Findings from a simulated disabled submarine survival trial

C. M. HOUSE, J. R. HOUSE, and E. H. N. OAKLEY

Institute of Naval Medicine, Alverstoke, Gosport, United Kingdom

House CM, House JR, Oakley EHN. Findings from a simulated disabled submarine survival trial. Undersea Hyper Med 2000; 27(4):175–183—Eleven volunteer submariners were exposed to simulated disabled submarine conditions for a maximum of 7 days to determine if the limited clothing and rations provided in escape compartments would compromise survival prospects. Daily rations were 0.568 liters of water (none on Day 1) and 100 g of barley sugar. The subjects wore working rig and the liner from the Mark 10 submarine escape and immersion equipment throughout, and slept in the outer dry suit. Air temperature fell from 22°C to 4.4°C over 2 days and then remained at 4.4°C. Although the subjects felt cold they were able to maintain their deep body temperature. The greatest threat to survival in this situation would be dehydration, one subject was withdrawn on Day 4 as his urine production over the previous 24 h was 130 ml and if not withdrawn and rehydrated this may have led to renal failure. Other medical problems suffered by the subjects during the 7 days included diarrhea, vomiting, hypoglycemia, headaches, and back pains, and, following the trial, non-freezing cold injuries to their feet. It is concluded that the rations are not adequate and could compromise the submariners ability to survive for 7 days in these conditions and during a subsequent escape procedure.

disabled submarine, thermoregulation, starvation, dehydration, non-freezing cold injury

If a Royal Navy (RN) submarine becomes disabled and unable to resurface, the current policy is that the crew on board should wait for rescue rather than attempting to escape by free ascent through the water. It is predicted that it could take up to 7 days to complete a rescue, during which time the crew could be trapped in the escape compartments which may be without power. However, at any time deteriorating conditions in the compartment may force the submariners to escape and wait for recovery on the surface.

The air temperature in the escape compartments without power is likely to fall to within 2°C of sea water temperature (1) which could be as low as 2°C (2). In some escape compartments, the submariners would have access to bunks, clothing lockers, and food stores; however, in others there would be none of these. Consequently, the crew could be exposed to an air temperature as low as 4°C wearing only their working clothing of shirt and trousers, socks and boots (0.6 clo). Mathematical modeling predicts that in these conditions and without any food the submariners would become hypothermic in 48 h (3).

All escape compartments are equipped with lifesupport equipment for emergency use, including survival rations and specialized suits for submarine escape and survival on the surface. The daily rations provided were 0.568 liters of water (although none is drunk on Day 1) and 100 g of barley sugars (96% carbohydrate; 396 kcal) per man. These rations were initially selected for use in 25-man liferafts by the RN following the Second World War, ultimately being chosen because of constraints of space and weight. They were adopted for use in disabled submarines when rescue became a viable option.

The submarine escape and immersion equipment (SEIE) consists of an impermeable suit made from polyurethane-impregnated nylon, an inner liner made from spun bonded polyethylene (TYVEK) (a registered trademark of DuPont Nemours International S.A.), and a one-man liferaft which is inflated once on the surface. Although designed for a different purpose, submariners trapped in an escape compartment would be able to wear this clothing while waiting for rescue. The clo value for the Mark 10 outer dry suit, liner, and working clothing is estimated to be approximately 2.0—this estimation is based on information from Olesen (4). With 2 clo of insulation, the mathematical model predicts that survival time will be indefinite, suggesting that wearing the SEIE is likely to prevent hypothermia for the duration of the trial.

The purpose of this study was to determine if the survival rations and clothing available for submariners, trapped in an escape compartment and exposed to cold air, were adequate to prevent hypothermia and ensure survival for 7 days. We also wanted to establish whether, after 7 days in these conditions, the submariners would be
able to perform the actions necessary to escape from a submarine. It was hypothesized that the submariners would not become hypothermic and would be able to survive for 7 days in these conditions; however, peripheral cooling could restrict their physical ability to perform the escape procedure.

**METHODS**

Subjects: Eleven submariners from RN establishments volunteered for the trial, all were male as all RN submariners are male. Their informed consent was gained in accordance with the Declaration of Helsinki and they all passed a full medical assessment before being allowed to participate. The protocol was approved by the Ministry of Defence (Navy) Personnel Research Ethics Committee, and the trial was conducted in the Environmental Medicine Unit at the Institute of Naval Medicine (INM).

Experimental design: The trial was conducted in three consecutive phases:

- Control period (began at 1100 on Day 1 and ended at 1900 on Day 2)
- Cold period (began at 1900 on Day 2, and ended with a mock escape exercise at 1900 on Day 9)
- Recovery period (began following the escape exercise and ended at 0900 on Day 11).

Conditions: The trial was conducted in a large environmental chamber at the INM which contains sleeping (bunk spaces), kitchen, and bathroom facilities. During the cold phase there was constant diffuse lighting in the chamber. Television, radios, videos, personal stereos, smoking, washing, showering, newspapers, and telephone calls were not permitted, but the subjects were allowed to read books. During the control and recovery phases washing, television, radios, videos, personal stereos, newspapers, and telephone calls were allowed.

Climatic conditions: Dry bulb ($t_{db}$) and wet bulb temperatures were monitored continuously at a central position in the chamber, and recorded on a data logger (Grants Instruments Ltd., Cambridge, England). The mean $t_{db}$ during the control and recovery phases was 22.8°C (SD 1.6°C) and the relative humidity was 48%. In the cold phase, $t_{db}$ fell exponentially over the first 48 h to 4°C, average $t_{db}$ for the following 5 days was 4.4°C (SD 0.4°C), and the relative humidity was 99%.

Clothing: During the cold phase the subjects wore their normal working clothing of NOMEX (registered trade mark of Dupont de Nemours International S.A.) shirt and trousers, socks, and leather ankle boots. Each subject was given an SEIE to use as he wished. The subjects chose to wear the liner continuously from 15 h after the cold phase began and sleep in the outer dry suit at night, on mattresses in the bunk spaces. They were provided with pillows but did not have blankets or sleeping bags. During the control and recovery phases, the subjects wore their working clothing and were provided with pillows, sleeping bags, and blankets.

Rations: During the cold period the subjects consumed 100 g of barley sugar sweets (396 kcal) and 1 pint (568 ml) of water per man per day, with no water in the first 24 h. All the rations for each day were consumed during the day as the subjects wished, but could not be held over to the next day. During the control and recovery phases the subjects were provided with cooked meals from a local RN establishment.

Mock submarine escape procedure: A mock submarine escape tower was constructed in the environmental chamber. The subjects were familiarized with the escape procedure during the control period and required to repeat the task at the end of the cold period or when they were withdrawn from the trial. The drill simulated the activities that the last man escaping from the submarine would have to make. This involved fully donning the SEIE and turning a series of handles on the tower in the correct sequence. The subjects were then required to lift the lower hatch lid (weighing 20 kg and not attached to the tower) using the lid handles through the opening at the bottom of the escape tower and then position it so as to cover the opening. They then had to remove the lid and tie a cord onto its handles and climb up the ladder into the escape tower, pulling up the lid and putting it in position in the bottom of the tower.

Physiologic measurements: Percentage body fat was calculated from skinfold measurements (5) taken during the control period and upon completion of the cold period. Nude body mass was measured throughout the trial (Sauter SD100 scales, Ebingen, Germany) at 0715 each morning following the first micturition, and immediately before and after the cold phase.

Deep body temperature was measured using disposable, ingested radio pills with the output signals from the pills received using a receiver unit (Remote Control Systems Ltd, Amersham, England). Measurements were made every 3 h from 0700 to 2200. In cold conditions, radio pill temperature has been shown to correspond with rectal temperature (6). Skin temperature was measured at eight sites: chest, upper arm, mid thigh, calf, forehead, middle finger pad, heel, great toe pad using skin thermistors, and recorded at 60-min intervals (Grants Instruments Ltd., Cambridge, England). Mean skin temperature was calculated from chest, upper arm, mid thigh, and calf temperatures (7).

Resting metabolic rate was calculated from expired air samples collected in Douglas bags. Collections of expired
air were made for 15 min with the subjects resting supine, following at least 30 min of supine rest. The expired air samples were analyzed for oxygen and carbon dioxide concentration using gas analyzers (ADC series 7000, Hoddesdon, England), and gas volume was measured using a dry gas meter (Harvard, Kent, England). Samples were collected each day at 0900, 1500 and 2100.

Urine output for each 24-h period (1900 to 1900) was collected. The volume was calculated from urine weight (Mettler Toledo, Switzerland) divided by the specific gravity, which was measured using a hydrometer with the temperature of the urine at 20°C.

Blood samples were taken from the forearm antecubital vein at 0700 before the subjects rose. Samples from each day were analyzed for glucose concentration (glucose oxidase reaction, Vitros Technology, Hemel Hempstead, England). Hematocrit ratio (calculated from packed cell volume and total blood volume, Technicon H1, USA) and hemoglobin concentration (cyanmethemoglobin method, Technicon H1) were measured and used to estimate changes in plasma volume (8). Measurements of blood glucose concentrations were also made immediately after the subjects completed the escape procedure; a different technique was used which required a drop of blood from a finger tip stab analyzed instantly using a blood glucose meter (reflectance photometry method, Boehringer, Mannheim, Germany).

Maximal voluntary grip strength was assessed daily using a hand dynamometer (MIE Medical Research Ltd, UK), consisting of two 22-cm-long arms, fixed 5.5 cm apart. The subjects were instructed to grip the dynamometer as quickly and as hard as possible for 5 s using their preferred hand; they had two attempts and the highest value was recorded.

Subjective measurements were taken at 1900 each day. The subjects were asked to rank the following factors: cold, thirst, hunger, humidity, boredom, and sleep quality in order of unpleasantness beginning with the factor that they found most unpleasant.

Assessment for non-freezing cold injury: During the 3–6 mo following the trial, all subjects returned to INM and were assessed in the Cold Injuries Clinic for non-freezing cold injuries (NFCI) to their feet. These were quantified using infra-red thermography before and after a mild cold stress test, measurement of their warm and cool thermal thresholds, and by clinical interview. Before the infrared thermography assessment the subjects were required to rest, recumbent on a couch in the environmental chamber (ambient temperature 30°C, relative humidity 40–60%) for a minimum of 30 min. One of each of the subject’s feet was placed in a thin plastic bag and immersed to the level of the mid-malleoli in a water bath (Grants Instruments, Cambridge) maintained for 2 min at 15°C. The foot was then taken out of the water and the plastic bag removed. The subjects remained recumbent on the couch while thermographs were taken of their feet using an Agema Thermovision 570 infra-red camera (FLIR Systems). Infra-red images were recorded on a remote computer running IRwin Research 2.01 software (Agema Infra-Red Systems) before immersion and immediately after and 5 min following immersion.

The thermal sensory thresholds were measured using the Middlesex Hospital Thermal Sensory Testing System. A 30-mm² thermode was placed on three of the toes of the subjects, the temperature of the thermode was changed and the subjects were asked whether they could detect the change. The degrees of subsequent temperature change depended on the subject’s response and continued until the minimum threshold for sensation was determined. On some occasions the temperature of the thermode did not change to ensure that a true threshold was determined.

Withdrawal criteria: A number of withdrawal criteria were specified for the study:

- any skin temperature falling to 8°C for 20 min or to 6°C at any time
- 24-h urine output of less than 200 ml
- request of subject, Independent Medical Officer, or project officer.

The skin temperature withdrawal limits were set so as to minimize the risk to the subjects of sustaining non-freezing cold injury. These criteria are recognized and accepted by the Ministry of Defence Personnel Research and Ethics Committee and are widely used internationally. These withdrawal limits have been used successfully in numerous research trials undertaken at the INM on several hundred volunteers. To minimize the risk of sustaining further non-freezing cold injury, subjects were instructed to report to the Independent Medical Officer any abnormal sensations (numbness, loss of sensation) in their extremities. Although a reduced urine output is a normal response to reduced fluid intake, a 24-h output below 100 ml is abnormal and can be a symptom of renal failure (9). The level of 200 ml was set to reduce the risk of the subjects developing renal failure, and plasma urea and creatinine were also measured.

Statistical analysis: The main performance criterion for the trial was the completion of the 7-day cold phase, followed by successful completion of the mock submarine escape routine. Mean daily physiologic measurements have been calculated from the values recorded in each 24-h period, from 1900 until 1900 the following day, beginning at 1900 h on Day 1 of the control period. Repeated
measures analysis of variance and the Scheffé method of multiple comparison (10) were used to identify any significant differences between the data in the control period and the 2nd and 3rd days in the cold.

RESULTS

Descriptive results: Four subjects completed all three phases of the trial. Three subjects requested to be withdrawn from the trial during the first 2 days of the cold period, two after 32 h, and one after 46 h. The first two withdrew stating that they felt it was too cold for them to continue, \( t_{ab} \) was 7.6°C. At the time of their withdrawal their deep body temperatures were both 37.3°C, mean skin temperatures were 28.7°C and 30.3°C, and their lowest peripheral skin temperatures were 19.2°C and 14.1°C. The third withdrew complaining of pain in his fingers (his finger temperature was 12°C and there was no evidence of cold injury).

Four subjects were withdrawn from the trial for medical reasons. Two after 66 h (2.75 days) of the cold phase as they had cold feet—one reported numbness in his feet and the other paresthesiae, their toe temperatures were 10.3°C and 9.1°C, respectively. The third subject was withdrawn after 96 h (4 days) of the cold phase; he had been suffering intermittently with a headache since the start of this phase, and during the previous 24 h had produced only a small volume of urine (130 ml). He was subsequently rehydrated and his urine output returned to normal. The fourth subject was withdrawn after 4 days and 22 h; he was nauseous, vomiting, and had been suffering with abdominal pain and diarrhea.

Of the four subjects who completed all three phases, one reported feeling nauseous and having a prickly-itching sensation in his armpits on Day 4 of the cold phase; this lasted for approximately 30 min. These symptoms suggested that he was hypoglycemic and a spot check of his blood glucose (from a fingertip drop of blood) taken at this time was found to be 2.2 mmol · liter⁻¹ [normal value in the fed state is 5.5 mmol · liter⁻¹ (11)]. A different subject suffered from diarrhea for approximately 24 h, between Days 5 and 6. Stool samples from the two subjects with diarrhea were analyzed for pathogenic bacteria; none was found. Two of the subjects who completed the 7-day cold phase suffered with cramping pains in their lower backs on Day 6.

The escape exercise was successfully completed by all 11 subjects during the control period and by the 8 subjects who repeated it (the procedure was not repeated by the first 2 subjects who withdrew voluntarily, nor the subject who was withdrawn because he was vomiting). The four subjects who had endured 7 days in the cold all reported that maximal effort was required to lift the lower escape hatch into position. The subject who requested to be withdrawn suffering from cold hands felt nauseated and shaky and weak upon completion of the escape exercise, and remained in the tower for approximately 5 min before feeling well enough to climb down the ladder.

Subjective results: Daily rankings revealed that during the cold phase the subjects found the cold to be the most unpleasant factor; they were least affected by thirst and hunger. The subjects stated that they would not have drunk their water and eaten all the barley sugars had they not been requested to as part of the study. The subjects commented that as the days went on they developed better strategies for sleeping and keeping warm. During the control and recovery periods the subjects ranked boredom and quality of sleep as the most unpleasant factors.

Statistical analysis of the results: Statistical analysis was undertaken on the data from the eight subjects who were either withdrawn from the cold period for medical reasons or who completed the 7-day cold period. Table 1 summarizes the physiologic findings.

The mean daily deep body temperatures of seven of the eight subjects fell during the first 2 days in the cold. The temperatures of the four subjects who completed the trial rose after the initial fall, increasing to a mean value of 37.4°C on Day 6 in the cold period. The lowest skin temperatures were recorded at the toe, mean daily toe temperatures for each of the 11 subjects are shown in Fig. 1. The toe temperatures of 10 of the 11 subjects fell upon exposure to cold; the temperatures for the remaining subject were maintained above 30°C for the entire trial—this was checked a number of times to ensure that it was not a measurement error.

The mean mass loss of the four subjects during the 7-day cold period was 6.1 kg (range 5.2–6.9 kg), this being a mean reduction in weight of 7.2% (range 6.5–8.3%). Their mean body fat fell from 20.8 to 19.5%. The greatest loss in weight occurred in the first 2 days in the cold period when urine output was greatest. Mean daily urine output on Days 1 and 2 in the cold period were 1,001 ml (range 558–1,617 ml) and 1,003 ml (range 201–1,967 ml), respectively, whereas total fluid intake over these 2 days was only 568 ml, resulting in a mean fluid deficit of 1,436 ml (range 332–3,016 ml). There was a 25.3% reduction in mean plasma volume from the control period to Day 3 in the cold. This reduction was significantly correlated with changes in toe temperature during this time period \( \rho = 0.63, P < 0.05 \). During the remainder of the cold period, plasma volume was virtually restored, and increased above control levels in the recovery period.

The mean value for the spot finger-prick blood glucose measurements made after the escape exercise for the four
<table>
<thead>
<tr>
<th>Variable</th>
<th>Control Period Mean (range)</th>
<th>Lowest Value in Cold Period Mean (range)</th>
<th>Day of Lowest Value</th>
<th>Significance (control and Days 2 &amp; 3 in cold period)</th>
<th>Day 7 in Cold, $n = 4$ Mean (range)</th>
<th>Recovery Period, $n = 4$ Mean (range)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Daily mean deep body temperature, °C</td>
<td>37.3 (36.9–37.5)</td>
<td>37.0 (36.8–37.2)</td>
<td>2</td>
<td>$P &lt; 0.05$</td>
<td>37.3 (36.8–37.8)</td>
<td>37.7 (37.3–38.2)</td>
</tr>
<tr>
<td>Mean skin temperature, °C</td>
<td>33.4 (33.0–33.9)</td>
<td>29.4 (29.1–30.1)</td>
<td>3</td>
<td>$P &lt; 0.01$</td>
<td>30.7 (28.2–32.4)</td>
<td>34.1 (32.9–34.8)</td>
</tr>
<tr>
<td>Toe temperature, °C</td>
<td>33.7 (32.4–34.3)</td>
<td>16.0 (9.6–30.2)</td>
<td>3</td>
<td>$P &lt; 0.01$</td>
<td>27.4 (24.3–32.4)</td>
<td>34.3 (33.0–35.8)</td>
</tr>
<tr>
<td>24-h urine volume, ml</td>
<td>1511 (952–2055)</td>
<td>490 (319–730)</td>
<td>5</td>
<td>$P &lt; 0.05$</td>
<td>775 (457–1080)</td>
<td>959 (663–1542)</td>
</tr>
<tr>
<td>Body weight, kg (n = 4)</td>
<td>83.9 (61.7–98.1)</td>
<td>77.8 (56.5–91.3)</td>
<td>7</td>
<td></td>
<td>77.8 (56.5–91.3)</td>
<td>80.8 (58.3–94.3)</td>
</tr>
<tr>
<td>Plasma volume, %</td>
<td>100 (63.7–84.3)</td>
<td>74.7 (52.0–74.7)</td>
<td>3</td>
<td>$P &lt; 0.05$</td>
<td>94.7 (79.6–107.1)</td>
<td>127.6 (123.3–131.7)</td>
</tr>
<tr>
<td>Glucose, mmol·liter$^{-1} a$</td>
<td>4.9 (4.5–5.2)</td>
<td>5.2 (4.6–5.8)</td>
<td>2 &amp; 3</td>
<td>$P &lt; 0.05$</td>
<td>5.0 (4.7–5.3)</td>
<td>5.5 (5.0–5.8)</td>
</tr>
<tr>
<td>$\text{VO}_2$, liter·min$^{-1}$</td>
<td>0.29 (0.22–0.42)</td>
<td>0.25 (0.16–0.33)</td>
<td>3</td>
<td>$P &lt; 0.05$</td>
<td>0.31 (0.27–0.33)</td>
<td>0.28 (0.23–0.31)</td>
</tr>
<tr>
<td>RER</td>
<td>0.92 (0.83–0.99)</td>
<td>0.68 (0.64–0.71)</td>
<td>2</td>
<td>$P &lt; 0.05$</td>
<td>0.76 (0.74–0.79)</td>
<td>0.91 (0.87–0.95)</td>
</tr>
<tr>
<td>Grip strength, N</td>
<td>500 (435–627)</td>
<td>459 (344–599)</td>
<td>2</td>
<td>$P &lt; 0.05$</td>
<td>434 (389–468)</td>
<td>450 (416–514)</td>
</tr>
</tbody>
</table>

*a* This variable increased during the first days in the cold.
FIG. 1—Mean daily toe temperature for each of the 11 subjects.
DISCUSSION

The results support the hypothesis that subjects exposed to these conditions are able to maintain thermal balance and survive for 7 days. The subjects did have cold extremities, and even though a number sustained peripheral cold injuries to their feet, peripheral cooling did not prevent them from successfully completing the escape exercise. Although the subjects did not become hypothermic they could have been thermally more comfortable.

Of the four subjects who were withdrawn for medical reasons, only the survival of the subject with the low urine output would have been in doubt. Had this been a real incident from which withdrawal was not possible, he could have developed potentially fatal renal failure. The two subjects who were withdrawn with cold feet would probably have developed severe non-freezing cold injuries in their feet had they remained in the cold. These would not have been life threatening nor would this have impaired their ability to escape. The subject who was withdrawn because he was vomiting would probably have survived a further 2 days exposed to these conditions. It is difficult to predict if the three subjects who voluntarily withdrew from the trial during Day 2 in the cold would have survived for 7 days in these conditions. At the time of their voluntary withdrawal, none of these subjects had any adverse objective symptoms; however, none of the subjects who were subsequently withdrawn had any symptoms at this stage of the trial either.

The mock escape exercise was realistic with respect to the actions that submariners would have had to make to undertake an escape. The exercise had to be undertaken in air as it would have been unethical for the subjects to have made a real escape in which they could have been fatally injured. Although only speculation, there is some doubt whether the subject who felt nauseous, weak, and dizzy in the escape tower when he finished the exercise, or the subject who was withdrawn because he was vomiting (who did not repeat the mock escape exercise), would have survived real escapes.

Although the trial was not intended to assess survivability on the surface following escape from a submarine, there are implications from the trial concerning surface survival. If rescue forces are not already on site, once on the surface the escapees would have to inflate their one-man liferaft, board it, and await rescue. Blood glucose measurements and symptoms shown upon completion of the escape exercise suggest that four of the eight subjects who undertook the exercise were hypoglycemic at this time. A reduction in the level of blood glucose concentration perfusing the hypothalamus may cause a failure in thermoregulation, and in subjects who were cold and shivering, insulin-induced hypoglycemia has been shown to inhibit shivering and decrease heat production (12). In submariners escaping from a submarine and then awaiting recovery on the surface, this would increase the possibility of their developing hypothermia and substantially reduce their survival prospects. However, it should be noted that as the blood was taken from the finger tips (which were cold and vasoconstricted) it may not be providing an accurate measurement of the blood glucose concentration in the blood perfusing the hypothalamus.

The subjects shivered intermittently throughout the cold phase; this was not of sufficient intensity to cause a reduction in venous blood glucose levels, which actually rose during the first 3 days of cold exposure. Wolfe et al (13) have demonstrated an increase in adipose tissue lipolysis in the first few days of starvation; suggesting that in the current study, glucose may have been conserved by an increased availability and oxidation of free fatty acids. Two of the subjects had diarrhea, as no pathogenic bacteria were detected in their stools it is thought that they had starvation diarrhea, a condition in which the epithelium of the intestine is unable to control absorption effectively because it does not have sufficient energy (14).

The negative fluid balance, which will have resulted from the restricted fluid intake and cold induced diuresis led to an initial reduction in plasma volume, which was subsequently restored, probably with fluid from the intracellular space. A relationship between dehydration and a reduction in peripheral skin temperatures during cold stress has previously been demonstrated (15). However, the present study showed that despite continued dehydration during the final days in the cold, peripheral skin temperatures rose and that this corresponded with the restoration of plasma volume. Interestingly, despite their
### Table 2: Summary of Cold Injury Among Subjects

<table>
<thead>
<tr>
<th>Subject</th>
<th>Duration in Cold Period, Days</th>
<th>Symptoms</th>
<th>Thermography, Degree of Cold Sensitization</th>
<th>Sensory Threshold</th>
<th>Warm Thermal Sensory Threshold in Toes, °C</th>
<th>NFCI Diagnosis</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1.3</td>
<td>none</td>
<td>moderate</td>
<td>normal</td>
<td>1.9</td>
<td>mild</td>
</tr>
<tr>
<td>2</td>
<td>4.0</td>
<td>PP</td>
<td>normal</td>
<td>normal</td>
<td>2.4</td>
<td>mild</td>
</tr>
<tr>
<td>3</td>
<td>2.8</td>
<td>CS</td>
<td>moderate-severe</td>
<td>abn</td>
<td>3.8</td>
<td>moderate</td>
</tr>
<tr>
<td>4</td>
<td>7.0</td>
<td>CS</td>
<td>moderate</td>
<td>abn</td>
<td>3.3</td>
<td>moderate</td>
</tr>
<tr>
<td>5</td>
<td>2.8</td>
<td>CS</td>
<td>moderate</td>
<td>abn</td>
<td>&gt;6</td>
<td>moderate</td>
</tr>
<tr>
<td>6</td>
<td>4.9</td>
<td>CS, P, S</td>
<td>low-normal</td>
<td>normal</td>
<td>2.7</td>
<td>mild</td>
</tr>
<tr>
<td>7</td>
<td>7.0</td>
<td>P</td>
<td>moderate-severe</td>
<td>normal</td>
<td>2.9</td>
<td>moderate</td>
</tr>
<tr>
<td>8</td>
<td>7.0</td>
<td>CS, P, N</td>
<td>moderate</td>
<td>abn</td>
<td>4.3</td>
<td>moderate</td>
</tr>
<tr>
<td>9</td>
<td>7.0</td>
<td>P, N</td>
<td>moderate-severe</td>
<td>abn</td>
<td>&gt;6</td>
<td>moderate</td>
</tr>
<tr>
<td>10</td>
<td>1.3</td>
<td>none</td>
<td>normal</td>
<td>peripheral neuropathy?</td>
<td>&gt;6</td>
<td>normal</td>
</tr>
<tr>
<td>11</td>
<td>1.9</td>
<td>none</td>
<td>normal</td>
<td>normal</td>
<td>1.3</td>
<td>normal</td>
</tr>
</tbody>
</table>

*Key:* abn = abnormal, PP = painful paresthesia, CS = cold sensitivity, P = pain, S = excessive sweating, N = numbness.
severe dehydration, all the subjects reported that they did not feel thirsty and did not want to drink the water. A similar loss of thirst was reported in an Arctic field trial in which the subjects were exposed to starvation and survival conditions for 5 days (16).

A regrettable finding of the study was the high incidence of NFCl sustained by the subjects. Although prior assessments were not made, it seems probable that participation in the trial was responsible for the majority of these injuries. The withdrawal criteria that we used to try to prevent NFCl were a skin temperature of 8°C or less for 20 min or a skin temperature of 6°C. Clearly these are not adequate for a trial of this nature. However, trying to determine appropriate limits based on the skin temperatures proves problematic, as one subject maintained his toe temperature above 30°C yet still sustained moderate NFCl. This finding is reported, in the hope that it may prevent other similar trials from causing NFCl.

We conclude that the rations and clothing currently provided in RN submarine escape compartments will probably sustain the majority of the crew while they wait for rescue inside the submarine. If they are forced to wait for 7 days they will suffer from a number of medical problems, the most serious and possibly fatal of these being renal failure. The provisions, however, are not adequate to ensure that the survival of the entire crew is not compromised by nutritional factors while awaiting rescue, during escape, and waiting for recovery once on the surface.

REFERENCES