crewman. These values, expressed in gm/day, are shown in Table II. It can be observed that the average CF value for preflight and inflight phases are similar indicating that the sum of skin and tissue losses were not different during these phases. The low (and even negative) values for postflight CF is due perhaps to a normal dry skin loss which is masked by a greater body tissue gain during the recovery period.

The final form of the water balance equation used in this study can be written by combining Equations (9), (11), and (13):

$$\Delta TBW = \Delta BWgt - \text{dry weight of food} + \text{dry weight of feces} + \text{urine volume} \times (s.g. - 1.0) + EFF(1.009\ CHO + 1.007\ FAT + 0.563\ PRO) + CF \qquad (16)$$

where s.g. is the specific gravity of urine obtained for each sample and given in Table III, and urine volume x (s.g. -1.0) represents the dry urine weight.

Each term in Equation (16) was measured daily and continuously over the entire preflight, inflight and postflight periods. Their average values for each crewman is shown in Table IV.

The change in total body water during a period of N consecutive days can be determined by algebraically summing (i.e., integrating) the daily water balance of each successive day in the interval:

$$\text{Change in Total Body Water over N consecutive days} = TBW(N) = \sum_{i}^{N} \text{daily water balance}_i = \sum_{i}^{N} \Delta TBW_i \qquad (17)$$

In this study $\Delta TBW(N)$ was computed for each day of the mission starting from either the day of launch or the day of recovery and summing backwards and forwards in time from these reference points. Thus, $TBW(N)$ has a value identically zero at the morning of launch or the morning of recovery. Mean values of $TBW(N)$ are used in this report by averaging the values for the three crewmembers on each flight (n=3) or by pooling two (n=6) or three (n=9) flights. The method of obtaining variances of $TBW(N)$ are given at the end of this section.

Evaporative Water Loss

Evaporative water losses were estimated on a daily basis from Equation (1):

$$\text{Evaporative water losses} = \text{water intake(food + drink)} + \text{metabolic } H_2O - \text{water excreted (urine + fecal)} - \Delta TBW \qquad (18)$$

where ΔTBW is the quantity obtained from Equation (15). The evaporative losses computed in this study are somewhat different than those obtained in the study completed last year. This difference is due to slightly different values for EFF and some of the stoichiometric coefficients used in computing IML, but more importantly due to the inclusion in this analysis of the correction factor, CF. Inasmuch as the CF was found to be very similar for preflight and inflight periods, the differences between preflight and inflight evaporative water loss would not be expected to change significantly. Any conclusions reached regarding those differences in the previous study would not be affected.

Water Balance Diagrams

Water balance diagrams were prepared using the following definitions for water intake and output:

$$\text{Total water intake} = \text{water(drink)} + \text{water(food)} + \text{metabolic } H_2O \tag{19}$$

$$\text{Total water output} = \text{urine volume} + \text{fecal water} + \text{evaporative water loss} \tag{20}$$

Changes in Body Tissue, Protein and Fat

The analysis includes changes in total dry body tissue (Δ Tis), protein (Δ Pro) and fat (Δ Fat) computed from the following assumed relationships:

$$\begin{aligned} \Delta BWgt &= \Delta TBW + \Delta Tis \\ &= \Delta TBW + \Delta Pro + \Delta Fat \end{aligned} \tag{21}$$

Thus, changes in total tissue weight can be found by subtracting ΔTBW from $\Delta BWgt$. Daily changes in total body protein were determined from the nitrogen balance:

$$\Delta Pro = 6.25\ (N(diet) - N(urine) - N(feces)) \tag{22}$$

Daily changes in body fat were computed from Equation (21) as:

$$\begin{aligned} \Delta Fat &= \Delta BWgt - \Delta TBW - \Delta Pro \\ &= \Delta Tis - \Delta Pro \end{aligned} \tag{23}$$

Total body changes in these quantities over any interval of N days can be found by summing up (integrating) the daily balances analogously to Equation (17) for total body water changes:

Changes in Total Body Tissue during N days $$TBTIS(N) = \sum_{i}^{N} \Delta Tis_i \tag{24}$$

Change in Total Body Protein during N days $$TBPRO(N) = \sum_{i}^{N} \Delta Pro_i \tag{25}$$

Change in Total Body Fat during N days $$TBFAT(N) = \sum_{i}^{N} \Delta Fat_i \tag{26}$$

Assumptions and Errors

The use of an average constant value for CF in the daily water balance represents the assumption that day-to-day skin and body tissue losses are similar. There is no information available indicating the variability of skin losses either on earth or in space flight. The assumption of a linear rate of fat loss has, however, been confirmed in this study. Body fat loss is believed to make the largest contribution to the correction factor in this study. Rates of protein losses or gains were also found to be nearly linear during the preflight and postflight periods. Most protein loss inflight appears to occur linearly over the first month before approaching a true body balance. Thus, while the assumption of linearity of CF may not be strictly correct for the later portions of the inflight phase, its use does not introduce serious error into daily water balances nor do accumulative errors occur in estimating total body water changes over large periods. This latter statement is borne out by the manner in which CF was obtained. Its derivation insures that changes in total body water over each flight phase obtained from the corrected water balance will be in absolute agreement with directly measured total body water. Estimates of CF, therefore, are highly dependent on the accuracy of the direct tritium dilution method. These estimates have been shown to be realistic when compared to independent data of skin losses and body tissue losses (see Table II and discussion earlier in this section under Dry Skin Losses). The use of direct total body measurements used in conjunction with the balance method has been previously recommended (Hegsted (1976) as a technique to correct metabolic whole-body balances for otherwise unaccountable losses and minimize accumulative error. In terms of numerical analysis this is a well known parameter estimation technique with known and restricted boundary conditions. The parameter being estimated in this case is the correction factor, CF, and the boundary conditions are the measured changes in TBW.

Random experimental error of this method includes the sampling and instrumental errors associated with measuring the terms in Equation (16); i.e. changes in body weight, dry food, urine volume and s.g., dry fecal mass and diet carbohydrate, fat and protein. Random errors associated with instrumentation have been previously estimated as less than $\pm$ 55 g/day (see Evaporative Water Loss report, October 1976).

The errors (variances) associated with the integrated quantities given in Equations (17, (24), (25), and (26) can be expressed as:

$$\sigma^2_{MN}(X) = \sum_{i}^{N} \sigma^2_{M}(\Delta X)_i \tag{27}$$

where $\sigma^2_{MN}(X)$ represents the variance of the change in X (i.e. X=total body water, tissue, protein or fat) for the average of M subjects at the end of N days; $\sigma^2_{M}(\Delta X)_i$ is the variance on the ith day of the average balance of X for M subjects. In this fashion the errors are observed to be accumulative starting from the reference day (i = 1, launch or recovery day). It is believed that this is an overestimation of true error, since most of the variance in the balance on any particular day is random, rather than a systematic error due to instrument calibration or experimental procedure. If the correction factor, CF, were not employed it may be appropriate to use accumulative errors since the daily water balance would always be underestimated by this quantity. Application of the correction factor would tend to correct and minimize accumulative errors. For these reasons both accumulative and non-accumulative standard errors were computed in this study. Accumulative errors are used in the 14-day analysis while non-accumulative errors (shown below) have been plotted for the extended period (30-day and entire mission) analysis. The non-accumulative variances for M subjects on the Nth day are computed in the standard fashion:

$$\sigma_{MN}^2(X) = \sum_{i}^{M}\left[\Delta X_i^2 - \frac{M\overline{\Delta X}^2}{M-1}\right] \tag{28}$$

where ΔX_i is the water, tissue, fat or protein balance for the ith crewmember on the Nth day and $\overline{\Delta X}$ is the average balance of M crewmen on the Nth day.

TABLE I

Digestive Efficiency Factor, EFF*

Flight	Man	Preflight	Inflight	Postflight	Weighted Avg.**
SL-2	1	0.967	0.966	0.968	0.967
	2	0.954	0.966	0.947	0.957
	3	0.961	0.965	0.972	0.965
SL-3	1	0.967	0.965	0.982	0.968
	2	0.958	0.960	0.953	0.958
	3	0.959	0.959	0.967	0.960
SL-4	1	0.950	0.955	0.948	0.953
	2	0.960	0.969	0.973	0.968
	3	0.963	0.961	0.959	0.961
	Mean	0.960	0.963	0.963	0.962
	SD	±.006	±.004	±.012	±.005

* $EFF = 1 - \frac{\text{Fecal Solids}}{\text{Food Solids}}$

** Last column used in water balance analysis

TABLE II

Water Balance Correction Factor, CF

Flight	Man	Preflight	Inflight	Postflight
SL-2	1	41.7	56.3	69.6
	2	100.0	126.5	32.1
	3	89.2	65.9	-11.2
SL-3	1	66.6	66.6	-118.1
	2	95.7	95.7	-49.0
	3	63.6	63.6	14.7
SL-4	1	24.9	26.0	74.1
	2	54.4	42.9	-7.8
	3	95.6	12.9	-27.9
Mean		70.2	61.8	3.6

TABLE III

Urinary Specific Gravity, s.g.

Flight	Man	Preflight	Inflight	Postflight
SL-2	1	1.019	1.020	1.017
	2	1.028	1.027	1.020
	3	1.009	1.013	1.009
SL-3	1	1.016	1.021	1.016
	2	1.021	1.021	1.019
	3	1.023	1.025	1.022
SL-4	1	1.016	1.021	1.014
	2	1.020	1.021	1.017
	3	1.028	1.031	1.015
Mean		1.020	1.022	1.017
SD		±.006	±.005	±.004

TABLE IV

MEAN VALUES OF TERMS IN WATER BALANCE EQUATION FOR SKYLAB CREW*

SUBJECT

		1	2	3	4	5	6	7	8	9	SKYLAB MEANS**
No. of Days Observed	Pre	30	30	30	20	20	20	26	26	26	
	Inf	28	28	28	59	59	59	84	84	84	
Δ Body Weight	Pre	-30.0 ± 68.5	-46.7 ± 65.5	-56.7 ± 60.4	[illegible] ± 83.2	-35.0 ± 118.8	80.0 ± 122.6	10.8 ± 67.2	-30.8 ± 79.8	0.0 ± 57.4	- 9.16 ± 14.1
	Inf.	-39.3 ± 88.0	96.4 ± 91.6	-114.3 ± 77.8	[illegible]	-61.0 ± 48.2	-71.2 ± [illegible]	0.0 ± 31.4	-16.7 ± 45.9	-16.7 ± 37.7	-53.5 ± 12.8
Food Solids	Pre	556 ± 8	619 ± 20	610 ± 13	[illegible] ± 6	561 ± 8	819 ± 10	617 ± 9	600 ± 11	616 ± 6	616 ± 27
	Inf.	578 ± 9	610 ± 10	585 ± 12	506 ± 8	572 ± 12	822 ± 19	639 ± 5	621 ± 5	646 ± 6	630 ± 26
Insensible Metabolic Loss	Pre	470 ± 7	525 ± 18	520 ± 13	471 ± 5.4	472 ± 4	690 ± 10	518 ± 8	515 ± 10	519 ± 6	522 ± 22
	Inf.	498 ± 9	522 ± 10	506 ± 11	527 ± 7.1	487 ± 10	701 ± 16	511 ± 4	536 ± 5	548 ± 6	541 ± 21
Urine Solids	Pre	25.5 ± 1.6	23.8 ± 1.7	24.6 ± 1.1	22.1 ± 1.1	23.3 ± 1.6	34.5 ± 1.5	27.8 ± 1.5	27.0 ± 1.8	53.0 ± 3.2	29.1 ± 3.2
	Inf	28.6 ± 1.1	30.6 ± 1.7	33.0 ± 1.9	24.5 ± 0.8	29.1 ± 0.8	17.4 ± 0.8	33.7 ± 0.9	32.7 ± 1.3	57.5 ± 1.6	34.2 ± 3.2
Fecal Solids	Pre	18.4 ± 3.7	28.1 ± 5.3	23.7 ± 5.9	18.1 ± 5.1	23.8 ± 3	33.6 ± 3.9	31.2 ± 2.1	24.1 ± 3.7	22.8 ± 5.1	24.9 ± 1.8
	Inf	19.7 ± 4.3	20.[illegible] ± 5.6	20.2 ± 3.0	20.7 ± 3.4	23.2 ± 3	33.6 ± [illegible]	28.7 ± 2.4	19.2 ± 2.7	25.1 ± 3.2	34.2 ± 1.6
Correction Factor	Pre	41.7	100.0	89.2	66.6	95.7	63.6	24.9	54.4	95.6	70.3 ± 8.9
	Inf.	56.3	126.5	55.9	66.6	95.7	63.6	26.0	42.9	12.9	61.7 ± 11.5
ΔTBW	Pre	-30.1 ± 67.5	11.0 ± 63.9	- 8.6 ± 58.4	38.3 ± 81.5	18.8 ± 116.4	82.2 ± 122.6	15.1 ± 67.8	-10.0 ± 77.8	74.2 ± 55.7	21.1 ± 12.6
	Inf.	-14.5 ± 86.4	- 6.4 ± 90.4	-74.7 ± 78.0	-23.1 ± 42.6	2.1 ± 47.2	-56.7 ± 67.6	- 9.2 ± 34.4	7.35 ± 45.7	-19.0 ± 36.4	-23.2 ± 25.6
σ(Δ TBW)	Pre	370	350	320	365	520	545	346	397	284	387***
	Inf.	457	478	413	327	362	519	316	119	334	393

* Mean ± SEM (N = number of days observed); all units in gm/day

** N = 9

*** Pooled mean squared standard deviation N_{pre} = 228, N_{Inf} = 513, k = 9

RESULTS

The results of the water balance analysis are contained in the computer printouts and microfilm hardcopy graphics which are being delivered separately and should be considered as attachments to this report. The most important results of this analysis have been summarized graphically within this report. A mass balance analysis (body fat and body protein) and an energy balance analysis have also been performed. The computer generated results of these analyses are included in the attachments mentioned above, but they will not be discussed in this report. Appendix A and B are summaries of the computer runs and graphics which are attached.

It was requested that special attention be devoted to the water balance during the first two weeks following launch and recovery, since this period would coincide with Shuttle orbit time. This information may be useful in predicting the response of the Shuttle crewmembers. Figures 1-14 summarize the most relevant water balance results for $\pm$ 14 days around launch and recovery. Figures 1 - 8 contain the graphs of water balance and its components at launch and recovery for each Skylab crew and for all crewmembers combined. Figures 9 - 12 illustrate the daily evaporative water losses for the same periods and for the same grouping of subjects. The integrated water balance provides an estimate of total body water changes, and these are shown in Figures 13 and 14 for the $\pm$ 14-day periods around launch and recovery.

In addition to these $\pm$ 14-day water balances, an additional effort was made to extend the time interval of study. The only continuous time periods in which all nine crewmembers are represented include: a) two weeks of preflight followed by the first four inflight weeks, and b) the last four inflight weeks followed by two weeks of recovery. The statistical sample is much greater during these intervals (nine crewmen represented) than, for example, in the second month inflight and it is probable that narr er confidence limits can be obtained. The changes in total body water for these periods are shown in Figures 15 - 17.

The trend of total body water changes as a result of space flight and recovery can best be visualized from a plot of this variable during the entire mission periods: preflight, inflight, and postflight. These entire mission plots are illustrated in Figures 18, 19, and 20. Total body water is shown in Figure 18, total body weight/mass is presented in Figure 19, and Figure 19 repeats the information of Figure 18 with the addition of computed total body water where no correction factor was used in the water balance.

It may be of interest at some future date to analyze the corresponding data for each crewman individually. This information is contained in Volume I (attached) of the microfilm graphics hardcopy. Volumes II - IV contain all of the original graphics that was used to assemble the figures in this report. Volume IV is probably of special interest, since it contains summaries of water mass, tissue, protein and fat balance and integrated changes in these quantities for the one month and entire mission intervals. The computer runs that generated these graphics are also attached (see Appendix A) and will be necessary if more accurate or aesthetically pleasing illustrations are desired for publication or similar purposes.

DISCUSSION

This study supports the general belief that the major source of body weight loss found in men returning from space flight is from a loss of body water. In the case of the Skylab crewmembers, this amounted to a mean decrease of 1400 ml following orbital insertion or about 2% of bc ' weight. During the flight there appears to be a general tendency for a small portion of this water to return. Upon recovery there is a rapid water gain which is only slightly less than the original loss, but occurs during a period of 5 or 6 days as compared to the original loss over two days.

Water Balance

The water balance charts of Figures 1 - 8 illustrate the particular routes by which the total body water changes following launch or recovery. Figure 1 summarizes the data for the average of all nine crewmen and Figures 2 - 4 shows the corresponding results for each of the three flights. It is clear that the major disturbance in water balance occurs during the first two days following launch. It is also evident that the body did not lose this water by either of the major output pathways: urine or evaporative water. In fact, total output did not change significantly and actually showed a tendency to decrease during this period.* Rather a mean decrease in total water intake of up to 40% by the second day appears to account for the negative water balance. Total water intake in these charts represents the sum of free liquid intake plus food water plus metabolic water. The first several days following launch was accompanied by motion sickness in the majority of crewmembers, the most severe occurring during the second mission, SL-3. On that flight the decrease in intake persisted for nearly a week. (See Figure 3). As will be discussed below, SL-3 was characterized by the largest loss in weight and body water during the week following launch.

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* Note that the scale of the water balance charts is negative below the zero line, so that a rise in urine or total output curves toward the top of the page signifies a decrease in that quantity. It should also be observed that the difference between the urine and total output lines represents the evaporative water loss. Evaporative water loss data are summarized separately in Figures 9 - 12.

The decrease in water intake was not expected. Motion sickness and motion sickness drugs probably played a role in blunting appetite and thirst. However, it is possible that the decreased intake is a normal result of the weightlessness response (i. e., via the angiotensin-thirst mechanism) and would have occurred in the absence of motion sickness.

An interesting aspect of this analysis is that evaporative water loss does not appear to play a major role in these changes in overall water balance. Evaporative water losses were substantial and nearly equivalent to the losses attributed to urine and fecal water combined. Furthermore, significant changes in evaporative water loss occurred during several specific days in the week following launch. For example, the first crew experienced dramatic losses on the third, fourth, and fifth day of the inflight phase (see Figure 10), coinciding with exposure to unusually high cabin temperatures as a result of a heat shield failure. On the other hand the crews of the second and third manned mission exhibited small decreases in evaporative water loss. (The differences between evaporative water loss following launch of the first crew compared to both of the subsequent crews combined is evident in Figure 12). However, in all these situations of either increases or decreases of evaporative water loss, there appears to be similar order of magnitude changes in water intake. Thus, the SL-2 crew apparently compensated completely for their increased evaporative water loss by increasing water intake and water balance during this period was nearly zero.

Another important point should be mentioned with respect to evaporative water loss. This parameter was expected to increase during the flight because of the low barometric pressures in Skylab (1/3 atm). However, in a previous report it was shown that inflight evaporative water loss actually decreased by about 8% on the average compared to preflight controls. While the mechanism for this phenomena is not known, it was believed to be due to a sweat suppression phenomena that was enhanced by lack of sweat dripping and reduced convection in zero-g. Figures 9 - 12 confirm that there was no increase in evaporative loss during the first two weeks inflight except for several days on SL-2. Based on the discussion in the previous paragraph, it is reasonable to assume that had evaporative water loss increased it would have been compensated for by an increase in water intake.

Water balance at recovery (see Figure 5) was essentially the reverse of that at launch. After a lag of one day (which included the recovery from orbit itself), a positive balance occurred which persisted for nearly a week. The day of recovery showed large increases in evaporative water loss (perhaps due to the thermal stresses of reentry) which were nearly compensated for by increases in water intake. The period of positive balance that ensued was due to more subtle changes than occurred during launch. It appears water recovery was accomplished by a water intake which was slightly higher than total output. This pattern differed only in the SL-3 crew (Figure 7) which exhibited the largest recovery water gains (as well as the highest losses following launch). This was partially attributed to an uncompensated decrease in evaporative water loss. It should be mentioned that the day before recovery was universally accompanied by large apparent decreases in evaporative water loss as well as in water intake. There is reason to suspect that these changes were not real but rather a result of inaccurate reporting of water intake data during the hectic pre-reentry preparations.. (Evaporative water loss is calculated as a function of water intake). Figure 8 more dramatically illustrates this possibility in that the last inflight day shows a mean SL-4 evaporative water loss that approaches zero.

In summary, the first two days following launch were characterized by a negative water balance which could be accounted for primarily by a decreased water intake ~~as well as~~ in spite of minor decreases in urine and fecal water. The decreases in direct total body water found on recovery day can, therefore, be attributed to losses occurring immediately following launch. Changes in evaporative water loss appear to be compensated by water intake and do not affect overall water balance significantly even during periods of unusually high loss. Compared to the negative water balance at launch positive water balance during the postflight period is less intense and of longer duration.

Total Body Water Changes

Changes in total body water during the two weeks before and after launch and recovery are shown in Figure 13 for the entire Skylab crew and in Figure 14 for each flight separately. It appears that on the average the crew was essentially in water balance during the preflight period although there may be a tendency for increasing total body water. In the few days prior to launch and recovery, however, there is a loss of nearly half a liter probably due to the busy workload preceding these periods which precluded fully adequate hydration (or perhaps inadequate reporting of water intake/output). The most notable features of total body water changes are the rapid changes following launch and recovery. The losses after launch approach a mean of 1400 ml and appear to be complete at the end of 2 days inflight, although each crew behaved somewhat differently. The return of body water during recovery requires nearly a week to reach a value similar to the original launch loss before it too levels off.

The largest losses occurred on SL-3 and the smallest on SL-2, but there appears to be a trend during the first two weeks inflight for the losses to converge toward a common value. At recovery, there is a reversal of this trend, the largest increases are seen for SL-3 and the smallest for SL-2. Figure 13 also shows that the computed change in total body water is always less than the change in body mass, the latter quantity being measured directly. The difference between these curves are assumed to represent the change in body fat and body protein. This implies a net loss of body tissue preflight and inflight and a net gain of body tissue postflight.

Throughout the manned space flight program there has been an assumption that the large and rapid changes in weight gain are due to the recovery of body water which was lost within several days after launch. The results of this study support that assumption to a large extent. However, as can be seen from Figure 13, there are increasing differences between body water and body weight change beginning almost immediately after recovery. Apparently there are linear rates of increase in body tissue gain upon reentry which become increasingly important with respect to weight changes after several days.

Figures 15, 16, and 17 extend the analysis by another two weeks inflight. That is, the entire first month inflight and last month inflight are shown. At the end of the first month inflight, a general tendency for slow return of total body water is evident, although the figures for the entire mission show this trend more dramatically. The differences between average crew total body water are also apparent in Figures 16 and 17. It is not completely clear why there is so great a variability in the initial loss of total body water. At the end of the second day there is a mean loss of 0.52, 2.52 and 1.16 liters (mean $\pm$ sd = 1.40 $\pm$ 1.19) for the crews of SL-2, SL-3, and SL-4, respectively. By the end of the 28th day these values become 0.89, 1.60, and 1.54 liters (mean $\pm$ sd = 1.34 $\pm$ 0.78). In other words, total body water has not appreciably changed, but the variance has been reduced by more than half.

One factor which may explain most of this variability is the SL-3 crew's response which shows losses up to 2.5 liters, more than twice as much as either of the other crew's loss. This has already been attributed to a large and persistent decrease in water intake (see Figure 3) possibly a result of motion sickness. The differences between the SL-3 crew and the other two crew's water response decrease with time into the mission. This is in contradistinction to some of the other variables such as body fat and protein which exhibit greater differences among subjects and crews as the mission progressed. Therefore, it may be proposed that the large variance in water loss following launch is due primarily to an abnormally large loss on SL-3 as a result of motion sickness.

The total body water (with respect to morning of launch) is shown for the entire preflight, inflight and postflight phases of each mission in Figure 18.

These plots dramatically indicate that weightlessness induces a water loss that is essentially sustained throughout the length of the flight period at some new level that is appropriate for the zero-g environment. The different responses for each flight are also apparent. These illustrations take on additional meaning when compared to the changes in body mass which are shown in Figure 19.

The smallest changes in body water occurred on the first flight. Although body weight continued to fall throughout that mission, water loss did not. This may indicate a large loss in fat tissue which contains relatively little water. On the other hand, the SL-3 crew appeared to maintain their weight throughout most of the inflight phase while total body water gradually increased during the second inflight month. This might indicate an exchange of fat for protein tissue since lean body mass contains nearly 75% water. Finally on SL-4 there is little difference between the body mass and body water curves. Both drop off at launch and maintain their levels (with a slight tendency to increase during the last month inflight) before returning to normal levels during the postflight phase. In interpreting these graphs it is well to keep in mind the fundamental differences between the three flights: a) each successive crew remained inflight a month longer, b) each successive crew exercised longer and harder, and c) each successive crew received a larger caloric intake/kg body weight. In addition, each crew comprised a very small statistical sample so that strong conclusions regarding differences due to flight time, exercise levels and caloric intake may be difficult to support since they could be masked by differences among the particular subjects.

Figure 20 shows the effect of the water balance correction factor (see Methods of Computation) on the predictions of mission total body water for each mission. The solid line is the result of using the correction factor and the dashed line represents the identical analysis with the correction factor omitted. To reiterate, the correction factor was based on the difference between the uncorrected water balance and the direct measurements of total body water and represents unaccountable dry skin and insensible metabolic losses. It is readily apparent that without the correction factor applied, errors accumulate rapidly and ridiculously large water losses are predicted (up to 6 liters during the second manned mission, which is approximately two kilograms larger than the maximum body weight loss). The use of the correction factor insures that the results from this water balance analysis agree with the direct total body water changes revealed by direct isotope dilution methods. It is possible from this analysis, therefore, to obtain an estimate of the true total body water measurements between the morning of launch and the morning of recovery, rather than between the days on which total body water was actually measured. (These are shown in the table below).

Estimate of ΔBody Weight and ΔBody Water Due to Weightless Flight: Comparison of Ground Obtained Data with Those Obtained from Water Balance Analysis:

	Water Balance*		Direct Measurement	
Flight	ΔBWgt	ΔTBW	ΔBWgt**	ΔTBW***
SL-2	-2.33 kg	-0.89 kg	-2.77 kg	-1.22 kg
SL-3	-3.90	-1.53	-3.73	-0.60
SL-4	-0.93	-1.00	-1.40	-0.63
Means	-2.39	-1.14	-2.63	-0.82

* Measurement interval: morning of launch to morning of recovery.

** Measurement interval: morning of launch to first shipboard weight.

*** Measurement interval: varies from (F-21 to R+0) - F-1 to R+1)

Total body water change as determined from direct measurement shows that it may underestimate true inflight TBW changes by about 30%. This, of course, is due to the fact that direct measurements could not be performed immediately prior to launch or reentry. The differences in body weight in the two columns above reflect both true changes due to reentry and inaccuracies in the mass measurement device.

Comparison with Other Skylab Experiments

To a large extent, the results reported in this study are supported by several other Skylab studies. The Stereometric Body Volume Measurement Experiment was performed preflight and postflight only (Whittle, 1976). It was calculated in their report that around 73% of the inflight weight loss resulted from the combined loss of fluid and muscle, the remainder being due to changes in body fat. Although body protein and fat changes have not been reported in the present study, they were analyzed along with body water and agree well with these other results. We have found that the total inflight weight loss may be partitioned as follows: water loss = 51%; dry protein loss = 14%; fat loss = 36%. Thus, water and muscle account for 66% of total weight change. The biostereometry study indicates that most of the volume losses occurred in the legs (muscle and fluid), abdomen and buttocks (fat). Each succeeding crew was said to have lost less leg volume due to the increasing exercise and caloric regime. A rapid increase in volume was observed in the first 5 days postflight resulting from an increase in body fluid. The increase was attributed primarily to the legs.

The Lower Body Negative Pressure study measured calf girth inflight and limb volume pre- and postflight (Hoffler, 1976). Calf girth revealed rapid, early (by fourth day) inflight decrements with very gradual leveling off. Limb volume determinations yielded postflight losses averaging 1.5 liters for both legs of all nine Skylab crewmen. Approximately 80% of the net inflight decrement was reported to have occurred by the third or fifth day in orbit when the first leg measurements were obtained. The earliest measurements were obtained on the ASTP crewmen in which there was shown nearly a liter loss from the legs by six hours in orbit. These suggested shifts of fluid from the leg do not imply loss of body fluid, but rather migration of fluid from the lower to the upper body. Nevertheless, the time intervals and magnitude of these early losses coincides rather well with the decreases in total body water found in the present study.

Another Skylab experiment was designed specifically to study inflight Fluid Shifts and Anthropometric Changes on SL-4 (Thornton, 1974). Results from this study reveal that by the time of the earliest inflight measurement on mission day 3, all crewmen had lost more than two liters of extravascular fluid from the calf and thigh. This leg volume change was greater by 800 ml than the average 1200 ml lost from the body by the third day, although the decrease by the end of the first week was about 1500 ml of total body water. It was suggested that the difference of about 1/2 liter that left the legs, but did not leave the body remains in the upper body, engorging the tissues and vessels above the heart. This fluid shift cephaled was confirmed by center-of-mass measurements. It was further revealed that this shift remained throughout the mission until recovery, when a sharp reversal occurred; a major portion of the reversal was completed within a few hours.

These Skylab experiments confirm that an average fluid loss from the body of nearly 1-1/2 liters occurs within the first two days and that almost all of this fluid may be attributed to having originated from the legs. The shift of fluids from the legs begins within a few hours, although it is not clear at this point whether total body water begins to decrease that early. These studies also confirm that the postflight recovery of water is nearly the reverse of that which occurred at launch with the exceptions that the gain is more gradual and not complete, probably due to a loss of body tissue which occurred inflight.

Finally, these results help clarify the problem of why there is often a poor correlation between weight loss and inflight duration and of weight loss and water loss in men returning from space. Weight loss is the sum total of fluid and tissue losses. Fluid losses occur early in flight and the volume lost is seemingly dependent on leg fluid volume which is shifted headward upon orbital insertion. In general, fluid loss is independent of flight duration. Tissue loss, however, is dependent on caloric intake, exercise levels, and mission duration. On short duration missions it would be expected that weight loss and fluid loss will correlate closely, but fluid loss and flight duration would not be related. On the other hand, for longer duration missions where tissue loss continues due to inadequate exercise or low caloric regimes, it would be expected that weight loss and flight duration might exhibit reasonable correlations, but not necessarily the relationship between weight and fluid losses.

APPENDIX A

List of Computer Runs of Water and Mass Balance Analysis Attached to Report

a) Printout of all programs and data base used in Skylab water, mass and energy balance.

b) Run #1: Skylab water, mass and energy balance including skin loss correction factor: Daily values of 30 input/output quantities for each of nine subjects.

c) Run #2: Skylab water, mass and energy balance: Average values of 30 input/output variables for pre-/in-/postflight phases for each of nine subjects.

d) Run #3: 14-day Skylab average water balance.

e) Run #4: 14-day Skylab average water and mass balance and total body changes.

f) Run #5: Extended run Skylab average total body water changes including skin loss correction factor.

g) Run #6: Extended run Skylab average total body water changes not including skin loss correction factor.

h) Run #7: Extend run Skylab average weight changes.

i) Run #8: Extended run Skylab average dry tissue weight changes.

j) Run #9: Extended run Skylab average total body protein changes.

k) Run #10: Extended run Skylab average total body fat changes.

l) Run #11: Skylab water, mass and energy balance not including skin loss correction factor.

Note: "Extended run" refers to time intervals greater than $\pm$ 14 days from launch or recovery. In particular these output include the first month and last month of flight as well as the entire mission (preflight, inflight and postflight). These runs necessitated special programming because the individual data that were required to be in computer memory would normally have exceeded the capacity available.

APPENDIX B

List of Microfilm Hardcopy Graphics of Water and Mass Balance Analysis Attached to Report

Volume I:	Skylab Water, Mass and Energy Balance: 30 input/output variables vs. time for each of nine subjects
Volume II:	14-Day Skylab Average Water Balance
Volume III:	14-Day Skylab Total Body Water, Tissue, Protein and Fat Changes
Volume IV:	Extended Run Skylab Total Body Changes: Entire Mission, First Month Inflight, Last Month Inflight, Preflight, Recovery: Total Body Water, Weight, Dry Tissue, Protein and Fat.

REFERENCES

Consolazio, C. F., R. E Johnson, and L. J. Becora, Physiological Measurements of Metabolic Functions in Man. McGraw-Hill, New York, 1963.

Hegstead, D. M. Balance Studies. J. Nutrition, 106:307-311, 1976.

Hoffler, G. W. Cardiovascular Studies on U. S. Space Crews - An Overview and Perspective. Presented at NATO Advanced Study Institute, University of Houston, Houston, Texas, 1975.

McHattie, L. A. Graphic Visualization of the Relations of Metabolic Fuels: Heat: O_2:CO_2, H_2O: Urine N. J. Appl. Physiol:15:677-683, 1960

Rambaut, P. C , C. S. Leach, and G. D. Whedon. Metabolic Energy Requirements During Manned Orbital Skylab Missions. Proc. Gravitational Biol. 19th Plenary Meeting of COSPAR, Philadelphia, PA., June 1976, Berlin, Akademie-Verlag (in press).

Roth, E. M. W H. Teichner, and A. O Mirarchi. Contaminants Standards. In: Compendium of Human Responses to the Aerospace Environment, edited by E. M. Roth. NASA, Washington, D. C.: 1968, Sect. 10-16, p. 13-36.

Thornton, W. E., G. W. Hoffler, and J. A. Rummel. Anthropometric Changes and Fluid Shifts. In: Proc. Skylab Life Sciences Symposium, NASA TM X-58154, NASA/JSC, Houston, Texas, p. 637, 1974.

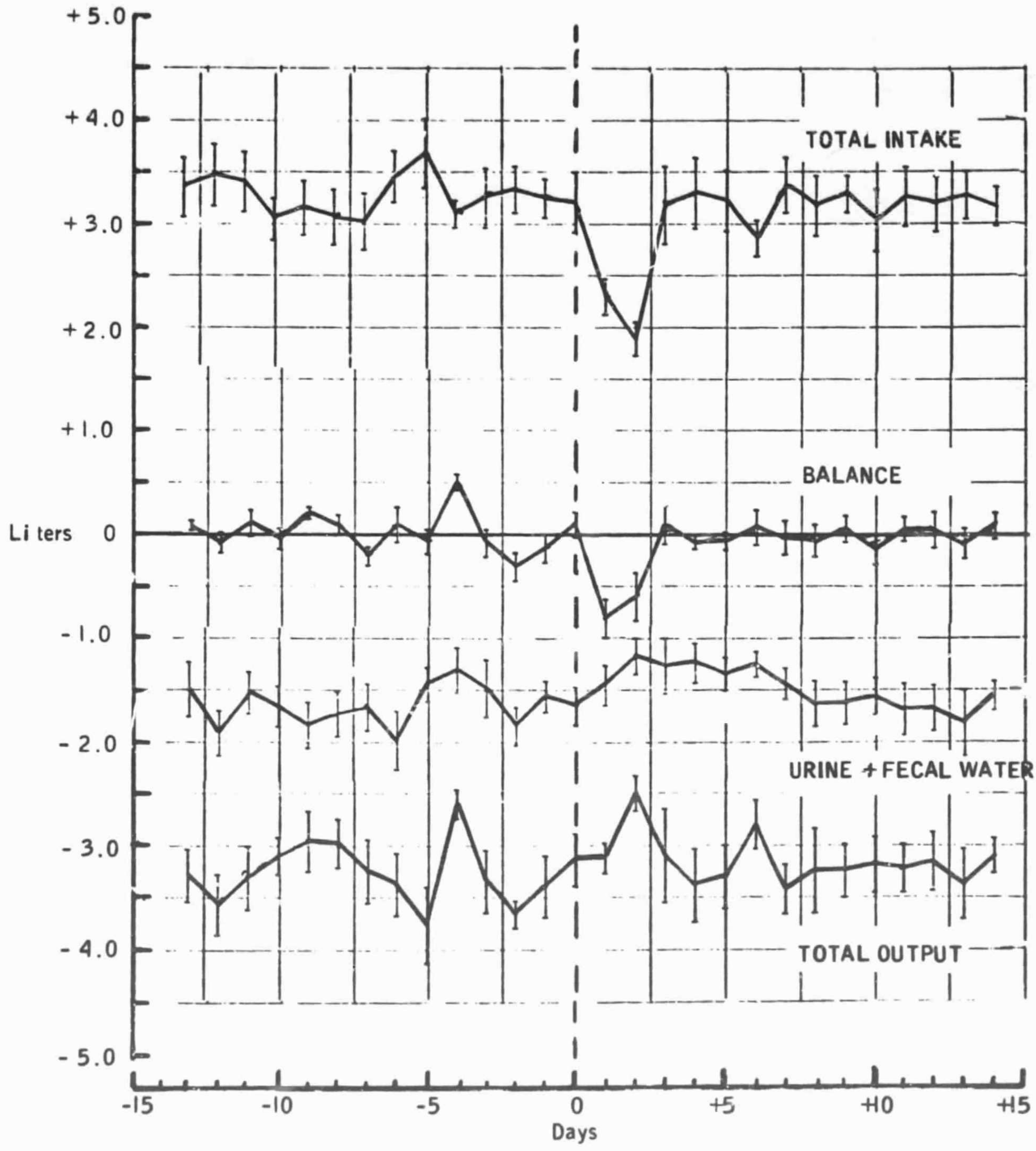
Webb, P. (Editor). Bioastronautics Data Book, 1st Ed., NASA, Washington, D.C., 1964.

PARTITIONAL WATER BALANCE FOR EACH MISSION

The components of water balance for each mission are shown in Table A-1. As noted earlier in the report, most of the dramatic changes occur near launch and recovery so that this information is masked by the values shown in Table A-1 which are daily means for the entire period. Nevertheless, there are some general conclusions that can be made from this data. Water balance was positive during the preflight period in two crews. A negative inflight water balance is observed for all flights which is greatest for the shortest flight. This trend is due in part to the averaging process which includes more observations for each successive crew although the initial drop in body water is approximately the same for all crews. Overall (means for nine subjects) it appears that the negative inflight balance was due mainly to a decreased water intake of nearly 5%, (compared to preflight) and in spite of a smaller decrease in output. The total output was also decreased (about -3%) due to a combined unexpected decrease in evaporative water loss (-8%) and small increase in urine volume (2%). Thus, if water intake had remained constant, the change in output would have led to a net retention of body water.

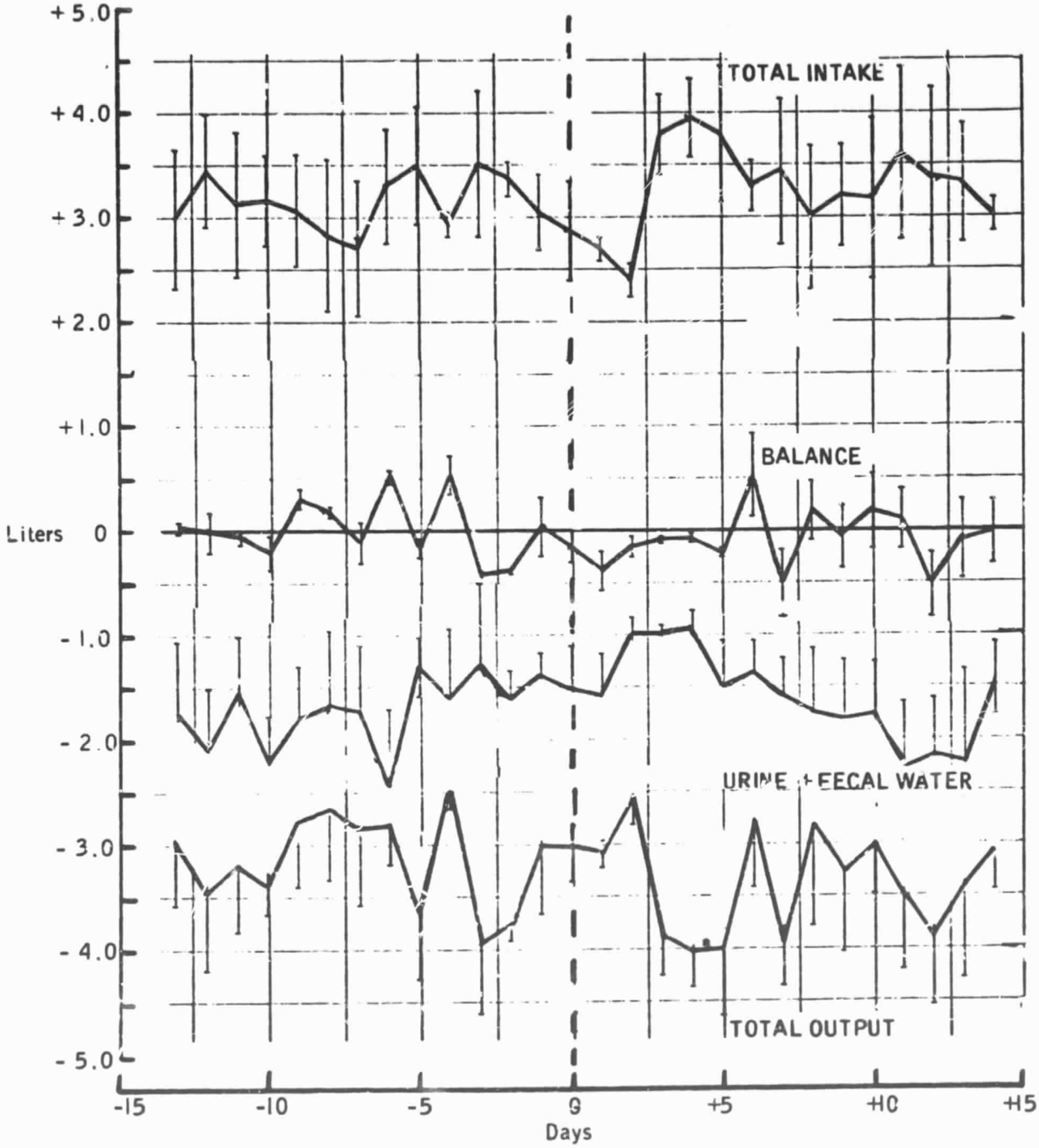
PARTITIONAL WATER BALANCE FOR EACH SKYLAB MISSION (N=3)

Mean (± SE) Daily Water Balance ml/day	SL-2			SL-3			SL-4		
	Preflight	Inflight	Postflight	Preflight	Inflight	Postflight	Preflight	Inflight	Postflight
INPUT:									
Water Ingested (food + drink)	2941 ± 536	2932 ± 533	3140 ± 577	2678 ± 295	2597 ± 302	2794 ± 371	3293 ± 225	2937 ± 227	3389 ± 354
Metabolic Water	340 ± 10	328 ± 5	359 ± 16	368 ± 47	362 ± 67	387 ± 44	351 ± 3	359 ± 5	371 ± 13
OUTPUT:									
Urine Volume	1640 ± 563	1702 ± 428	1835 ± 477	1333 ± 116	1356 ± 98	1374 ± 73	1660 ± 161	1672 ± 93	1986 ± 387
Fecal Water	79 ± 8	67 ± 5	18 ± 5	90 ± 25	77 ± 18	64 ± 22	77 ± 26	61 ± 8	70 ± 20
Evaporative Water	1573 ± 82	1522 ± 133	1619 ± 125	1576 ± 272	1552 ± 435	1653 ± 534	1881 ± 274	1575 ± 160	1652 ± 288
NET WATER BALANCE:									
Mean:	-9	-32	28	46	-26	90	26	-11	52
SE :	± 12	± 22	± 8.84	±19	±17	± 53	±25	± 4	± 8
No. of Days Observed :	30	28	14	20	59	17	26	84	18



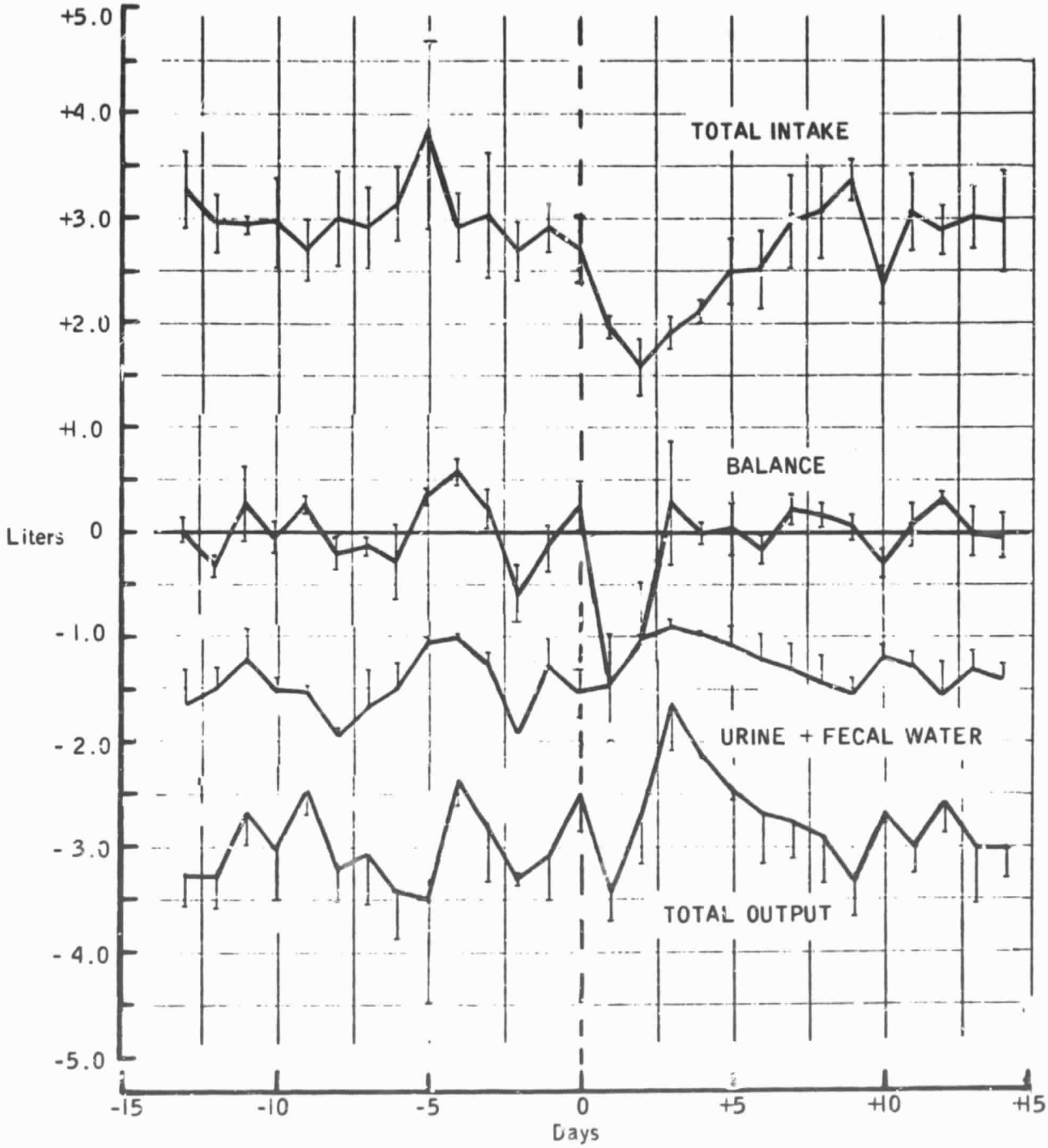
WATER BALANCE 14 DAYS BEFORE AND AFTER LAUNCH OF SKYLAB CREW
(N = 9)

FIGURE 1



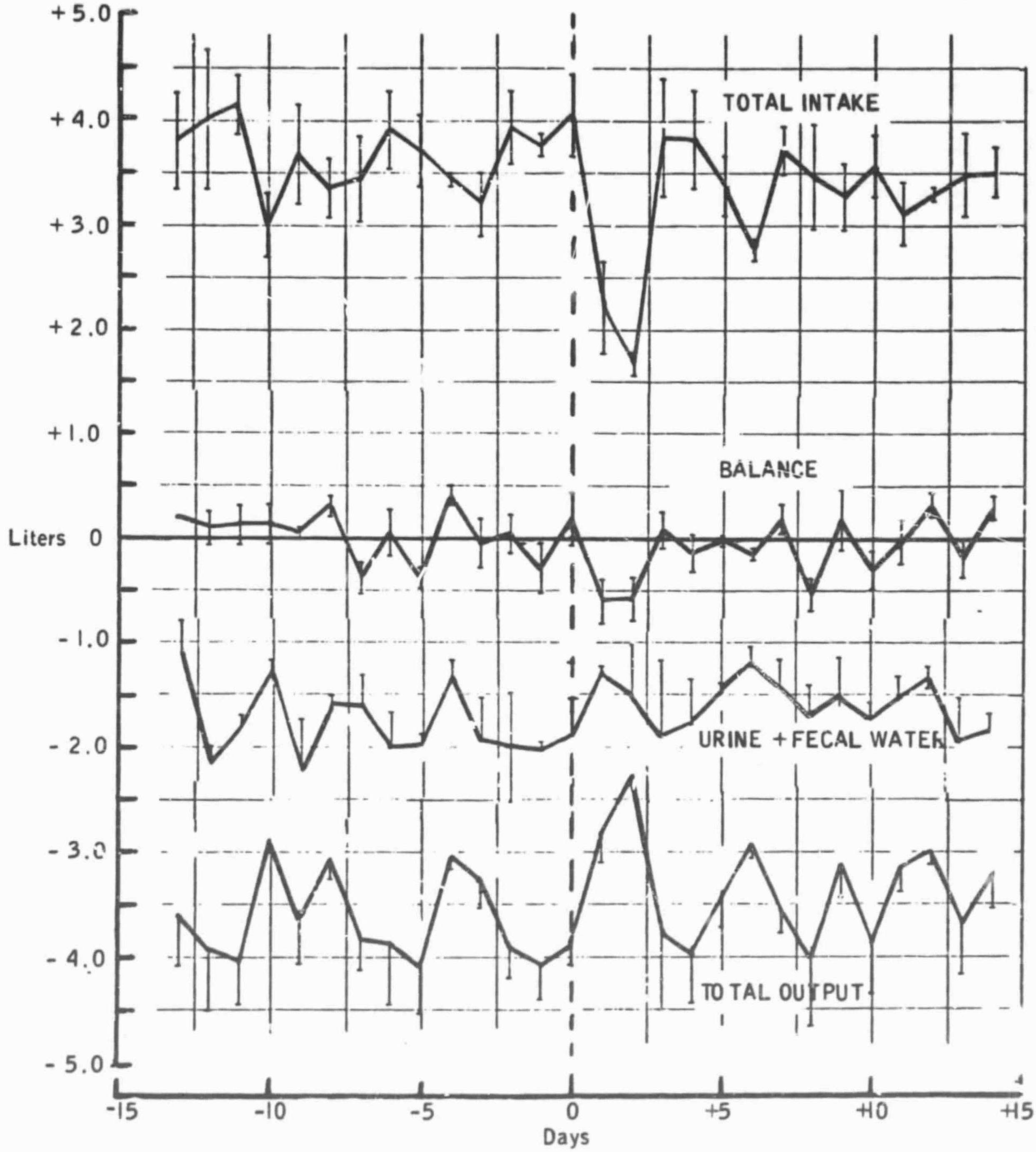
WATER BALANCE 14 DAYS BEFORE AND AFTER LAUNCH OF SL2 (N=3)

FIGURE 2



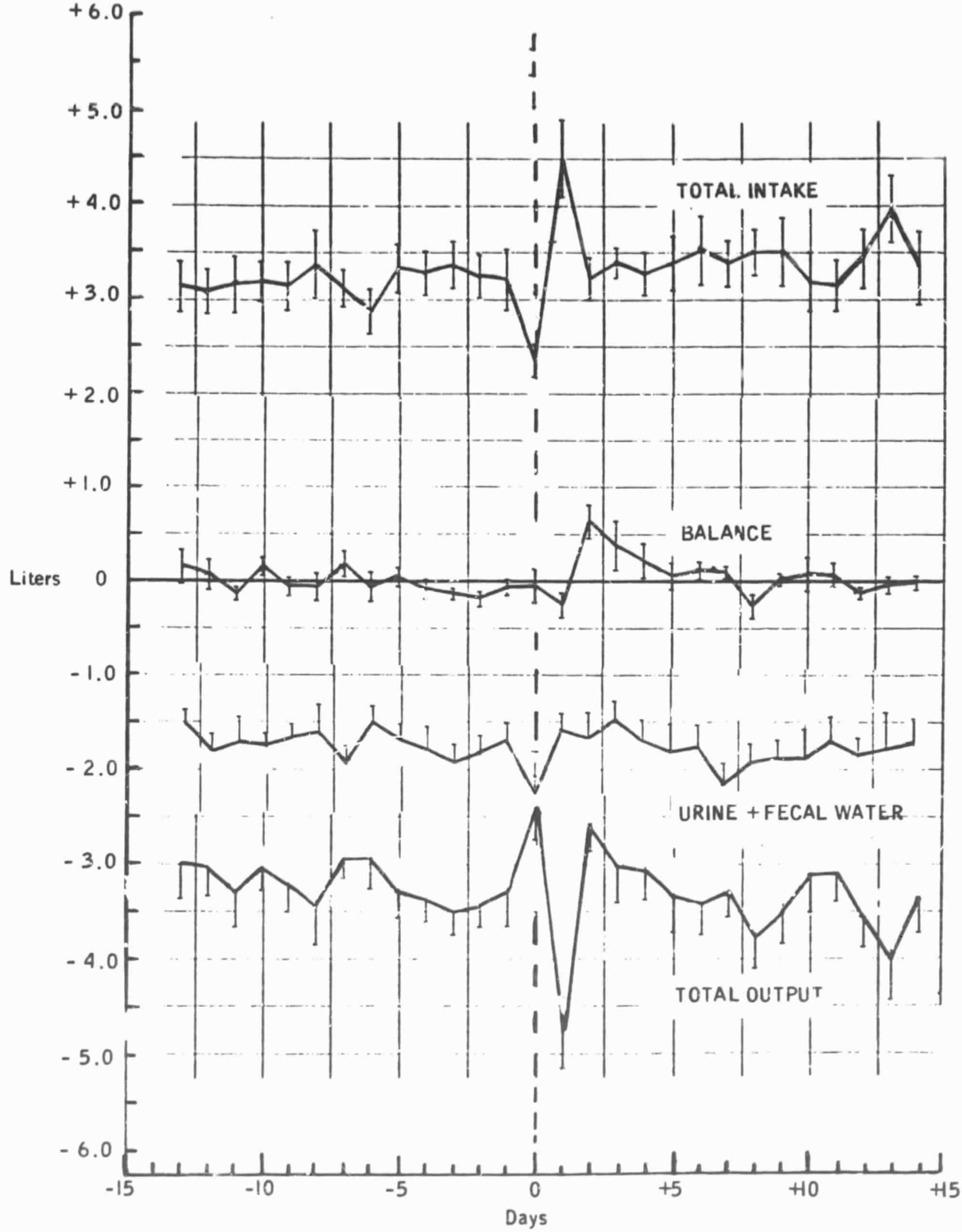
WATER BALANCE 14 DAYS BEFORE AND AFTER LAUNCH OF SL 3 (N=3)

FIGURE 3



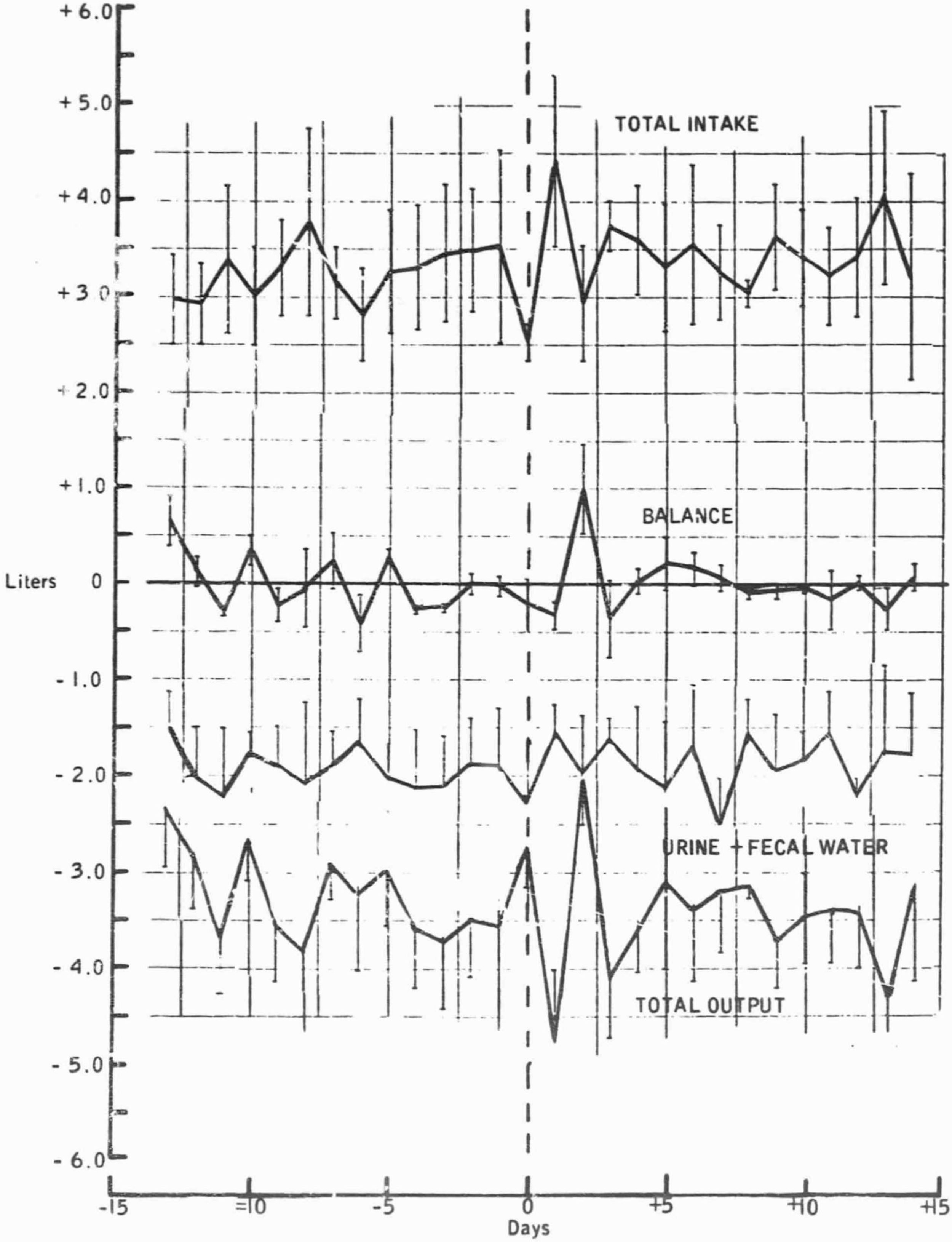
WATER BALANCE 14 DAYS BEFORE AND AFTER LAUNCH OF SL4 (N=3)

FIGURE 4



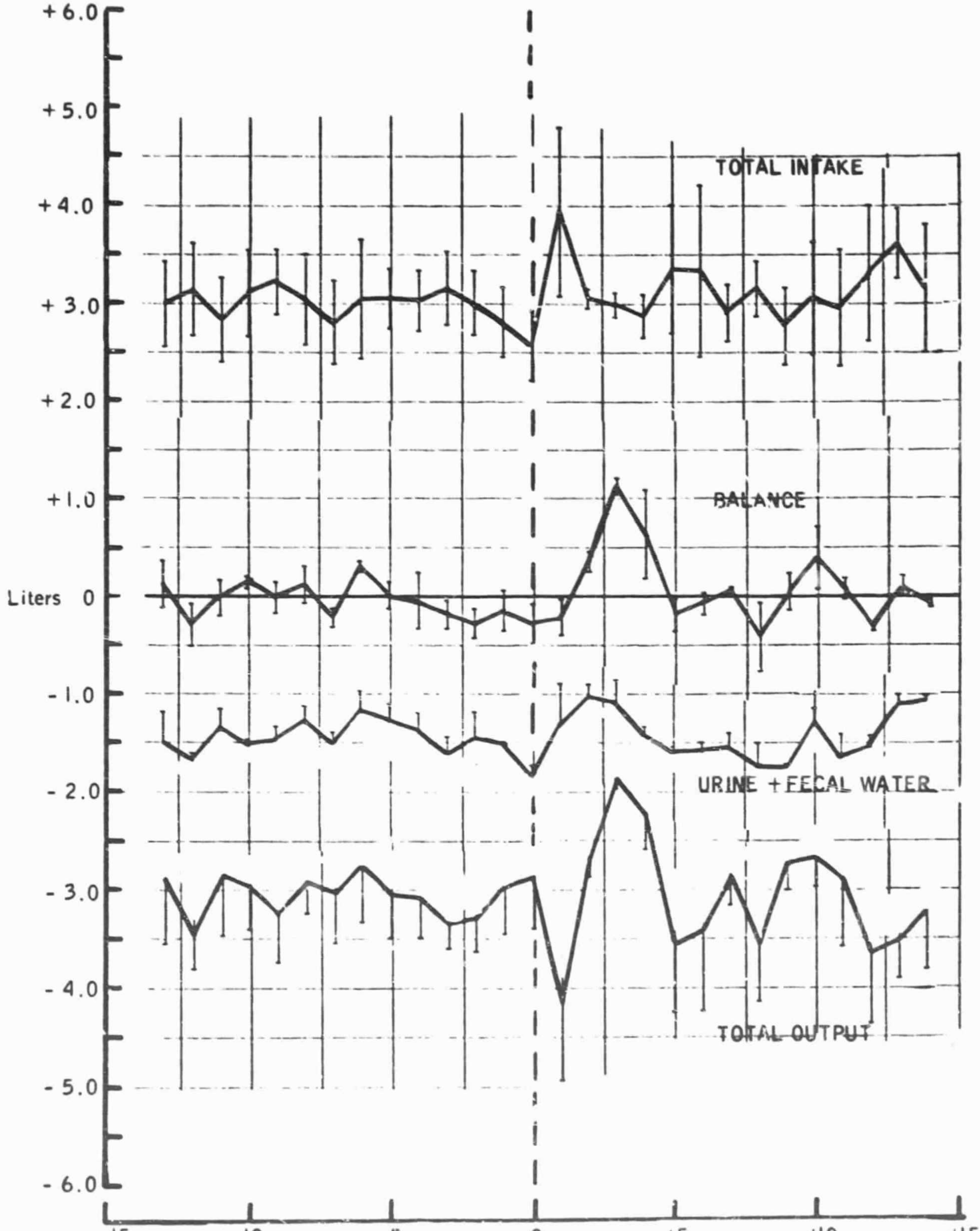
WATER BALANCE 14 DAYS BEFORE AND AFTER RECOVERY OF SKYLAB CREW
(N = 9)

FIGURE 5



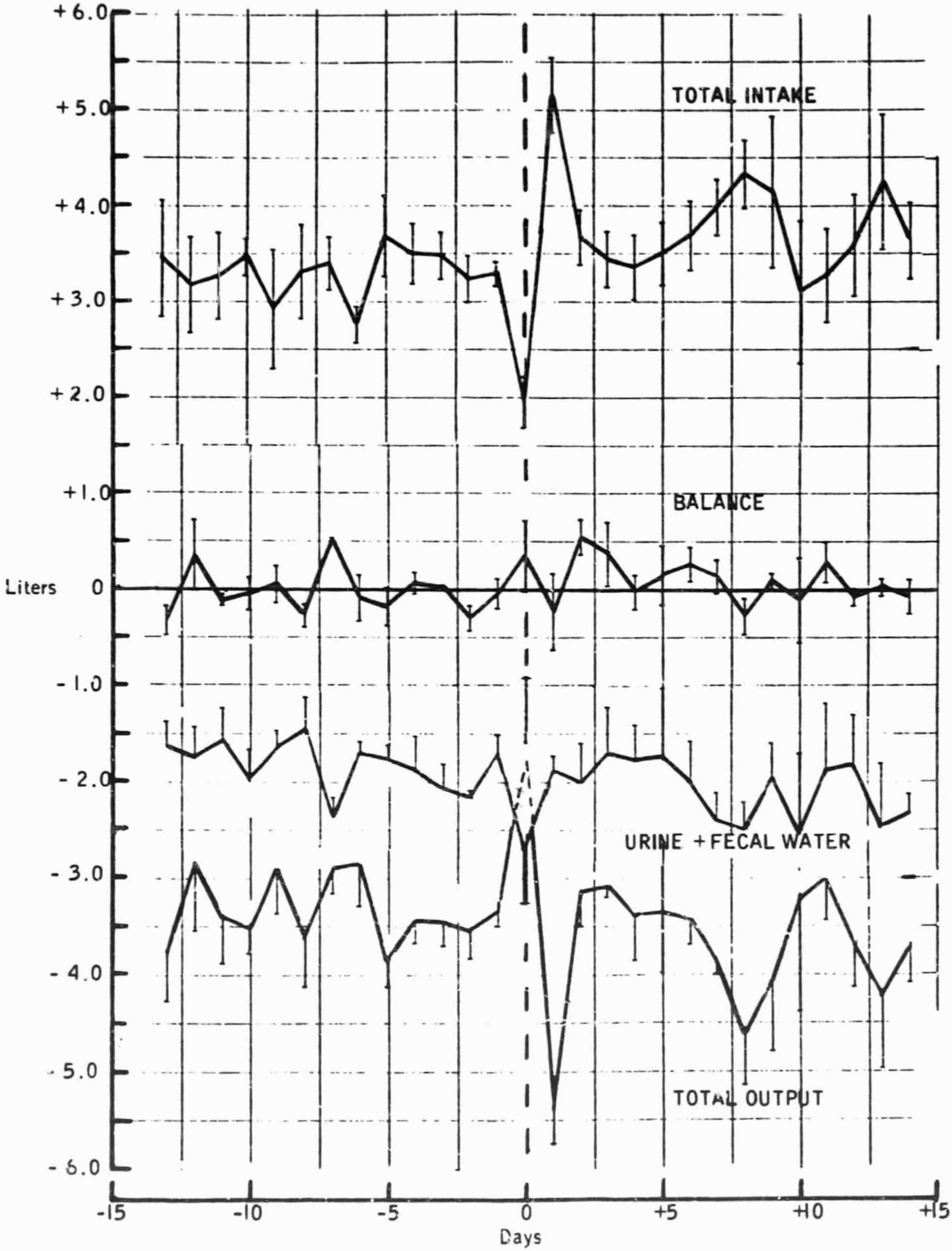
WATER BALANCE 14 DAYS BEFORE AND AFTER RECOVERY OF SL2 (N=3)

FIGURE 6



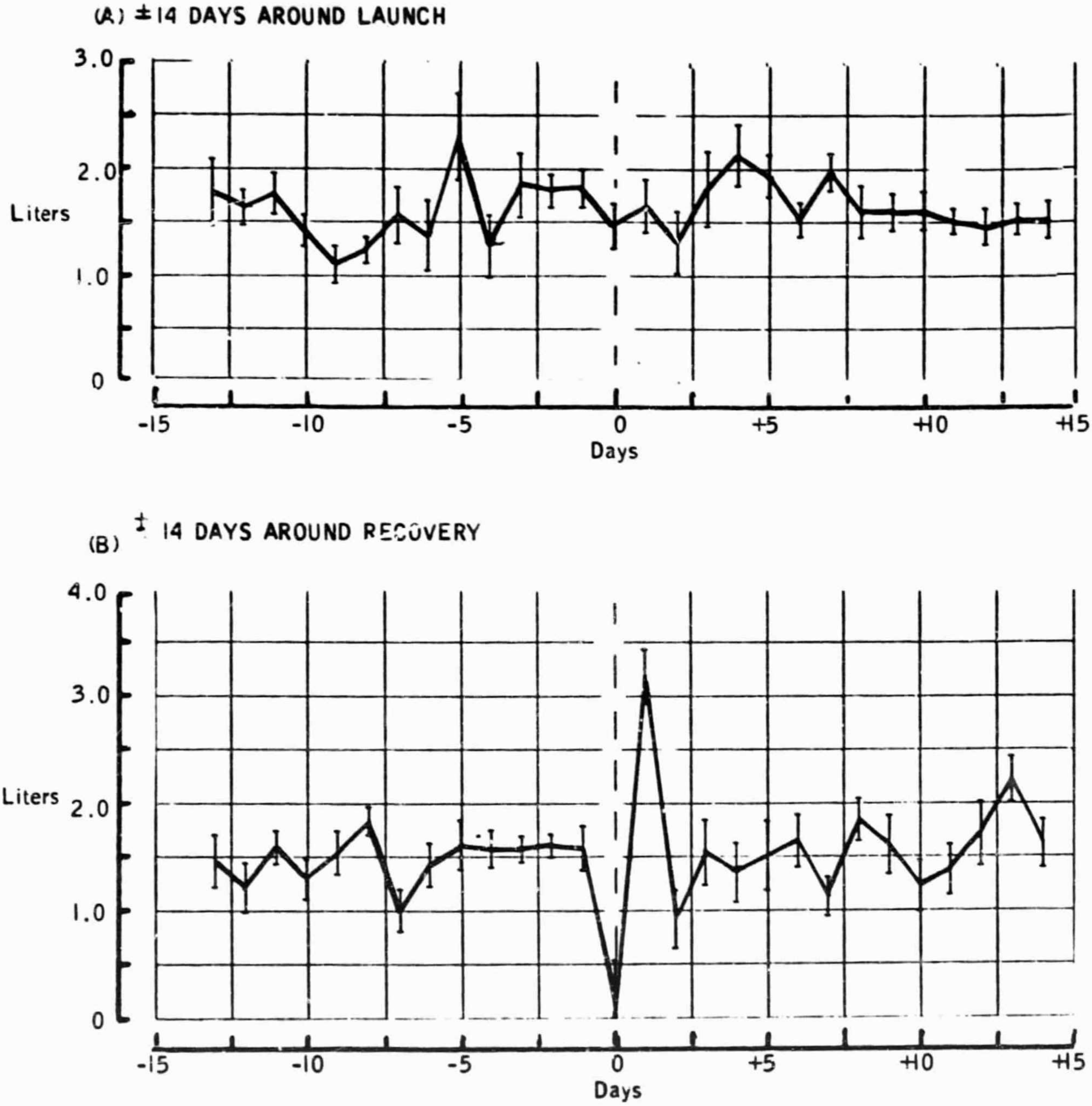
WATER BALANCE 14 DAYS BEFORE AND AFTER RECOVERY OF SL 3 (N=3)

FIGURE 7



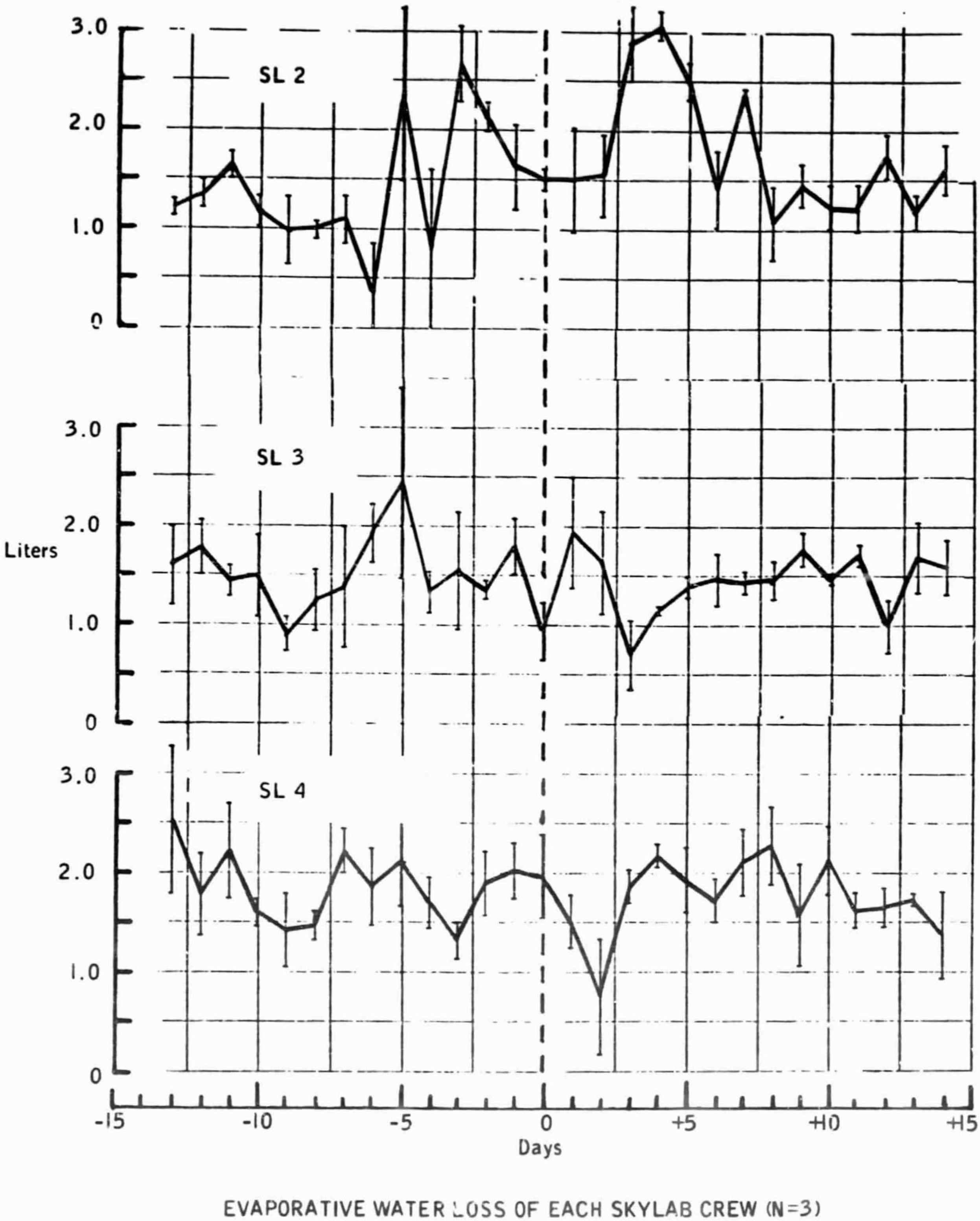
W'TER BALANCE 14 DAYS BEFORE AND AFTER RECOVERY OF SL 4 (N=3)

FIGURE 8



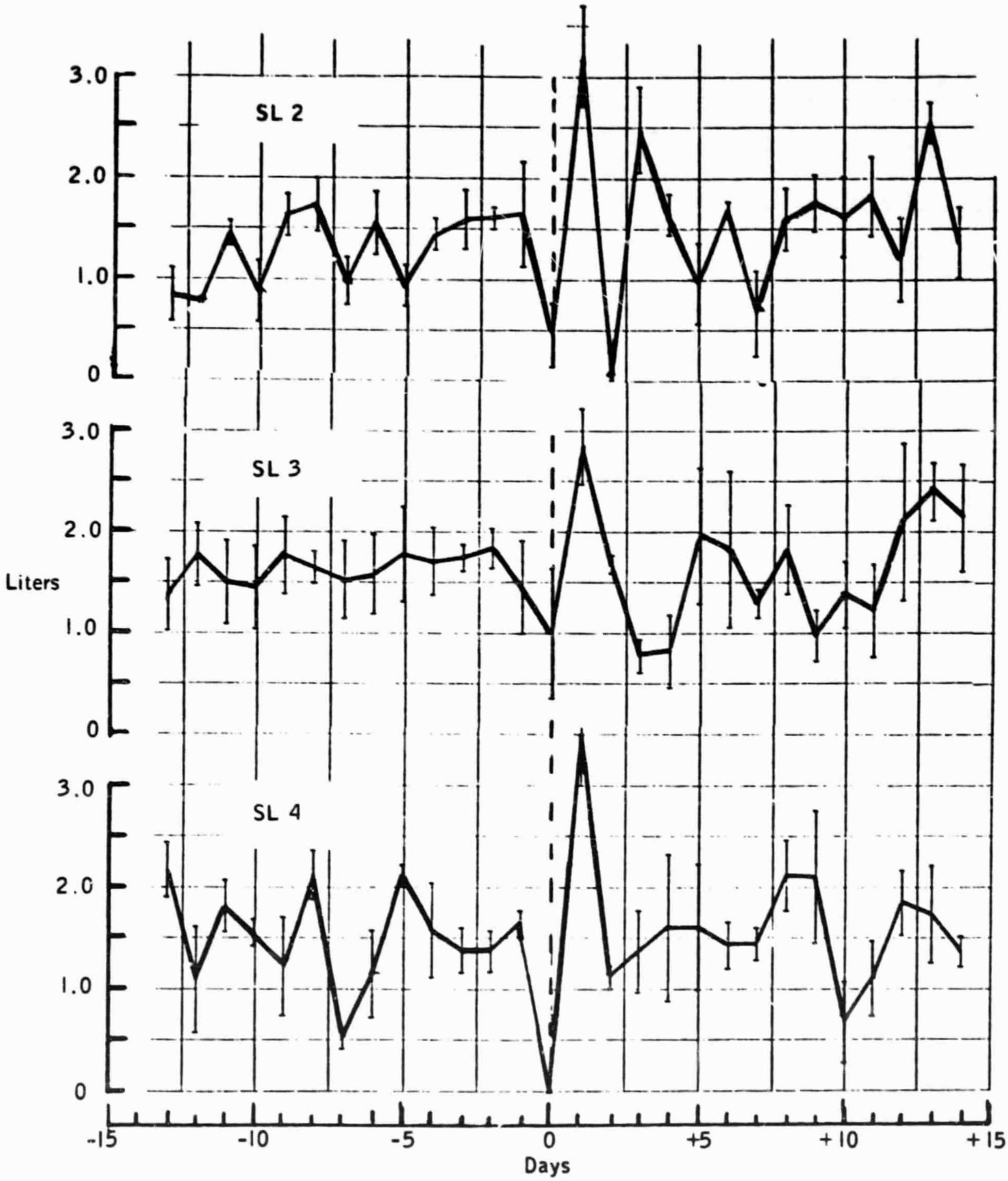
EVAPORATIVE WATER LOSS OF SKYLAB CREW (N = 9) AT LAUNCH AND RECOVERY

FIGURE 9



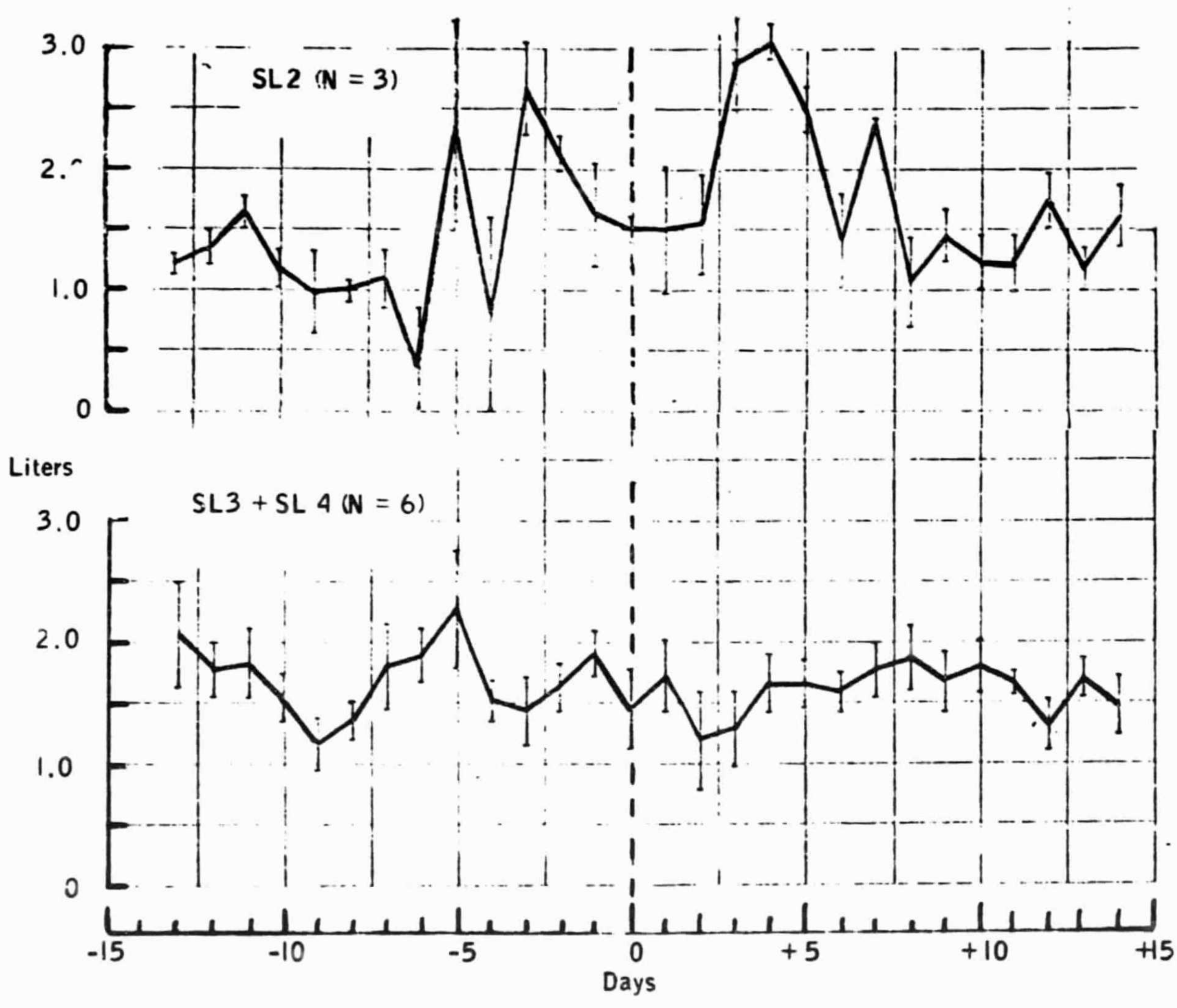
EVAPORATIVE WATER LOSS OF EACH SKYLAB CREW (N=3)
14 DAYS BEFORE AND AFTER LAUNCH

FIGURE 10



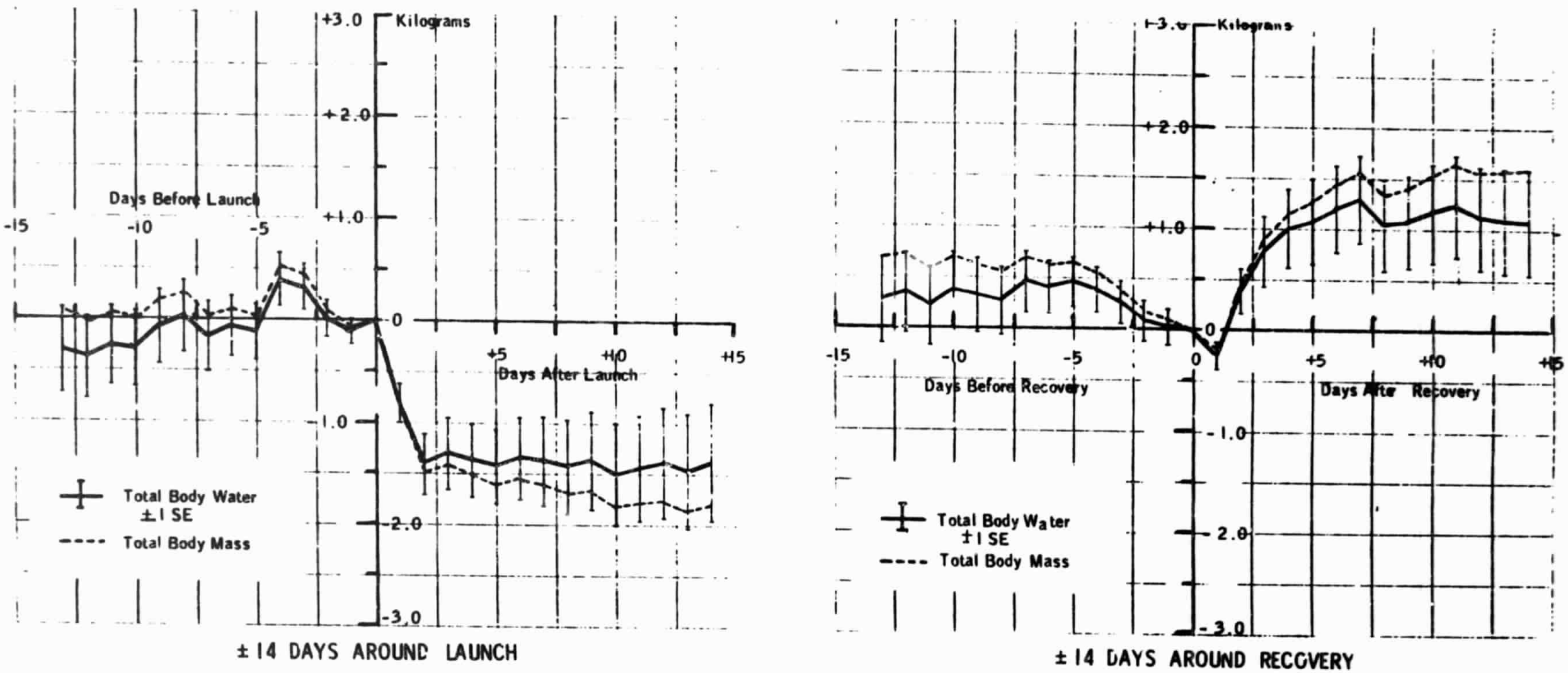
EVAPORATIVE WATER LOSS OF EACH SKYLAB CREW (N=3)
14 DAYS BEFORE AND AFTER RECOVERY

FIGURE 11



COMPARISON OF EVAPORATIVE WATER LOSS AT LAUNCH
BETWEEN SL2 CREW AND COMBINED SL3 + SL4 CREWS

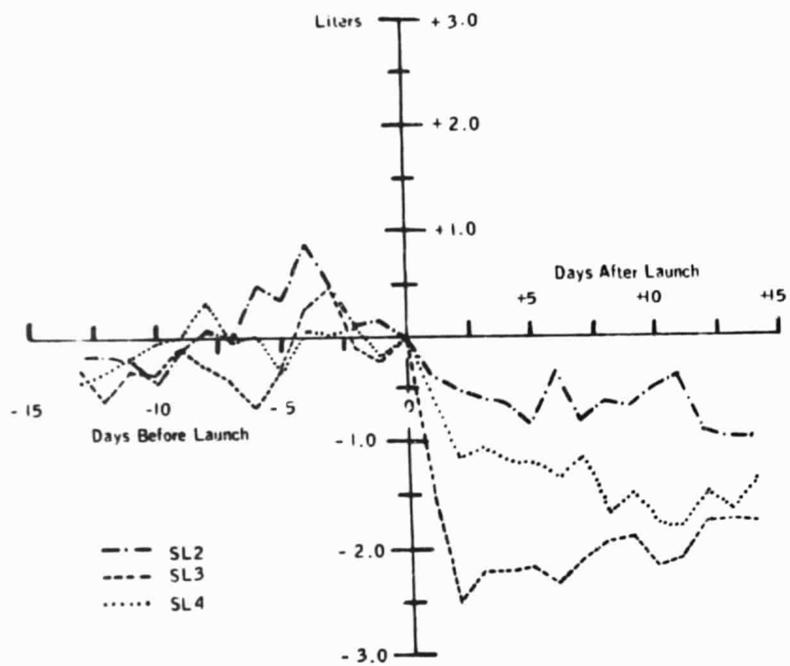
FIGURE 12



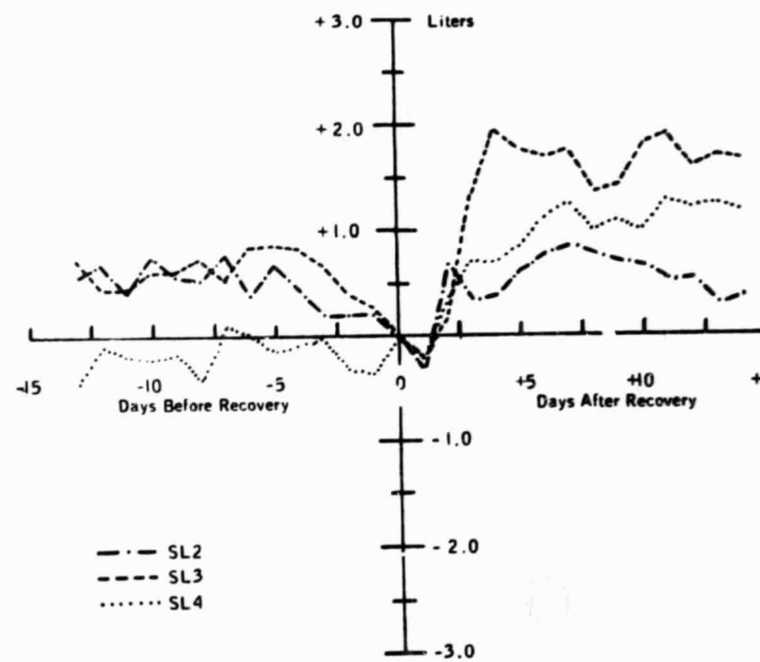
DAILY CHANGES IN TOTAL BODY WATER AT LAUNCH AND RECOVERY OF ENTIRE SKYLAB CREW (N = 9)

(Values are shown as changes from morning of launch or recovery)

FIGURE 13



± 14 DAYS AROUND LAUNCH

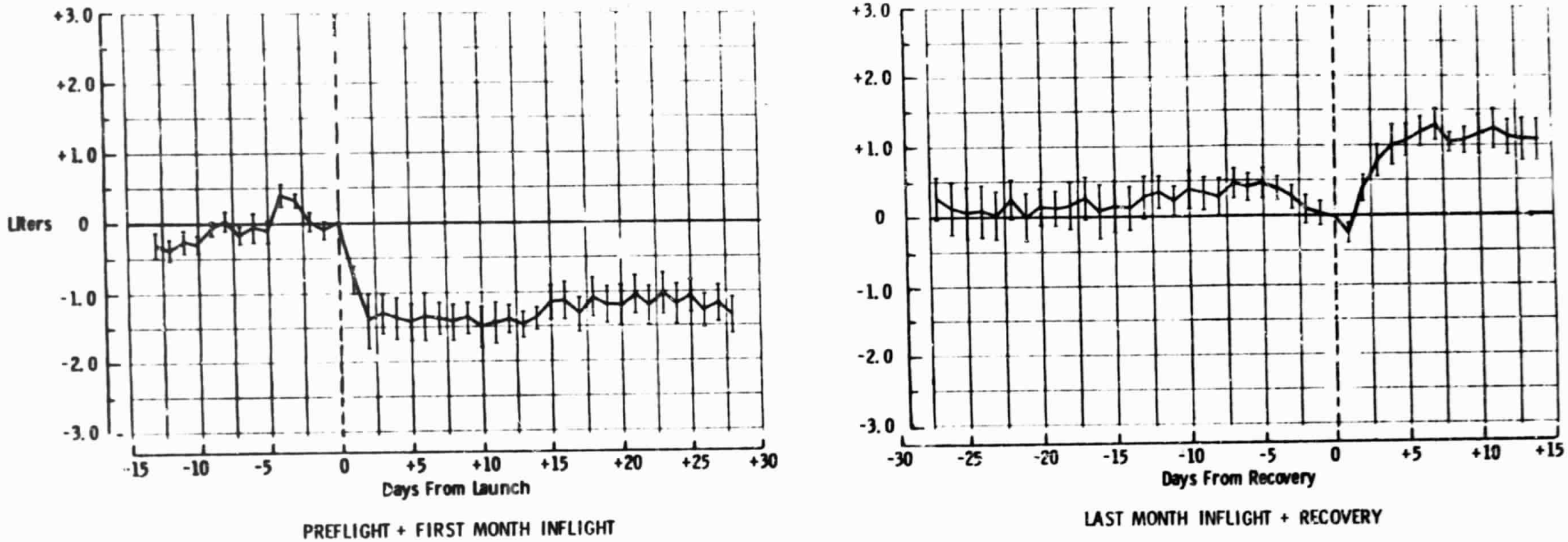


± 14 DAYS AROUND RECOVERY

DAILY CHANGES IN TOTAL BODY WATER AT LAUNCH AND RECOVERY OF EACH SKYLAB CREW (N = 3)

(Values are shown as changes from morning of launch or recovery)

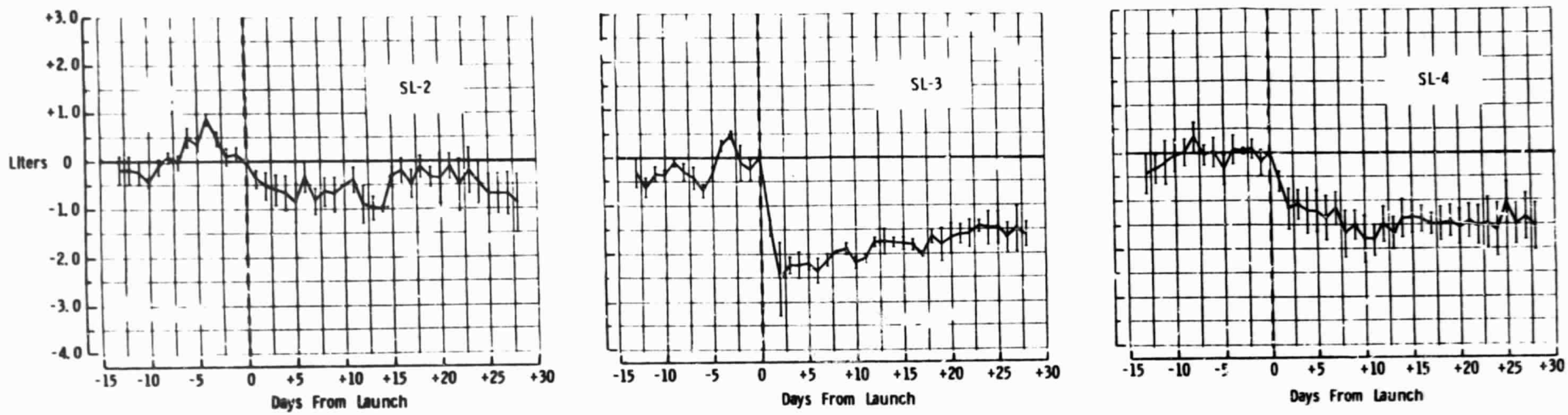
FIGURE 14



CHANGE IN TOTAL BODY WATER AT LAUNCH AND RECOVERY OF ENTIRE SKYLAB CREW (N=9)

(Values are shown as changes from morning of launch or recovery)

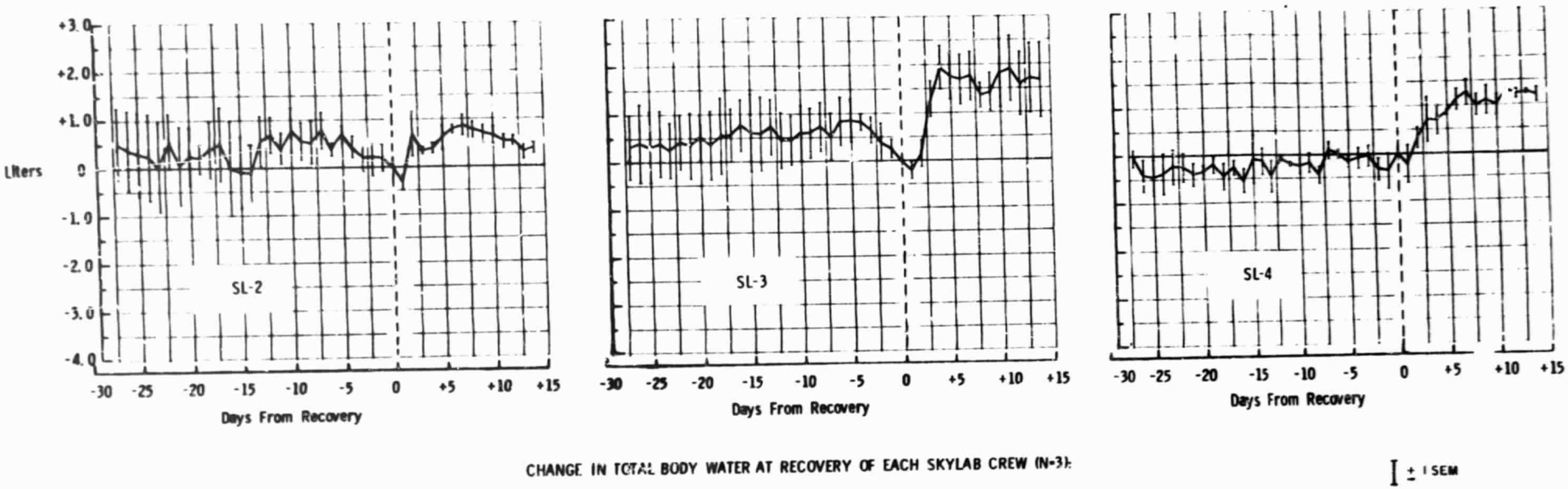
FIGURE 15



CHANGE IN TOTAL BODY WATER AT LAUNCH OF EACH SKYLAB CREW (N=3):
PREFLIGHT + FIRST MONTH INFLIGHT

(Values are shown as changes from morning of launch)

FIGURE 16

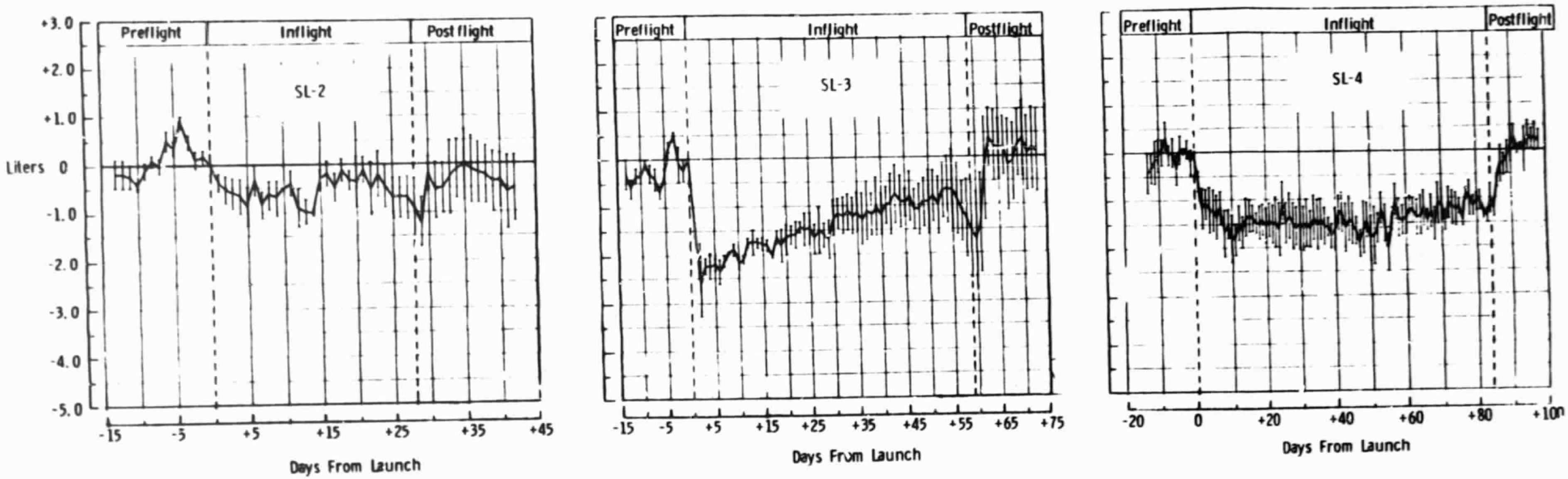


CHANGE IN TOTAL BODY WATER AT RECOVERY OF EACH SKYLAB CREW (N=3):

LAST MONTH INFLIGHT + RECOVERY

(Values are shown as changes from morning of recovery)

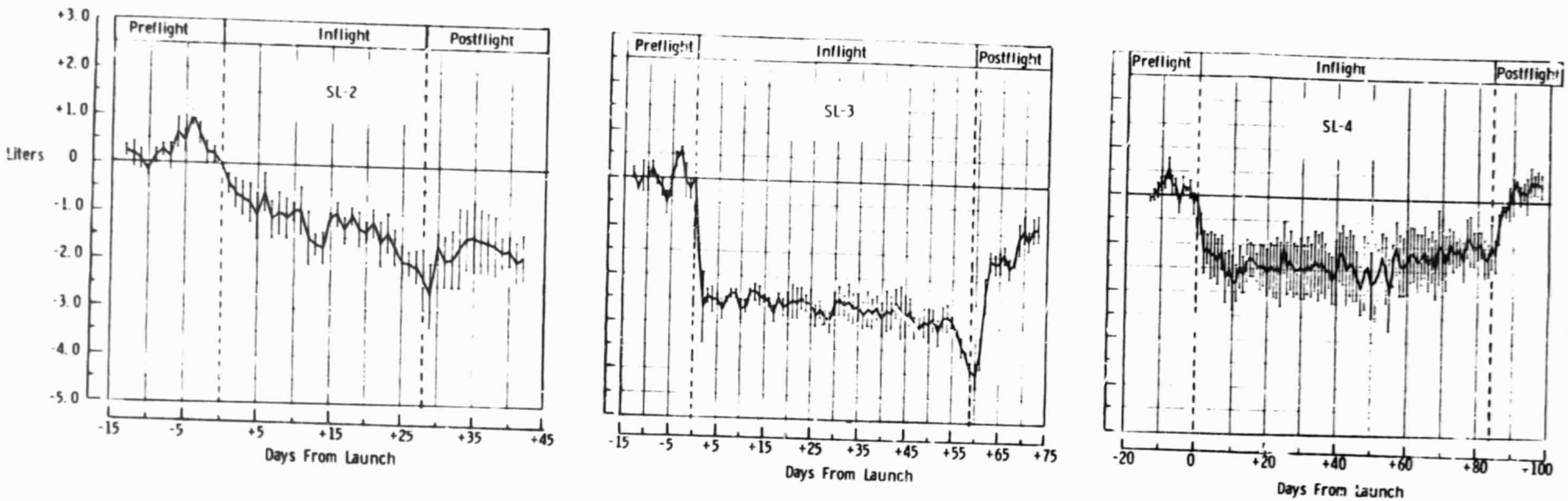
FIGURE 17



CHANGE IN TOTAL BODY WATER DURING ENTIRE MISSION OF EACH SKYLAB CREW (N=3)

(Values are shown as changes from morning of launch)

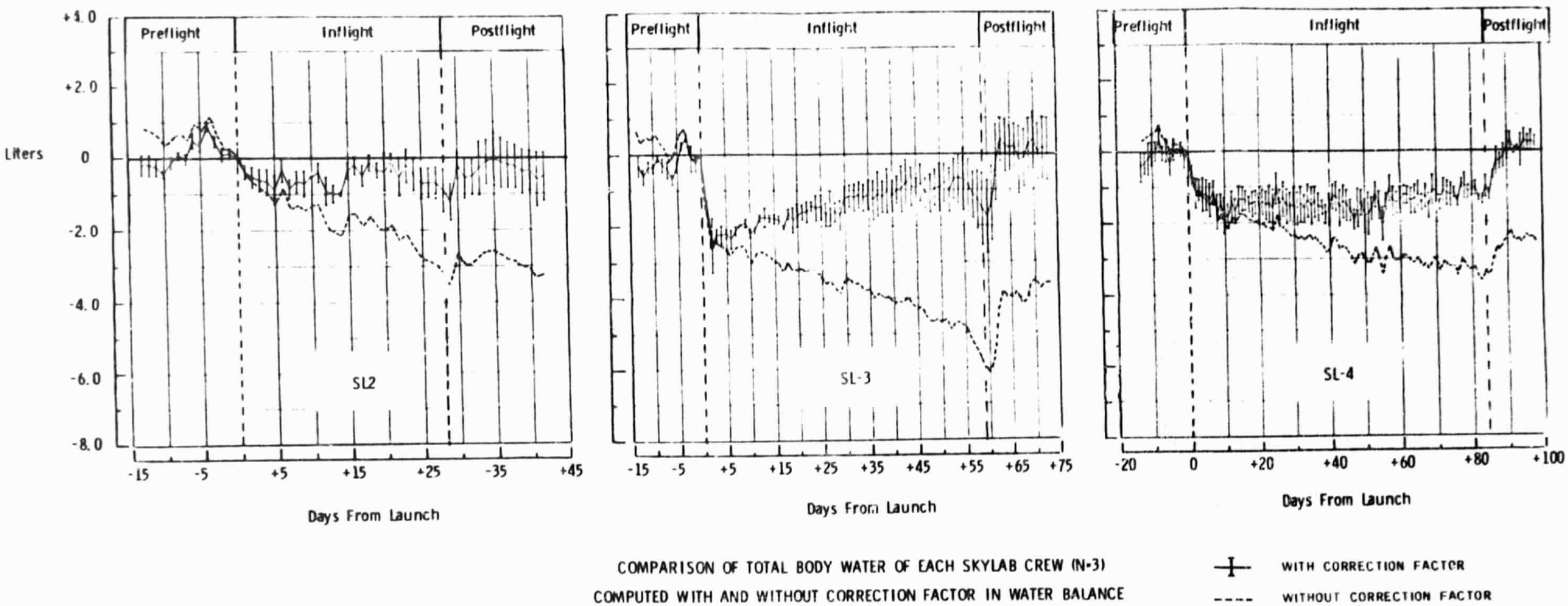
FIGURE 18



CHANGE IN TOTAL BODY WEIGHT DURING ENTIRE MISSION OF EACH SKYLAB CREW (N=3)

(Values are shown as changes from morning of launch)

FIGURE 19



COMPARISON OF TOTAL BODY WATER OF EACH SKYLAB CREW (N=3)
COMPUTED WITH AND WITHOUT CORRECTION FACTOR IN WATER BALANCE

(Values are shown as changes from morning of launch)

FIGURE 20

PARTITIONAL WATER BALANCE FOR EACH SKYLAB MISSION (N=3)

Mean (± SE) Daily Water Balance ml/day	SL-2			SL-3			SL-4		
	Preflight	Inflight	Postflight	Preflight	Inflight	Postflight	Preflight	Inflight	Postflight
INPUT									
Water Ingested (food + drink)	2941 ± 536	2932 ± 533	3140 ± 577	2678 ± 295	2597 ± 302	2794 ± 371	3293 ± 225	2937 ± 227	3389 ± 354
Metabolic Water	340 ± 10	328 ± 5	359 ± 16	368 ± 47	362 ± 67	387 ± 44	351 ± 3	359 ± 5	371 ± 13
OUTPUT									
Urine Volume	1640 ± 563	1702 ± 428	1835 ± 477	1333 ± 116	1356 ± 98	1374 ± 73	1669 ± 161	1672 ± 93	1986 ± 387
Fecal Water	79 ± 8	67 ± 5	18 ± 5	90 ± 25	77 ± 18	64 ± 22	77 ± 26	61 ± 8	70 ± 20
Evaporative Water	1573 ± 82	1522 ± 133	1619 ± 125	1576 ± 272	1552 ± 435	1653 ± 534	1881 ± 274	1575 ± 160	1652 ± 288
NET WATER BALANCE:									
Mean	-9	-32	28	46	-26	90	26	-11	52
SE	± 12	± 22	± 8.84	±19	±17	± 53	±25	± 4	± 8
No. of Days Observed	30	28	14	20	59	17	26	84	18