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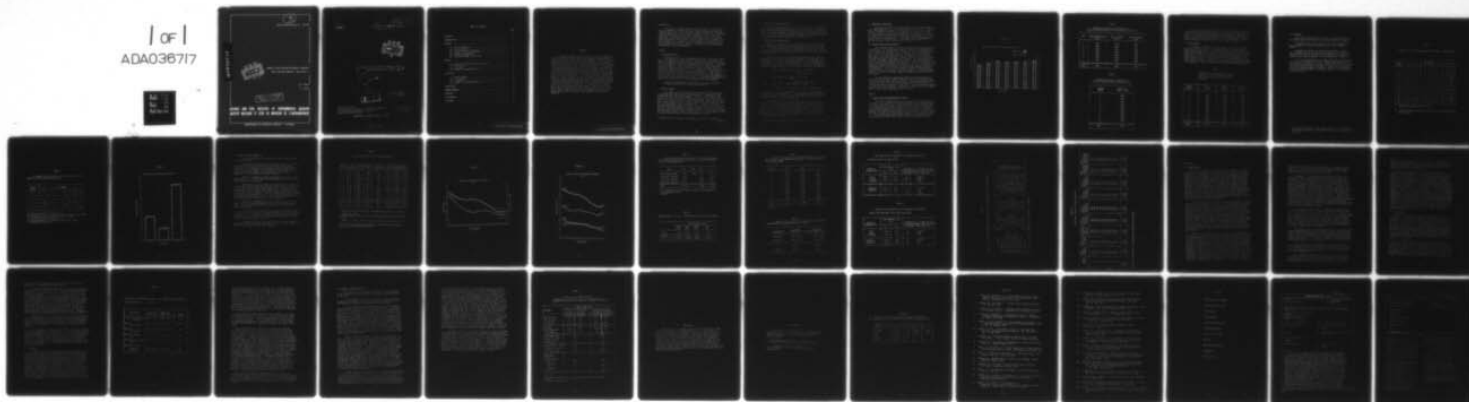
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CHANGES IN BODY COMPOSITION DURING A SIMULATED ARCTIC MILITARY --ETC(U)  
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CHANGES IN BODY COMPOSITION DURING A SIMULATED  
ARCTIC MILITARY EXERCISE: "KOOL STOOL I"

W.J. O'Hara

C.L. Allen

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INSTITUT MILITAIRE ET CIVIL DE MEDECINE DE L'ENVIRONNEMENT

DEPARTMENT OF NATIONAL DEFENCE — CANADA

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W.J./O'Hara  
C.L./Allen

Bioscience Division  
Defence and Civil Institute of Environmental Medicine  
1133 Sheppard Avenue West, P.O. Box 2000  
Downsview, Ontario M3M 3B9

DEPARTMENT OF NATIONAL DEFENCE - CANADA

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#### ABSTRACT

A one week simulated Arctic military exercise was undertaken to observe whether certain physiological changes observed during actual two week military patrols in the Canadian subarctic and Arctic would also occur within a cold climatic facility. Energy balance studies were conducted; predictions of daily energy expenditure were quite similar for both studies, respective values for the actual and simulated studies being 3358 and 3355 kcal/man/day. While the men in the northern study were estimated to be in caloric balance, the infantrymen in the cold chamber had a daily caloric deficit of over 500 kcal, a total experimental imbalance calculated to be equivalent to a 0.5 kg loss of body fat. In the Arctic, 52 men incurred a 38% reduction in mean skinfold thickness, a loss equivalent to a 4.2 kg depletion of mean body fat over two weeks, while in caloric balance. In the one week simulated study, ten Arctic trained infantrymen had a comparable one week skinfold loss of 19%, estimated to be equivalent to a 2.4 kg loss of body fat ... a value 4.5 times greater than predicted from energy balance studies. There were physiological indications that dehydration had developed by the conclusion of the study. There was an 80% daily incidence of ketonuria and unexpectedly 50% of the subjects had glucosuria on one or more occasions.

## INTRODUCTION

Ten Arctic trained infantrymen spent one week in a cold climatic facility, exposed to factors similar to those encountered during long range military patrols in the Canadian subarctic and Arctic. Temperature, workload (back-packing and simulated toboggan pulling), ration and fluid intake were continually monitored to simulate realistic Arctic patrol conditions. Energy and fluid balance was studied daily in conjunction with anthropometric measurements. The body composition variables followed included height, weight, skinfold thickness, skin thickness, body fat, lean body mass and body density as estimated from both underwater weighing and skinfold measurements.

## METHODS

### 1) Energy Expenditure

Predictions of energy expenditure during work in the cold climatic facility at DCIEM\* were made by monitoring heart rate, using ECG telemetry. Two subjects were monitored for the entire week, while the third ECG transmitter was rotated daily between the other subjects. Individual and group values for energy expenditure during the work periods were obtained by converting heart rate values into kilocalories of energy expended as described elsewhere (1). The energy costs of leisure activity and sleep were derived using conventional methods (1). Each 24 hour period (0700 hours to 0700 hours) was divided into three main segments of activity: work, leisure and sleep. Strictly maintained time schedules and observation diaries allowed an exact daily time allotment for each of the three types of activity. The daily energy cost was calculated as:

Daily Energy Expenditure = time spent in each activity (min)  
X metabolic cost of each activity (kcal/min) (2).

### 2) Caloric Intake

Each subject was issued one RP4 ration pack at 0700 hours daily. Each ration pack contains about 3600 kcal, which is comprised of 52% carbohydrate, 32% fat and 16% protein. There are seven different RP4 rations available, each ration being used in turn. The caloric yield of each item in terms of protein, fat and carbohydrate content (the approximate Atwater factors of 4, 9, 4 kcal/g respectively were used) was available in the Canadian Forces nutrition table ... "Caloric Composition: Canadian Combat Ration Pack - RP4-1967". No substitution or accumulation of ration items were permitted. Every evening at 2300 hours all ration packs were collected and unused portions itemized. This procedure allowed the exact daily caloric intake of each subject to be determined, and also the proportions of protein, fat and carbohydrate ingested.

\* Defence and Civil Institute of Environmental Medicine, Downsview,  
Ontario.

### 3) Fluid Balance and Urinalyses

Every morning, each man was given 2 litres of water. Sharing was not allowed, but extra portions were allocated whenever the requirement arose. Flasks were collected at bedtime, and unused water was measured. All urine was also collected, measured for volume and examined microscopically. A standard urinalysis reagent strip was used to detect the presence and concentration of protein, glucose and ketones.

### 4) Changes in Body Composition

Initially, the subjects had their height, weight and four skinfold thicknesses measured by standard techniques as described elsewhere (3, 4). Skinfold and body weight measurements were carried out immediately after arising each morning, skinfold measurements being made on the right hand side by one experienced observer using the same Harpenden skinfold calipers.

The four sites (triceps, subscapular, suprailiac and abdominal skinfolds) were marked with a waterproof marker to increase the reproducibility and accuracy of repeated measurements (4). The abdominal skinfold was not included in skinfold formulae or in any subsequent reference made to the "mean skinfold thickness". Values for skinfold thickness were converted to density and percentage body fat by the formulae:

$$\text{Density} = 1.1447 - 0.0612 (\log_{10} \Sigma 3 \text{ skinfolds})$$

(after Durnin, 5).

$$\text{Percent body fat} = \frac{(4.570 - D)}{D} - 4.142) 100^*$$

(after Brozek et al, 6)

$$\text{Then... Body fat (kg)} = \text{Body weight (kg)} \times \frac{\% \text{ fat}}{100}$$

$$\text{Lean body mass (kg)} = \text{Body weight (kg)} - \text{Body fat (kg)}$$

Changes in body composition were also estimated by underwater weighing (4, 8) on two occasions ... in the morning of Day 1 and again after the experiment ended. Residual lung volumes were determined by a nitrogen dilution rebreathing technique. (7).

Measurements of skin thickness were taken on three separate occasions: before, midway and after the study was completed. At least five successive measurements of skin thickness were taken at each of the four sites applying Harpenden skinfold calipers to the natural fold of the skin on the dorsum of both hands and feet. The smallest value recorded at each site was used to compute individual and group mean values for skin thickness. The object of such measurements was to test whether a state of general dehydration would be reflected by a decrease in skin thickness.

\* This formula was recommended by the International Biological Program.



## 5) Temperature Regulation

During work periods in the cold climatic facility the average ambient temperature was  $-32.7^{\circ}\text{C}$ , ranging from  $-29.9^{\circ}\text{C}$  to  $-37.7^{\circ}\text{C}$ . During lunch, the chamber was warmed to a temperature of about  $-20^{\circ}\text{C}$ . Work schedules in the cold room usually terminated at 1630 hours, at which time the chamber was once again rewarmed to a temperature of  $5.5^{\circ}\text{C}$  for the evening's leisure activities. Each night the men slept on air mattresses in Arctic sleeping bags. The average sleeping temperature in the facility was  $-6.9^{\circ}\text{C}$ , ranging from  $-17.2^{\circ}\text{C}$  to  $-1.7^{\circ}\text{C}$ .

## 6) Exercise Stations and Circuits

The three major modes of activity included walking about the chamber carrying a 22.7 kg back pack, treadmill walking (two electrically driven treadmills) with back pack and riding a bicycle ergometer with no pack. Small daily increments in the slope and speed of the treadmill were made as the experiment progressed in order to maintain exercise heart rates relatively constant. Toboggan pulling, a routine method of transport used during long range Arctic patrols, was simulated by the use of a 7 kg weight, tethered to the subject's waist and supported by a pulley mounted on the back of each treadmill. While on the bicycle ergometer the subject determined his own workload and rate of pedalling, the temperature within the cold facility providing an adequate stimulus to brisk pedalling. The two bicycle ergometer exercise stations were instituted on Day 3 in an attempt to relieve monotony. To provide further variety in the exercise format, jogging (without back pack) was used on Day 5 and 6.

For work scheduling convenience the men were divided into two groups of five men each. Rotation through five exercise stations constituted one exercise circuit for that day. Each day consisted of three to five circuits. The five exercise stations for each group of five subjects were always identical. There was a 5 minute rest period between each exercise station rotation, and either a lunch period or an extended coffee break between each major exercise circuit.

## RESULTS

### 1) Energy Expenditure and Caloric Intake

The caloric intake for each man was monitored very accurately. The mean caloric intake for the ten men appears to have increased abruptly on two occasions: on Day 2, which was the first day of actual work in the cold and again on Day 7 when the men experienced the greatest daily energy expenditure of the experiment. Although the carbohydrate content of the ration pack provided 52% of the energy, the caloric yield from fat and protein on these two days was considerably greater (Figure 1). The estimated daily mean energy expenditure, the measured caloric intake and the resultant daily caloric balance are shown in Table 1.

Figure 1.

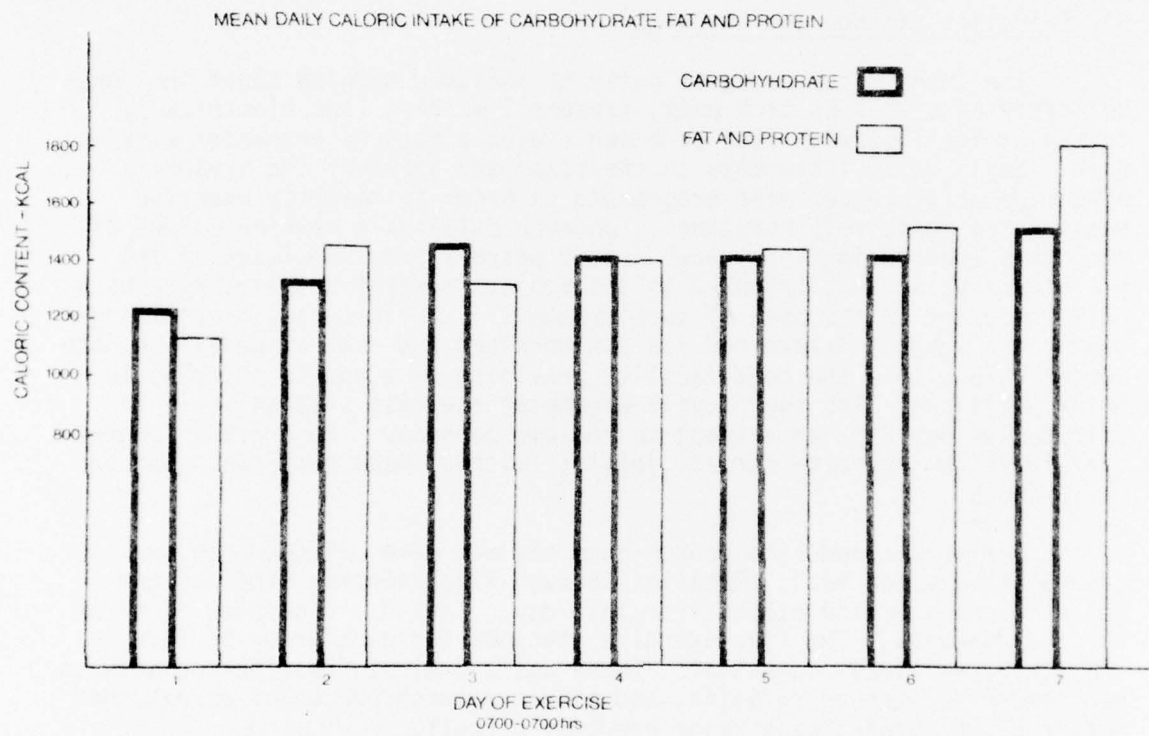


TABLE 1

The Mean Daily Energy Expenditure, Caloric Intake and Energy Balance for the Seven Day Study (N=10)

Day	Energy Expenditure (kcal)	Caloric Intake (kcal)	Caloric Balance (kcal)
1	2761	2370	-391
2	3097	2785	-312
3	3425	2782	-643
4	3610	2818	-792
5	3350	2865	-485
6	3472	2943	-529
7	3771	3313	-458
Mean	3355	2839	-516

TABLE 2

The Mean Daily Caloric Intake (kcal) for Each Subject During the One Week Study

Subject Number	Mean Daily Caloric Intake
1	2986
2	2636
3	2567
4	2890
5	3047
6	2588
7	3065
8	2955
9	2756
10	2905
Mean	2839



In spite of an increasing mean caloric intake during the study, the men were in negative caloric balance throughout the experiment. The extent of the imbalance ranged from -312 kcal on Day 2 to -792 kcal on Day 4. Only on Day 7 was the estimated energy expenditure appreciably greater than the 3600 kcal available in the RP4 ration packs. Table 2 shows the average individual caloric intakes over the study.

## 2) Fluid Balance

Individual differences in fluid intake, urine output and fluid balance are shown in Table 3. A formal analysis of variance (ANOVA) demonstrated a significant ( $p < 0.025$ ) inter-subject variation in the mean daily fluid consumption during the study, with individual values ranging from 1289 ml to 2071 ml. Although the basic fluid ration was set at 2 litres/man/day, subject number five was issued an additional litre of water on Day 6 because of excessive thirst. The ANOVA for fluid intake also indicated a highly significant inter-individual difference ( $p < 0.005$ ) in the amounts of fluid consumed per day over the seven day exercise (1).

TABLE 3

The Mean Daily Fluid Intake (ml), Urine Output (ml) and Resultant Fluid Balance (ml) for Each Subject Over the Seven Day Study

Subject Number	Fluid Intake	Urine Output	Fluid Balance
1	1909	1526	+ 383
2	1714	1292	+ 422
3	1471	746	+ 725
4	1665	1494	+ 171
5	2071	1408	+ 663
6	1289	1036	+ 253
7	1314	1182	+ 132
8	1819	1561	+ 258
9	1683	1455	+ 228
10	1569	1326	+ 243
Mean	1650	1302	+ 348

### 3) Urinalyses

Apart from amorphous debris and calcium oxalate crystals, the microscopic analysis of the urine samples was essentially negative.

Proteinuria was a common finding, all 24 hour samples from Day 2 through Day 7 inclusive demonstrating at least a trace of protein.

Unexpectedly, 50% of the subjects had glucosuria on one or more occasions. During the course of the study, four different subjects exhibited a 3+ glucose\* in their urine, while subject one demonstrated a similar reaction on five different days (Table 5).

Ketonuria was absent on Day 1, when the men were not subjected to exercise in the cold. All of the subjects showed ketonuria at some subsequent time during the study. During the remaining six days, the subjects exercised for an average of 4.8 hours/day in the cold, with an 80% daily incidence of ketonuria. Almost 50% of the positive tests were seen post-exercise, during the evening's leisure period (Table 4, Fig. 2).

\* The manufacturer (Ames) of this standard urinalysis reagent strip quotes that a value of 3+ represents a value > 500 mg glucose/100 ml of urine.

TABLE 4

The Number\* of Positive Ketonuria Tests Per Day in Each Subject.

Subject Number	DAY NUMBER					
	2	3	4	5	6	7
1	0	1	3	3	1	2
2	1	1	0	0	2	2
3	0	2	0	1	2	1**
4	1	1	1	0	0	3
5	2	2	1	3	4	2
6	1	2	3	3	1	1
7	1	1	2	0	0	1
8	1	1	2	1	2	2
9	1	2	2	0	0	0**
10	1	3	4	4	4	5

\* There were no positive tests on Day 1

\*\* These two subjects could not void for the final urine collection at 0700 hours.

TABLE 5

The Number<sup>\*</sup> of Positive Glucosuria Tests Per Day in Five Subjects, With Indicated Concentrations. +

Subject Number	DAY NUMBER					
	2	3	4	5	6	7
1		3+		3+	1+, 3+	3+
2				3+		
5	3+	1+			3+	
6	2+			3+		
9						2+

\* There were no positive tests on Day 1.

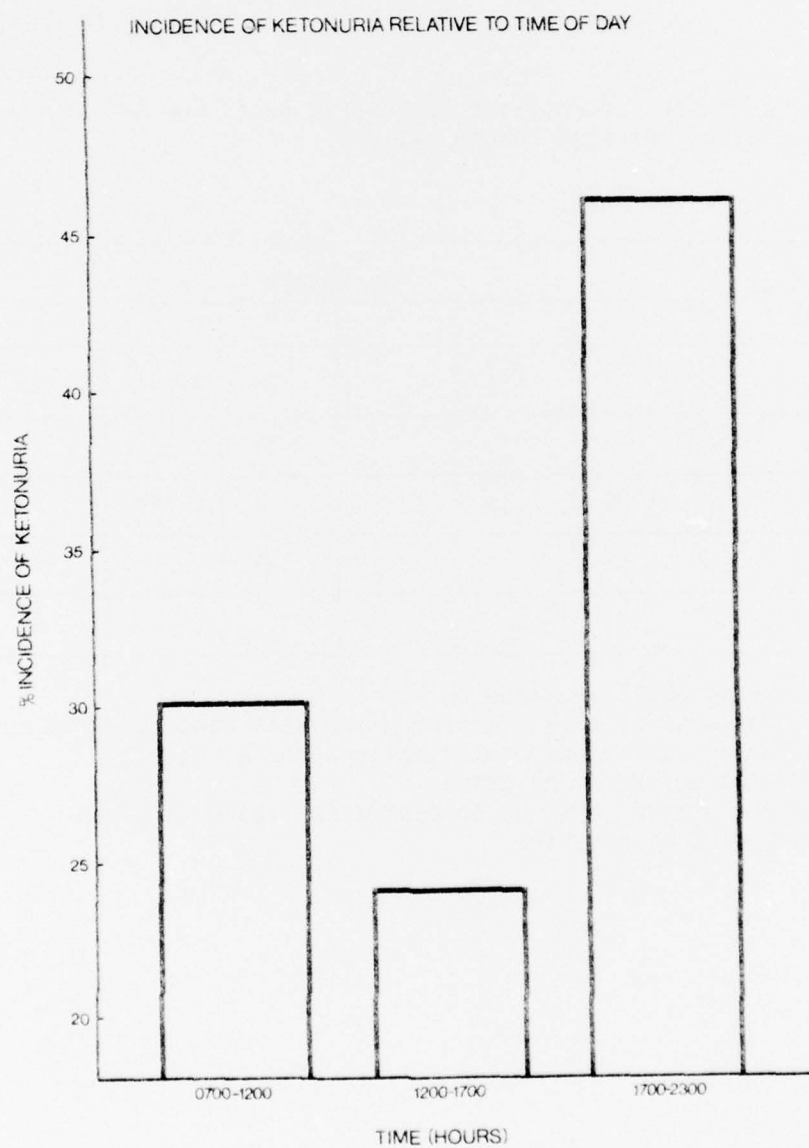
+The manufacturer of this standard urinalysis reagent strip quotes the following equivalent concentrations for glucose:

1+: 100 -250 mg/100 ml of urine

2+: Glucose present, but no concentration value is given

3+: >500 mg/100 ml of urine

Figure 2.





#### 4) Changes in Body Composition

The initial physical characteristics of the ten participants are shown in Table 6.

Anthropometric measurements were repeated after the study had terminated. At this time the men had lost 2.6 kg of body weight ( $p < 0.001$ ) and sustained a 2.6 mm reduction in mean skinfold thickness ( $p < 0.005$ ). This represented a 3.25% decrease in body weight and a 19.1% diminution of mean skinfold thickness. Daily changes in body weight and skinfold thickness are shown in Figure 3.

Abdominal skinfold sites were also measured each day. Losses ranged from 13.5% for the triceps skinfold measurement to a 25.4% loss at the abdominal site (Fig. 4).

Measurements of skin thickness folds were taken at four sites on each subject before and after the study, while the fold on the dorsum of the right hand was also measured midway through the experiment on the morning of Day 4. Since a skin thickness fold includes two layers of skin, then the skin thickness changes in absolute terms will be about 50% of the recorded fold value. These results are summarized in Table 7 and analyzed statistically in Table 8. The individual measurements for the mean value of all four sites are shown in Table 9.

Measurements of body density were taken before and after the seven day study using both underwater weighing and skinfold measurements. Table 10 gives a statistical evaluation of the changes indicated by each method.

The total body fat content of the subjects was computed before and after the trial, using both underwater weighing results and skinfold measurements. A comparison of the changes indicated by the two methods is made in Table 11. Similarly, estimations of lean body mass (LBM) by both methods are shown in Table 12.

A summary and a statistical analysis of the average changes in body composition for the group are shown in Table 13, while Table 14 outlines the changes for individual subjects.

TABLE 6

## Initial Characteristics of the Ten Subjects

Subject number	Age (years)	Height (cm)	Weight (kg)	Mean skin-† fold (mm)	BSA* (m <sup>2</sup> )	Body Density**	
						Skinfold/Water	
1	20	171	95.6	26.9	2.1	1.028	1.036
2	19	175.5	71.2	6.8	1.9	1.065	1.073
3	21	178.4	86.2	13.5	2.0	1.046	1.046
4	19	176.3	72.1	7.5	1.9	1.062	1.077
5	19	166.3	64.7	7.9	1.7	1.060	1.069
6	20	184	77.3	9.4	2.0	1.056	1.073
7	21	181	79.6	14.4	2.0	1.045	1.062
8	20	185.3	91.1	20.2	2.1	1.036	1.059
9	19	181.5	73.8	13.0	1.9	1.047	1.058
10	33	178	98.2	17.0	2.2	1.040	1.041
Mean	21.1	177.7	81.0	13.7	2.0	1.049	1.059
±SD	4.3	5.8	11.3	6.4	0.13	0.012	0.014

† Average value of the triceps, subscapular and suprailiac skinfolds.

\* Body surface area.

\*\* Body density was estimated from skinfold thickness according to the formula:

$$\text{Density} = 1.1447 - 0.0612 (\log_{10} \Sigma 3 \text{ skinfolds}) \text{ (after Durnin, 67).}$$

Body density from underwater weighing was determined using standard techniques described elsewhere (6,8).



Figure 3.

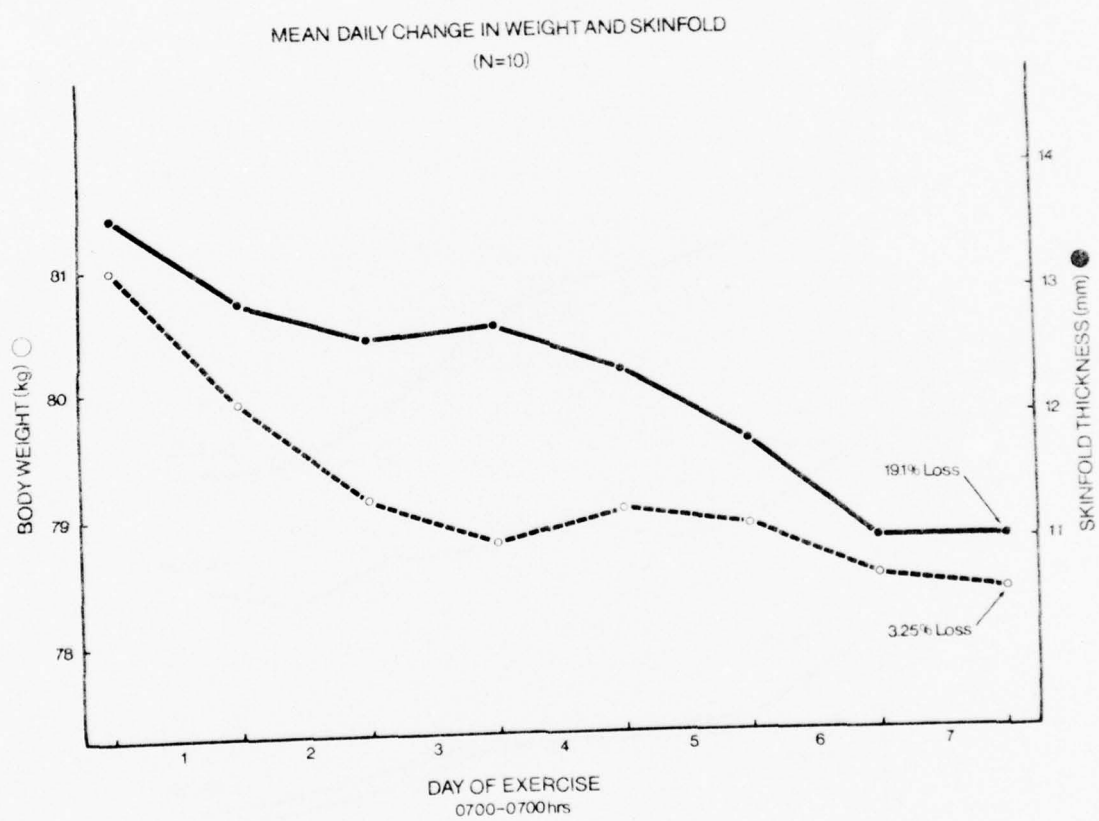


Figure 4.

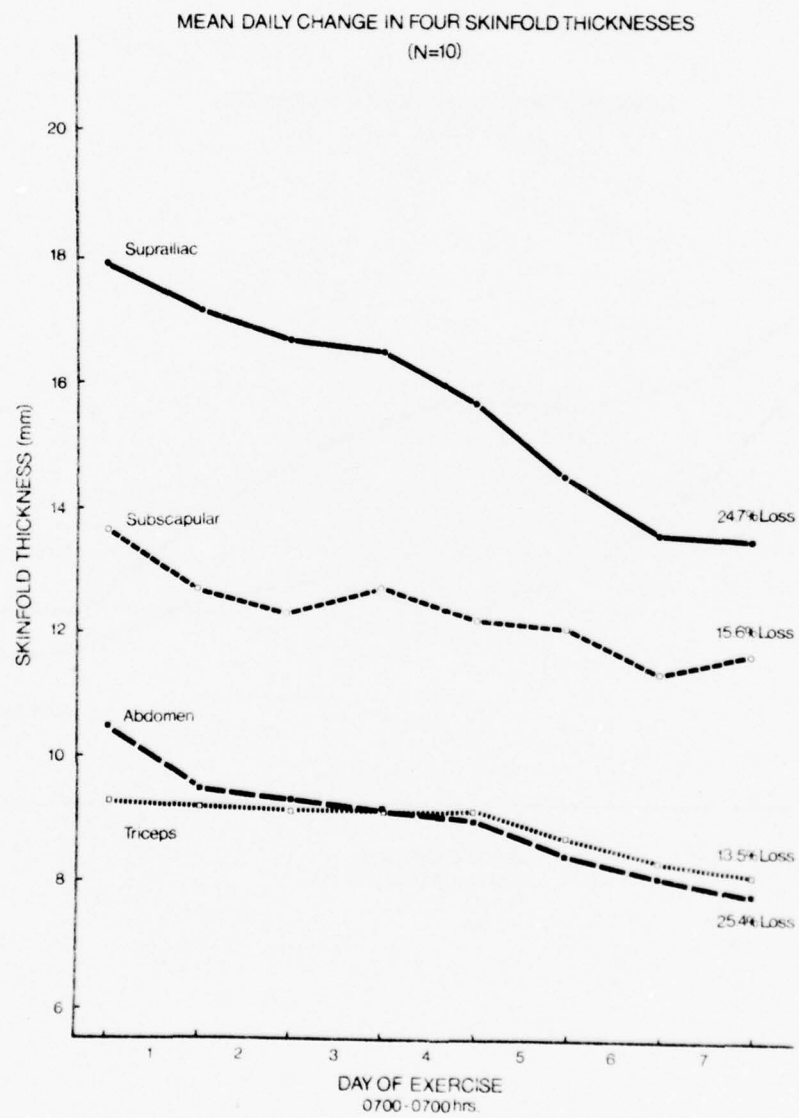


TABLE 7

Mean Values and Percent Changes (%  $\Delta$ ) for Skin Thickness Folds\* (mm) Measured Before (Pre) During (Mid) and After (Post) the Seven Day Study (N=10).

Site	Pre	Mid	Post	% $\Delta$
Right hand (dorsum)	3.09	2.92	2.90	- 6.2
Left hand (dorsum)	3.16		2.91	- 7.9
Right foot (dorsum)	2.85		2.46	-13.7
Left foot (dorsum)	2.78		2.47	-11.2
Mean	2.970		2.685	- 9.6†

\* The thickness of a single layer of skin will be about 50% of the value for a fold.

†  $p < 0.001$

TABLE 8

Mean Changes ( $\Delta$ ) In Each of the Four Skin Thickness Folds (N=10).

	Skin Thickness Site			
	Right Hand	Left Hand	Right Foot	Left Foot
$\Delta$ (mm)	-0.19	-0.25	-0.39	-0.31
t value	2.53	2.79	6.88	5.89
p	<0.05	<0.025	<0.001	<0.001

TABLE 9

Individual Average Values and Percent Changes (%  $\Delta$ ) In Four Skin Thickness Folds (mm) Measured Before (Pre) and After (Post) The Seven Day Study.

Subject	Pre	Post	% $\Delta$
1	3.05	2.70	-11.5
2	2.93	2.55	-12.8
3	3.13	3.00	- 4.0
4	2.58	2.38	- 7.8
5	3.18	2.80	-11.8
6	3.20	2.90	- 9.4
7	2.85	2.68	- 6.1
8	3.08	2.83	- 8.1
9	2.83	2.70	- 4.4
10	2.90	2.33	-19.8
Mean	2.970	2.685	- 9.6 +

+  $p < 0.001$

TABLE 10

A comparison of Body Density Values Derived from Skinfold Measurements and Underwater Weighing. (N=10)

MEASUREMENT	SKINFOLD (MEAN DENSITY $\pm$ SD)	UNDERWATER (MEAN DENSITY $\pm$ SD)
Pre-Trial	1.049 (0.012)	1.059 (0.014)
Post-Trial	1.054 (0.012)	1.065 (0.014)
$\Delta$	+0.005	+0.006
P Value	<0.001	<0.001

TABLE 11

Total Body Fat (kg) Computed by Two Methods Before (Pre)  
and After (Post) the Study (N=10).

Method of Determination	Total Body Fat (kg) ( $\pm$ SE)		Differences ( $\Delta$ ) Between Pre and Post Measurements ( $\pm$ SD) and Their Statistical Significance (p)	
	Pre	Post		
Sum of Three Skinfolts	18.0 (2.0)	15.7 (1.8)	$\Delta$ $\pm$ SD P	-2.35 kg $\pm$ 0.29 <0.001
Underwater Weighing	14.5 (2.1)	12.1 (2.0)	$\Delta$ $\pm$ SD P	-2.35 kg $\pm$ 0.39 <0.001

TABLE 12

Changes in Lean Body Mass (kg) Computed by Two Methods  
Before (Pre) and After (Post) the Study (N=10).

Method of Determination	Lean Body Mass (kg) ( $\pm$ SE)		Differences ( $\Delta$ ) Between Pre and Post Measurements ( $\pm$ SD) and Their Statistical Significance (P)	
	Pre	Post		
Sum of Three Skinfolts	63.0 (1.8)	62.7 (1.9)	$\Delta$ $\pm$ SD P	-0.28 kg $\pm$ 0.25 NS
Underwater Weighing	66.5 (1.8)	66.2 (2.0)	$\Delta$ $\pm$ SD P	-0.28 kg $\pm$ 0.35 NS

TABLE 13

Differences ( $\Delta$ ) Between Initial (Pre) and Final (Post) Body Composition Values (N=10).

Measurement	Pre ( $\pm$ SE)	Post ( $\pm$ SE)	$\Delta$ ( $\pm$ SD)	t	p
Body Weight (kg)	81.0 (3.6)	78.4 (3.5)	-2.6 (0.15)	17.21	<0.001
Mean Skinfold* (mm)	13.7 (2.0)	11.1 (1.5)	-2.6 (0.60)	4.34	<0.005
Skin Thickness Fold (mm)	3.0 (.06)	2.7 (.07)	-0.3 (0.04)	6.44	<0.001
Body Density (skinfold)	1.049 (.004)	1.054 (.004)	+0.005 (.001)	10.70	<0.001
Body Density (water)	1.059 (.005)	1.065 (.005)	+0.006 (.001)	6.47	<0.001
Body Fat (skinfold; kg)	18.0 (2.0)	15.7 (1.8)	-2.35 (0.29)	8.04	<0.001
Body Fat (water; kg)	14.5 (2.1)	12.1 (2.0)	-2.35 (0.39)	6.09	<0.001
LBM (skinfold; kg)	63.0 (1.8)	62.7 (1.9)	-0.28 (0.25)	1.12	NS
LBM (water; kg)	66.5 (1.8)	66.2 (2.0)	-0.28 (0.35)	0.80	NS

\* Mean value for triceps, subscapular and suprailiac skinfolds.



TABLE 14  
Individual Changes in Body Composition

Subject Number	Body Weight Loss (kg)	Mean Skinfold Loss (mm)	Mean Skin Fold Loss (mm)	Density Increase (Skinfold Estimate)	Density Increase (Hydrostatic Estimate)	Fat Loss (kg) (Skinfold Estimate)	Fat Loss (kg) (Hydrostatic Estimate)	LBM Change (kg) (Skinfold Estimate)	LBM Change (kg) (Hydrostatic Estimate)
1	3.1	6.9	0.35	.008	.004	4.1	2.4	+1.0	-0.7
2	2.6	1.5	0.38	.006	.004	2.2	1.4	-0.4	-1.2
3	2.8	1.4	0.13	.003	.004	1.7	2.0	-1.1	-0.8
4	3.3	1.5	0.20	.006	.008	2.1	2.5	-1.2	-0.8
5	2.2	1.3	0.38	.005	.006	1.6	1.8	-0.6	-0.4
6	2.1	1.4	0.30	.004	.008	1.7	2.6	-0.4	+0.5
7	2.8	2.1	0.18	.004	.003	2.0	1.4	-0.8	-1.4
8	2.2	4.5	0.25	.006	.003	3.1	1.5	+0.9	-0.7
9	2.0	1.5	0.13	.004	.007	1.4	2.4	-0.6	+0.4
10	3.2	3.9	0.58	.007	.012	3.6	5.6	+0.4	+2.4
Mean ( $\pm$ SD)	2.63 (0.15)	2.61 (0.60)	0.28 (0.04)	.005 (.001)	.006 (.001)	2.35 (0.29)	2.35 (0.39)	-0.28 (0.25)	-0.28 (0.35)

\* Mean value for triceps, subscapular and suprailiac skinfolds



## DISCUSSION

### 1) Energy Balance

The most likely source of error in the energy balance study would include the measurement of caloric intake and the prediction of energy expenditure. The availability of detailed nutrition tables containing the precise caloric amounts of protein, fat and carbohydrate for every item in all seven RP4 ration packs enabled an exact measurement to be made, not only of ration wastage, but of the total nutritional composition of all food ingested by the men throughout the study. Sharing or accumulation of ration items, if it occurred at all, would only alter individual or daily assessments, but it would not affect the overall mean daily caloric intake, which was the measure of energy consumption used in the balance study. Pulse predictions of oxygen consumption have an accuracy within 5% to 10% (12). The mean daily energy expenditure determined from telemetered heart rates of seven subjects during scheduled work periods was 1691 kcal. Over the course of six days a 10% error could result in an additional expenditure of 1015 kcal, or an equivalent fat loss of only 0.15 kg per man.

There was a significant difference in energy expenditure shown by subject five, the shortest of the group. His energy expenditure, as predicted from heart rate, was significantly greater than all of the other subjects monitored during cold work schedules (1). Energy balance studies set his deficit for seven days at 4,993 kcal, or in terms of body composition an expected fat loss of 0.7 kg. Skinfold measurements and underwater weighing place his fat loss at 1.6 kg and 1.8 kg...these respective values being 2.2 and 2.5 times greater than anticipated from conventional energy balance methods. Telemetry monitoring was also done on subject one, the "fattest" of the group, who incurred the greatest loss of body fat and diminution in skinfold thickness. Energy balance figures for this individual set his total deficit at 2582 kcal, which is equivalent to a 0.4 kg loss of body fat. The 7 mm reduction in his mean skinfold thickness, however, was equivalent to a 4.1 kg reduction in body fat, a value eleven times greater than the energy balance figures.

LeBlanc (ref. 30, 1957) states that surveys of food consumption during northern military exercises "always overestimate the food consumed ...by approximately 10%" and this was "due to the fact that it is impossible to collect plate waste". LeBlanc does not substantiate how he arrived at a figure of 10%, but lack of refuse collection on the trail would seem to be the most likely reason. The attitude of local government and civilian agencies about pollution in the Canadian north instigated the implementation of a strict pollution control program by the Commanding Officer, "Exercise New Viking" on 1 April, 1970. It was estimated that the collected refuse from RP4 rations during New Viking exercises from 1 September 1971 to 1 September 1972 weighed 35.7 tons. Since the inception of this program, all refuse has been collected daily in "bags plastic garbage" from each tent group, and returned by vehicle to the "Training Headquarters" in Churchill, or, in the case of remote areas, to the "Main Exercise Headquarters". The 3400 kcal estimate of

food consumption based on plate wastage during the "New Viking 1973" exercise (3), which the present study was meant to simulate, would have certainly been a more realistic value than the earlier food surveys where no pollution control was in effect.

Measurements of energy expenditure and caloric intake indicated the men were in negative energy balance for each day of the experiment. The estimated mean daily caloric deficits ranged from 312 kcal on Day 2, to a 792 kcal deficit on the fourth day of the study. There was both adequate leisure time and sufficient rations available to establish a positive caloric balance ... the 761 kcal daily plate wastage could have erased the overall mean daily caloric deficit of 516 kcal. Although there was no significant inter-subject difference in caloric intake, the apparent trend of an increasing caloric intake during the course of the study was significant at the 5% level (by a formal analysis of variance, ref. 1). When the experiment terminated the men had accumulated a 3610 kcal deficit, equivalent to one complete daily ration pack, or in terms of body composition a half kg loss of body fat. Anthropometric measurements not only confirmed that a loss had occurred, but indicated a fat depletion four and one-half times greater than this ... 2.35 kg ( $p < 0.001$  by both skin-fold techniques and underwater weighing).

Energy balance studies show a quantitative difference between the caloric intake during cold chamber experiments and actual Polar trials. During the two week northern military trial ... "New Viking 73", which the present study was meant to simulate, ration wastage was about 200 kcal/man/day out of the 3600 kcal available in the daily ration pack. Identical rations were used in the present study. The daily wastage of 761 kcal/man in the cold chamber was considerably greater than in the northern study, especially since the men in the cold facility had a caloric deficit each day, while the northern infantrymen maintained an approximate caloric balance.

During the ten days of northern patrol activities the mean daily energy expenditure was estimated at 3484 kcal, thus a cumulative daily deficit of about 84 kcal/man/day would have developed with a 3400 kcal intake. However, during the four days of bivouac, the caloric intake remained high in spite of the greatly reduced daily energy expenditure (2698 kcal/man/day, ref. 3) so that by the end of the two week exercise the men were in positive caloric balance.

Similar observations were made by A.L. Muir (10) during four winter sledging journeys in the Antarctic; the mean caloric intake at the station was 3,700 kcal per day, while "in the field virtually all of the men consumed all of their sledging rations (4,300 kcal) with very little plate wastage" (11).

In the present simulated patrol, the mean caloric intake was only 2839 kcal per day despite access to 3600 kcal. The estimated mean deficit was thus 516 kcal per day. A somewhat similar lack of energy balance was observed when six obese subjects exercised in a

climatic chamber at  $-34^{\circ}\text{C}$ , 3.5 hours per day for ten consecutive days while on an unrestricted caloric intake (4). The mean daily energy expenditure of the obese subjects was estimated at 3381 kcal, while the mean caloric intake was only 1975 kcal, resulting in an average daily deficit of 1406 kcal/man.

One factor which may make an important difference to the number of calories consumed in the chamber and in the Arctic is the amount of time "available" for the preparation and eating of foods. During the "New Viking 73" trial, a time and motion survey and observation diaries showed that the infantrymen had an average of 11.4 hours available each day for eating and leisure activities (3). During "leisure periods", entertainment and recreational distractions were essentially non-existent. Even magazines encroached upon the load carrying capacity of the individual. The long hours of darkness and of "leisure activity" provided the men with ample opportunity to indulge in one of the few comforts available ... eating. In the cold climatic facility recreation and entertainment took up a considerable proportion of "leisure activity" time; there was access to TV, radio, cards, reading material and evening films; friends and relatives were allowed visits, and the soldiers were constantly exposed to the various news media. The six obese subjects continued with their normal life style after departing from the chamber. Thus "availability of time" to eat without distraction apparently accounts for the greater caloric consumption observed during actual northern exercises ... "Our total food intake is determined more by what stops us eating than by what starts us" (28).

## 2) Fluid Balance

A complete fluid balance study was not undertaken in this experiment ... and therefore one can only speculate on the status of hydration of the subjects. Nevertheless, there were indications that some degree of water depletion was present by the conclusion of the study. There was a highly significant decrease in the mean skin thickness fold ( $p < 0.001$ ) by the end of the experiment. Skin thickness measurements normally vary from 0.8 mm over the chest to 2.1 mm on the back, with intermediate values for the arm, abdomen and thigh (13). If fluid loss was responsible for the observed 10% reduction in mean skin thickness, then an initial average skin thickness of 1.5 mm (approximated from 0.8 and 2.1 mm) spread over a BSA of  $2.0 \text{ m}^2$  (average value for the ten subjects) would represent a 300 ml fluid loss from the skin alone.

It was estimated that the men had an average daily caloric deficit of 516 kcal, or a total experimental imbalance of -3610 kcal. If the stores of body glycogen are exhausted, about 1650 ml of water are released (the hydration and combustion of each gram of body glycogen releases about 2.7 and 0.6 ml respectively, ref. 12), effectively dissipating more than 50% of the resultant heat production (12). Thus exercise alone tends to produce an intracellular fluid loss, while a plasma or extracellular form of dehydration occurs as a response to

heat stress alone. Sweating, which was largely avoided during this experiment, is a manifestation of heat stress.

Intracellular dehydration may affect the muscle's tolerance to an accumulation of metabolites or even alter the biochemical processes involved in muscular contraction (12). Some previous studies have shown a small decrease (less than 10%) in maximum isometric strength after dehydration (12). Our ten subjects demonstrated a small loss of isometric knee extension strength and of hand grip strength (Table 15) immediately after the cold trial, before there had been any opportunity to rehydrate or replenish glycogen stores. Similarly, there was no significant improvement in the bicycle ergometer evaluation of aerobic power (neither absolute nor relative values) despite the specificity of the training undertaken (3 1/4 hours of pedalling the bicycle ergometer) and the positive effect a 2.6 kg loss of body weight should have had upon the relative aerobic power. Unexpectedly, even the pulmonary function values were less than initially (Table 15).

Anthropometric tests (both skinfold measurements and underwater weighing) demonstrated a 0.28 kg reduction of LBM after the cold exposure. The LBM loss was not statistically significant for the group as a whole, but the five subjects with the least incidence of ketonuria showed a 1.3% mean reduction in LBM which was significant ( $p < 0.01$ , Table 16).

"As an athlete's voluntary intake of fluid often fails to match his rate of dehydration, so do normal men exposed to both cold climatic chambers and subarctic field experiments" (1). Lennquist (14) observed that even moderate cold conditions within the strictly standardized environment of a cold climatic chamber, resulted in a negative water balance and a reduced capacity for physical work. Cold exposure in the field (15) results in a strongly negative water balance which apparently cannot be prevented ... increasing the fluid intake only leads to a greater diuresis.

### 3) Urinalyses

A total of 12 urine samples were positive for glucose over the one week trial. During the northern trial "New Viking 73" (3) only one test was strongly positive for glucose out of a total of 50 urinalyses conducted. Subject one from the simulated patrol (who demonstrated four 3+ glucose readings) and the one case of glucosuria from the northern trial were investigated medically with negative results. The etiology of the glucosuria is obscure, but two possible contributing factors could be acetone specifically and the ketone bodies generally. Blood acetone, quantitatively, has continued to be considered a minor ketone body (16) in spite of the fact that blood acetone is difficult to measure and blood-levels have rarely been estimated (16). However, in severe ketonemia, acetone may constitute a significant fraction of total ketones (17). The body acts as a reservoir for acetone because it is strongly hydrophilic and lipophilic; because of its limited metabolism large amounts of acetone can accumulate and



TABLE 15

Lung Function, Strength and Aerobic Power, Measured Before and After  
the Seven Day Trial (N = 10)

MEASUREMENT	PRE-TRIAL MEAN ( $\pm$ SE)	POST-TRIAL MEAN ( $\pm$ SE)	P VALUES
Forced Vital Capacity (Liters)	4.95 (0.18)	4.87 (0.16)	NS
FEV 1.0 (Liters/sec)	4.02 (0.16)	3.94 (0.16)	p<0.01
Peak Flow (Liters/min)	587.8 (18.3)	577.5 (17.7)	NS
Hand Grip Strength (kg)	52.7 (1.4)	52.2 (1.7)	NS
Knee Extension Strength (kg)	58.7 (1.5)	57.8 (2.5)	NS
Predicted $\dot{V} O_2$ Max. ml/kg/min	46.7 (2.2)	49.8 (2.4)	NS
Liters/min	3.74 (0.18)	3.86 (0.18)	NS

in its slow elimination, acetone resembles such anaesthetic agents as ether and methoxyflurane (16). The formation of acetone from acetoacetate during ketoacidosis has been suggested as an additional means of buffering the associated acidosis (16). Acetone has a relatively low toxicity ... the principal toxic effect is upon the central nervous system where high doses produce narcosis (18). Acetone accumulation produces disturbances of renal function and carbohydrate tolerance (18, 19), possibly contributing thus to the multiple occurrences of glucosuria observed in the present study. The ketone bodies are oxidized by extrahepatic tissues in proportion to their blood concentrations (20), being oxidized in preference to glucose (21). Ten of the 12 positive tests for glucosuria were observed in the five subjects with the greatest incidence of ketonuria (Table 16).

Ninety three urine samples were positive for ketones. All three ketone bodies are excreted in the urine; however, the standard reagent strip method used in this study only detected acetoacetic acid and to a lesser degree, acetone. Since 3-hydroxybutyrate is quantitatively the predominant ketone body in the blood and urine (21), our method probably underestimated the frequency and intensity of ketosis considerably.

Almost 50% of the positive tests for ketonuria were observed during the evening's leisure activity period (Figure 2). Free fatty acids (FFA) which are the precursors of ketone bodies are mobilized from fat depots by a variety of stimuli including cold (22, 23) and exercise (24, 25). FFA once mobilized have two possible major pathways of degradation ... oxidation by the citric acid cycle or the formation of ketone bodies (21). Once formed, ketones are oxidized by extrahepatic tissues in preference to FFA, and even glucose (21). When the blood ketone concentration reaches approximately 70 mg/100 ml, as much as 90% of the oxygen consumption can be attributed to the oxidation of ketone bodies (21). During exercise, the plasma concentration of FFA remains just above fasting levels (25), while after exercise there is a dramatic increase in the plasma FFA concentration (24). This post-exercise augmentation of FFA should be much greater in subjects with ketosis since the FFA formed during exercise would not be adequately utilized in the presence of ketone bodies ... a preferential fuel! Thus a plethora of FFA occurs post exercise ... and as the blood level increases, there is a disproportionate increase in the conversion of FFA to ketones with relatively little oxidation via the Krebs cycle (21). When the blood ketone concentration exceeds about 70 mg/100 ml, the oxidative machinery becomes saturated and any further increase in ketogenesis not only rapidly elevates the blood ketone concentration, but also increases their excretion in the urine (20, 26).

An analysis of variance was conducted on the total number of positive tests for ketonuria in each of the ten subjects over the course of the study (Appendix A). There was a significant inter-subject variation in the incidence of ketonuria ( $P < 0.05$ ). The trend to an increasing number of positive tests as the study progressed was also significant ( $P < 0.025$ ).

#### 4) Changes in Body Composition

The 2.35 kg loss of body fat combined with 0.28 kg reduction in LBM, resulting in a 2.63 kg loss of mean body weight by the end of the study.

The estimated 0.3 kg (300 ml) fluid loss from the skin would account for the entire 0.3 kg loss of LBM predicted from both skin-fold conversion techniques and underwater weighing results.

It is unlikely that muscle protein was used as an endogenous source of energy to meet the mounting caloric deficit. In most countries, 9-13% of the food energy is provided by dietary protein (27). The usage of carbohydrate, fat and protein from the rations was estimated at 1401 kcal, 958 kcal and 480 kcal respectively (Fig. 1). The 480 kcal (120 g) of potential food energy derived from protein would provide 17% of the average daily food energy. During starvation, the same proportion of the energy as in a normal diet is usually derived from protein (28). A 65 kg man contains about 10 kg of protein, and 3% of this, 300 g, is available as a labile reserve (29) ... a reserve which is utilized before significant tissue destruction or wasting of skeletal muscles occur (28). This reserve is carried in the cytoplasm of cells of all organs, but probably mainly in the liver (28). Accordingly, our subjects with a mean body weight of 81 kg, would have had a labile reserve of about 375 g.

The ten subjects sustained a 516 kcal deficit for each of 7 days. Initially, most of the glycogen stores are expended (28). For the last 4 days, therefore, the 516 kcal daily deficit would be met from body protein and fat stores. About 17% of the daily deficit should be derived from the labile protein reserve ... 88 kcal or 22 g of protein daily for 4 days. "To provide the remainder of the energy needed by a starving man, ... fat has to be withdrawn from the stores daily" (28); at 7 kcal/g of body fat, this would amount to 61 g of fat daily for 4 days. Not all the fat in the body can be used for energy; there is a requirement for 2 or 3 kg to remain as part of essential cell structures (28). Our estimated body fat loss was much greater than 244 g. Nevertheless, the total of 2.35 kg, still left the average subject with 12 kg of body fat (Table 11) ... 9 to 10 kg available as an energy reserve. The estimated daily loss of 22 g of protein for 4 days would deplete the 375 g labile reserve by only 88 g, leaving adequate protein and fat stores for almost another two weeks at the same daily deficit before significant tissue destruction or skeletal muscle wasting would occur.

Seventy percent or 65 positive tests for ketonuria were observed in five subjects (numbers 1,5,6,8, and 10). The group of five men with the greatest incidence of ketonuria was compared with the others in terms of initial body composition and changes that occurred over the study (Table 16). The group exhibiting frequent ketonuria had a greater initial body weight, with substantially larger LBM and fat components than the other five men. While the absolute body weight loss (2.6 and



2.7 kg respectively) was quite similar for both groups, the reduction in mean skinfold thickness and body fat loss were considerably greater for the group with frequent ketonuria (3.6 mm vs 1.6 mm and 2.8 kg vs 1.9 kg respectively). In terms of relative fat loss, however, the two groups were very similar, both demonstrating a 14% loss by skinfold determinations and an 18% loss by underwater estimations (Table 16). A higher incidence of ketonuria occurring in conjunction with a greater loss of body fat was also observed in the cold chamber study involving six obese subjects (4). Over the course of 10 days the greatest incidence of ketonuria was found in the heavier and more obese subjects who tended to a greater total loss of body fat than the lighter and "leaner" subjects (respective fat losses of 5.1 kg and 4.5 kg). Both studies suggest that heavier men with a greater amount of body fat experience a greater incidence of ketonuria ... resulting in a greater loss of total body fat than "leaner" subjects when they work or exercise in the cold under similar circumstances. During the "New Viking 73" exercise a representative tent group (Group 1) demonstrated an 82% incidence of ketonuria (3). When the six individual tent groups were compared on the basis of body composition, it was observed that the three tent groups (Groups 3, 5 and 6) with the greatest initial amount of body fat and thickest skinfolds also incurred the greatest reduction in both of these measurements by the end of the long range patrol activities (3).

The main objective of the present study was to ascertain whether infantrymen working in a simulated Arctic environment would demonstrate comparable losses in body fat to those observed in 52 infantrymen during an actual Arctic military exercise (3). Over one week of simulated Arctic conditions, there was a 19% reduction in the mean skinfold thickness, equivalent to a 2.4 kg loss of body fat ... while in the northern study the equivalent values were 38% and 4.2 kg respectively over two weeks of activity. The men in the chamber lost 4.5 times more body fat than anticipated from energy balance determinations, while the 4.2 kg loss of body fat observed in the northern study was also completely unexpected ... since the subjects were in caloric balance.

TABLE 16

A Comparison of Observations on  
Two Groups of Five Subjects Each: The Group with the  
Greatest and the Group with the Least Incidence of Ketonuria

VARIABLE	Mean Values (N=5)			
	Group** with the Greatest Incidence of Ketonuria		Group with the Least Incidence of Ketonuria	
	Skinfold	Underwater	Skinfold	Underwater
Body Fat (kg)	20.7	16.7	15.3	12.2
Fat Loss (kg)	2.8	2.8	1.9	1.9
% Fat Loss	13.5	18.2	13.5	18.1
LBM (kg)	64.7	68.7	61.3	64.4
LBM Change (kg)	+ 0.25	+ 0.2	- 0.81*	- 0.8
% LBM Change	+ 0.3	+ 0.2	- 1.3	- 1.2
Body Weight (kg)	85.4		76.6	
Weight Loss (kg)	2.6		2.7	
% Weight Loss	3.0		3.5	
Mean Skinfold + (mm)	16.3		11.0	
Skinfold Loss (mm)	3.6		1.6	
% Skinfold Loss	22.2		14.6	
Mean Daily Values For:				
Caloric Intake (kcal)	2896		2783	
Fluid Intake (ml)	1731		1569	
Urine Output (ml)	1371		1234	

\*  $p < 0.01$

+ Mean value for the triceps, subscapular and suprailiac skinfolds

\*\* Subjects 1,5,6,8 and 10

### Conclusion

Rapid fat loss in response to work in the extreme cold has been observed during both actual and simulated Arctic military exercises. While 52 men sustained an estimated 4.2 kg loss of body fat during a 2 week period involving Arctic patrols, 10 men demonstrated a comparable one-week loss of 2.4 kg during a simulated patrol...the equivalent skinfold losses being 38% and 19% of initial readings, respectively. Standard energy balance calculations conducted on men working at these temperatures fail to equate the estimated energy expenditure with the actual anthropometric measurements of body fat loss...one possible explanation is that the full caloric yield from body fat is not realized when FFA degradation bypasses the Krebs cycle with ketone body formation, metabolism and excretion (4).

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Table A 1

Analysis of Variance for the Total Number of Positive  
Tests for Ketonuria on Ten Subjects for the Seven Experimental Days.

SOURCE	df	SS	MS	F	P
Subjects	9	33.2	3.7	4.02	<0.05
Days	6	26.7	4.5	4.86	<0.025
Error	54	49.5	0.9		
Total	69	109.4			



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# KEY WORDS

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Cold Climatic Facility

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13. ABSTRACT A one week simulated Arctic military exercise was undertaken to observe whether certain physiological changes observed during actual two week military patrols in the Canadian subarctic and Arctic would also occur within a cold climatic facility. Energy balance studies were conducted; predictions of daily energy expenditure were quite similar for both studies, respective values for the actual and simulated studies being 3358 and 3355 kcal/man/day. While the men in the northern study were estimated to be in caloric balance, the infantrymen in the cold chamber had a daily caloric deficit of over 500 kcal, a total experimental imbalance calculated to be equivalent to a 0.5 kg loss of body fat. In the Arctic, 52 men incurred a 38% reduction in mean skinfold thickness, a loss equivalent to a 4.2 kg depletion of mean body fat over two weeks, while in caloric balance. In the one week simulated study, ten Arctic trained infantrymen had a comparable one week skinfold loss of 19%, estimated to be equivalent to a 2.4 kg loss of body fat ... a value 4.5 times greater than predicted from energy balance studies. There were physiological indications that dehydration had developed by the conclusion of the study. There was an 80% daily incidence of ketonuria and unexpectedly 50% of the subjects had glucosuria on one or more occasions.		

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# KEY WORDS

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Fluid Balance Studies

## INSTRUCTIONS

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