U. S. NAVAL SUBMARINE MEDICAL CENTER

Submarine Base, Groton, Conn.

REPORT NUMBER 514

PHYSIOLOGICAL EVALUATION OF THE BRITISH MARK VII SUBMARINE ESCAPE IMMERSION SUIT DURING IMMERSION

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Bureau of Medicine and Surgery, Navy Department
Research Work Unit MF022.03.03-9027.03

Released by:

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SUBMARINE MEDICAL RESEARCH LABORATORY
U. S. NAVAL SUBMARINE MEDICAL CENTER REPORT NO. 514
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SUMMARY PAGE

THE PROBLEM

To determine the survival time and the general performance of the British Mark VII Submarine Escape Immersion Suit (SEIS). When in the first series of tests, the suit did not provide the desired 24-hour survival time under the specifically required environmental conditions, further tests to determine the estimated survival time under less severe conditions were conducted.

FINDINGS

The British Mark VII did not provide a 24-hour survival time at the extreme environmental condition (29°F water, 10°F air, 20 MPH wind) specifically desired. However, when the water temperature was elevated to 44°F, and the air temperature increased to 32°F, 24-hour survival time can be predicted for most men.

APPLICATION

The information presented in this report should permit development of an improved submarine escape suit incorporating the desirable features of the British Mark VII SEIS. At present, submarines have essentially no exposure protection for men once the escape compartment is flooded and exit procedures are initiated.

ADMINISTRATIVE INFORMATION

The work covered by this report was performed under BuMed Research Work Unit MF022.03.03-9027, during the period 1 April 1967 to 1 March 1968. The study was conducted by investigators from the Submarine Medical Center, Groton, Connecticut, using facilities at the Aerospace Crew Equipment Department, Naval Air Engineering Center, Philadelphia, Pennsylvania. This report was approved for publication on 14 March 1968. It is Report No. 3 on the above mentioned Work unit, and has been designated as Submarine Medical Research Laboratory Report No. 514.

PUBLISHED BY THE NAVAL SUBMARINE MEDICAL CENTER

ABSTRACT

This study determined the general performance and survival time afforded by the British Mark VII Submarine Escape Immersion Suit in 29°F water, 10°F air, and 20 MPH wind speed. Tests were also conducted in 90°F water, and 85°F still air. It was found that the British suit did not provide 24 hours estimated survival at 29°F water, 10°F air, 20 MPH wind in all subjects, and that the four subjects were taken from the water after an average time of 2.8 hours of exposure. Damage to the hands and feet would probably occur between 5.1 and 9.1 hours. Death would probably occur after 5.6 to 24 hours of exposure. Tests conducted at 90°F water, 85°F still air, indicated that no major problem will be encountered under these conditions. The environmental conditions were then changed in a step-wise fashion from 29°F water, 10°F air, and 20 MPH wind, until 24-hour estimated survival time was obtained. At 44° water, 32°F air, and 20 MPH wind, 24-hour survival may be predicted for most men based on results in the limited number of subjects used in this investigation.

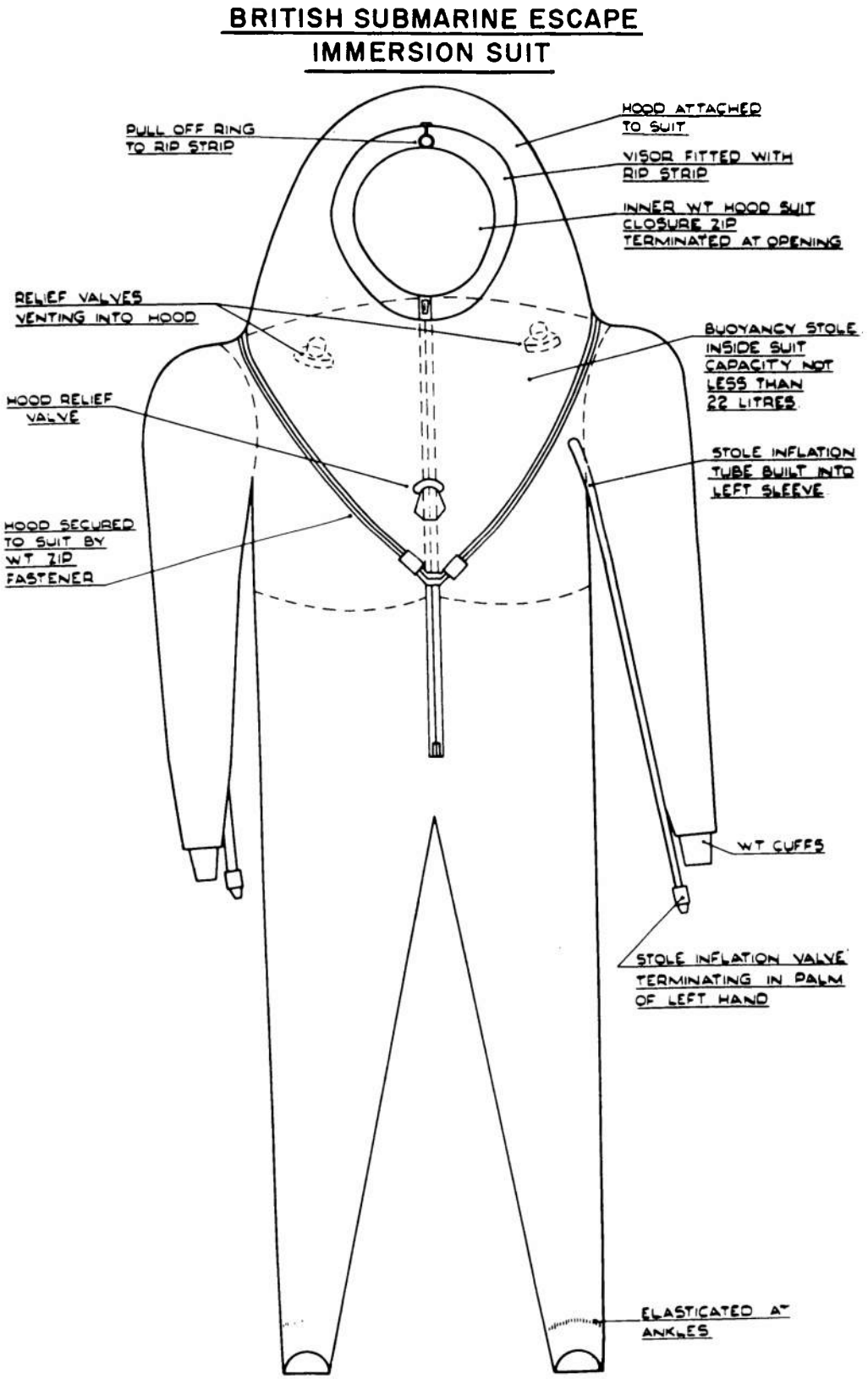

Figure 1. — A Sketch of the Escape Immersion Suit Used in These Trials.

PHYSIOLOGICAL EVALUATION OF THE BRITISH MARK VII SUBMARINE ESCAPE IMMERSION SUIT DURING IMMERSION

INTRODUCTION

At the present time U.S. Navy submariners have essentially no exposure protection following escape from a bottomed submarine. The Steinke Hood, the escape appliance currently employed by the Fleet, together with whatever the man can don before escape, is all the thermal protection that is available.

The British Navy has developed an escape suit affording reasonable exposure protection, when consideration is given to storage requirements, cost, simplicity of operation, and capability for a 600-foot ascent. This escape suit embodies the concepts of individual escape versus the U.S. Navy group escape approach. Elliott[1] describes this individual escape concept in detail together with the trials that were conducted. The escape suit utilized in his study was the British Mark VI Submarine Escape Immersion Suit shown in Fig. 1. The main features of the associated single man escape tower are described in Fig. 2. McNutt[2] conducted a thermal evaluation of this suit. He exposed:

1. 12 men wearing the British SEIS to 41°F water and 58.6°F still air for three hours;

2. 9 men under the same conditions for six hours;

3. 5 men to 50°F water, and 62.6°F still air for six hours.

He concluded that damage to the hands and feet of those wearing the suit would result after about 6 to 12 hours at 41°F water and 58.6°F still air. He also estimated that most men wearing the suit under the same environmental conditions would die after about 12 to 18 hours. In water at 50°F and 62.6°F still air, the projected survival time would be 12 to 24 hours. In June of 1967, additional tests were conducted under similar environmental conditions to reinforce the survival times predicted from the previous trials and to consider other related problems encountered with the suit.[3] The initial results tend to reinforce the previous trials and point out other problem areas. These British trials did not incorporate the more severe environmental conditions encountered by U.S. Navy submarines, and they did not include appropriately broad ranges of temperatures. Therefore, it seemed desirable to determine survival times under such conditions, as well as other deficiencies in the suit.

In response to a request from the Director, Deep Submergence Systems Project Office, the Submarine Medical Center undertook an investigation to determine how long men could be expected to survive under various environmental conditions using the British Mark VII Submarine Escape Immersion Suit. The specific extreme environmental conditions encountered during routine patrol operations were used as starting point.

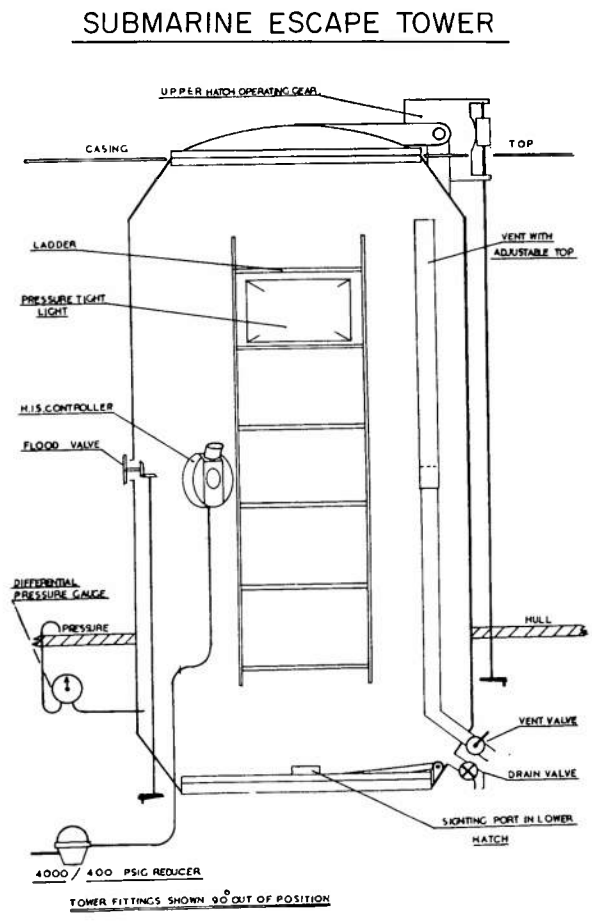

Fig. 2. A Diagram Illustrating the Principal Features of the Single Man Escape Tower.

Investigators from the Military Operations Branch of the Submarine Medical Center, utilizing the facilities of the Aerospace Crew Equipment Department, Philadelphia, Pennsylvania, were directed to conduct this experimentation.

Lethal immersion in cold water is an ever present threat to submariners. There is, therefore, a need for an effective buoyant exposure suit-hood combination. Escape from bottomed submarines in cold water may be required because of fire, explosion, collision, or recovery from flooding. Means must be provided for survival in water until rescue forces arrive. Recent studies conducted by the Submarine Safety Center indicts that a minimum survival time of 24 hours is required.

Thermodynamically, the human body may be considered a core surrounded by a protective outer shell. If the difference between the core temperature and the water temperature is great enough, body heat loss is directly proportional to this difference. Cold stress occurs when large amounts of body heat are lost. McQueen[4] describes amnesia and disorientation at core temperatures below 94.2°F. These results are based on clinical experience with hypothermic anesthesia. Voluntary motion disappears at body temperature of 80.6°F, and cardiac irregularities have been described when the temperature goes below 90°F.[5] In humans, the critical low temperature for consciousness is approximately 86°F. Reports indicate that the untreated volunteer immersion subject becomes thermolabile and tends to become poikilothermic[6] below 94°F. If crew members are to survive and benefit from rescue operations, central temperatures should be maintained above 94°F.

For the most part, the environment controls the skin temperature of the body. Skin temperatures are higher over the trunk and lower over the extremities, usually approximating 91°F. Discomfort occurs at about 88°F.[7] A skin temperature maintained at 55°F or below may frequently result in pain and nerve damage. The rate of heat loss in the extremities is considerably higher than the trunk and head areas.

Loss of body heat takes place during immersion in cold environments through the processes of respiration, conduction-convection via the body shell, and by micturation and sweating. In the process of respiration, inspired air is warmed, humidified, and then expired with the resultant loss of a considerable amount of heat. The amount of loss is proportional to the volume of air breathed per unit of time.

Conduction-convection transfer from the skin to the environment is another mechanism of body heat loss. The loss by this process is proportional to the temperature gradient between the skin and the surrounding medium. The insulative value of the body shell, skin and adipose tissue; the rate at which heat is conducted to the skin via the underlying vascular system; and the thermal capacity and conductivity of the environment control the rate of heat transfer. Vasoconstriction of the vessels of the "shell" tissues, which function as a heat exchange, and the thickness of the skin and adipose tissue control the rate of heat loss. The thermoconductivity of the skin varies with the degree of vasoconstriction.

Immersion in cold water increases urine output to a significant degree under certain conditions. Experiments conducted by Beckman[6] et al have shown that the urinary volume may be increased to 1-3 liters in 3 hours due to immersion and chilling. Excretion of two liters of urine by a diver in 50°F water could lower the mean body temperature by 1.8°F.

The balance of the heat loss from the body and the heat gained from metabolism within the body determines the body temperature. Since the rates of heat loss and heat gain may be of large magnitude, the body temperature is a delicate and sensitive indicator of the state of thermal balance.

Behnke and Yaglou[8] showed that, when a group of nude men entered 43°F water, excruciating pains all over the body were experienced. This was the period of vasoconstriction, when skin temperatures were falling and core temperature was rising. As skin temperatures approximated the water temperature, the pain subsided and central temperature began to fall. Cyanosis and shivering were observed very early and the shiver-

ing progressed to a state of violent shaking. In addition to the pain, it is known that as core temperature decreases, there is progressive deterioration and impairment of higher mental processes. At 90°F a condition of stupor exists and unconsciousness occurs in most individuals below 86°F. Drowning becomes a significant problem in cold immersion situations because of less discriminating sensory perception and motor function.

If drowning is prevented by the support of life vests, the effect of immersion hypothermia on cardiac rhythm occurs. Angelakos[9] has shown that, in dogs anesthetized with pentobarbital, ventricular fibrillation was the predominant mode of death at temperatures 75 to 68°F, while cardiac arrest accounted principally for mortality at lower temperatures—about 62 to 59°F.

Death may occur after removal form frigid water. This "rewarming shock" has been a commonly-observed phenomenon, and together with electrolyte alterations or irreversible renal, endocrinologic, or other damage, can produce death even after rescue. When possible, a man should be rewarmed in 108 to 112°F water, but great care should be taken never to have the water warmer than 112°F.[10]

Critchley[11] describes the loss of will to live, as the "spiritual failure" and lists it as the cause of 20% of the deaths among immersed personnel. Beckman and Reeves[12] describe the fact that one of two cases of "spiritual failure" in their tests, was actually suffering from hypoglycemia. Further, 5 of the 24 subjects (21%) had measurable hypoglycemia, this suggests that hypoglycemia may be the major physiological factor in the so-called "spiritual failure" of shipwrecked survivors.

McNutt[2] exposed eleven men for three hours in the British Submarine Escape Immersion Suit and nine men for six hours in the British SEIS in 41°F water, 58.6°F air temperature and no wind. He also exposed five men for six hours in 50°F water, 62.6°F air temperature, with no wind. He terminated the exposure when one of the following occurred:

a. Subject request.

b. Body surface temperature fell below 47°F.

c. Deep body temperature reached 95°F.

d. Cardiac arrythmia observed.

The above exposures resulted in the following:

(1) Of eleven subjects who began the trial, in 41°F water, all completed the full exposure time except one person who was removed after 2 hours and 40 minutes, because of nausea due to the motion of the water.

(2) Of nine subjects exposed to 41°F water for six hours, seven completed the trial. One man was removed because of pain and numbness in the feet and legs after four hours. His toe temperature was 49°F. Another man was removed after five hours because of severe cramps in the leg with temperatures of 55.2°F in the toe, 52°F in the heel, and 88.4°F in the thigh. A third man was in pain and some distress for the last 30 minutes of the test, but he consented to complete the full time. His temperatures were 50.9°F in the toe, 53.6°F in the heel, and 74.7°F in the thigh. The feet of these three subjects and one other felt "numb" for about one to two hours after exposure ended. There was no evidence of damage or loss of sensation after twelve hours.

(3) In 50°F water and 62.6°F air all five subjects completed six hours of exposure. One man became nauseated due to the rocking motion during the test.

Taking into account the variability between the limited number of subjects examined, and considering other relevant data, the following conclusions were reached:

(1) The skin and the deep body temperatures both decrease with lengthening exposure time. Hands and feet begin to suffer from cold injury after six to twelve hours in water of 41°F.

(2) In 50°F water, such cold injury will not occur until twelve to twenty four hours.

(3) The rate at which the deep body temperature falls indicates that in 41°F water many men will die in twelve to eighteen hours.

Ryan[3] has indicated that in recent tests conducted by the Royal Navy with twenty four men in 41°F water all subjects asked to be taken from the water after approximately five hours of immersion. Coldness and pain of the hands, feet, back, apparently

due to the prolonged period in the supine position, appear to have been the limiting factors. Initiation of micturition has presented difficulties. Although a limit of 95°F core temperature had been set for removal of subjects from the water, the body temperature of the subjects had not approached this temperature at the time of removal.

METHODS AND MATERIALS

Four enlisted submariners were subjects for this project. The physical measurements of the four subjects are listed in Table I. Each subject was notified twenty four hours before his participation and instructed to:

1. abstain from alcoholic beverages for twelve hours before the experiment;
2. obtain a normal night's sleep; and
3. eat a well-balanced breakfast prior to reporting to the laboratory.

No food or water was taken by the subjects during the experiments.

Multipoint surface temperatures were monitored using fifteen thermistors. The locations are shown in Table II. Core temperatures were measured employing a rectal thermistor probe, and a single lead electrocardiogram was monitored continuously.

Baseline laboratory studies and physical examinations were performed on each subject. A general physical examination, specific anthropomorphic measurements, ECG, CBC, cholesterol, and urinalysis were performed. All laboratory studies were within normal limits. Table III provides anthropomorphic data.

TABLE II
THERMISTOR POSITIONS

POSITIONS
Rectal
Right big toe, bottom
Right foot, dorsum
Right calf, lateral
Right mid-thigh, lateral
Right mid-thigh, medial
Xiproid
Right upper chest
Right scapula
Low back
Right index finger, pad
Right hand, dorsum
Right forearm
Right arm, deltoid area
Forehead

The environmental laboratory (Fig. 3) was 24 x 24 x 15 feet and contained a pool 18 feet in diameter and 4 feet deep. The following ranges were possible within this laboratory:

1. air temperature 10°F to 85°F;
2. water temperature 29°F to 90°F; and
3. wind velocity 0-20 miles per hour.

Two subjects were tested at a time. All four subjects were exposed to each set of environmental conditions. Each subject completed a pre-trial questionnaire (Fig. 4); then voided and were weighed nude; the volume and specific gravity of the urine was recorded (Table IV); thermistors and ECG leads were attached; and the subjects were then dressed in their underwear, a standard

TABLE I

PHYSICAL CHARACTERISTICS OF EXPERIMENTAL SUBJECTS

SUBJECT	AGE	HEIGHT (cm)	WEIGHT (kg)	SURFACE AREA (M^2)	%BODY FAT	SPEC. GRAV.
D	27	170.5	82.5	1.92	14.9	1.07
H	29	168.5	75.0	1.82	14.9	1.07
G	23	178.5	76.0	1.91	13.4	1.07
L	20	173.4	67.0	1.77	13.0	1.08
AVERAGE	24.8	172.8	75.1	1.85	14.0	1.07

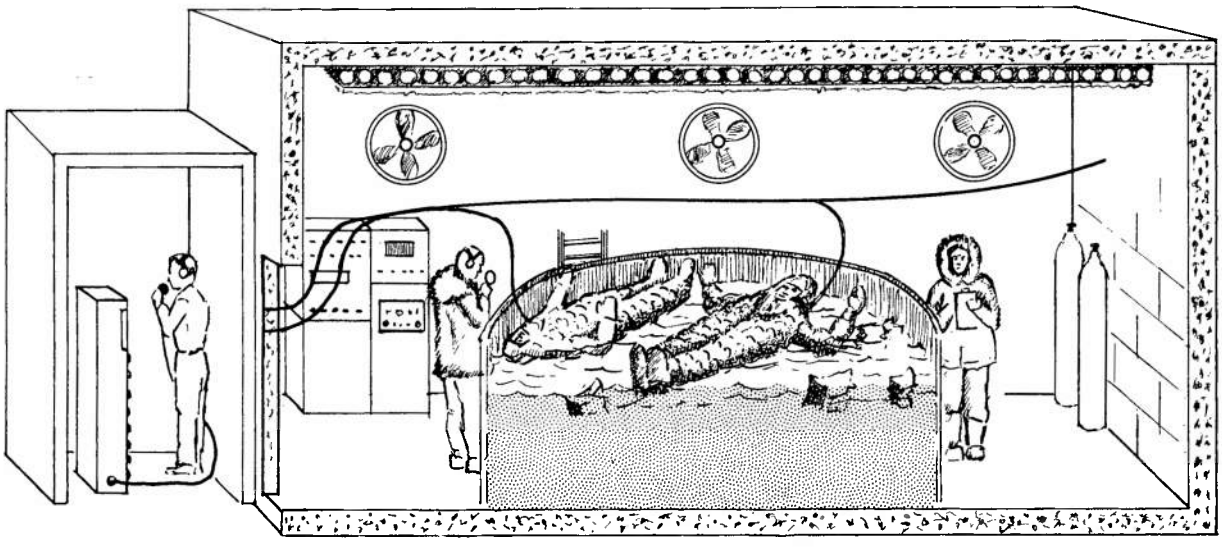

Fig. 3. Cut-Away Sketch of the Environmental Laboratory and Pool.

Polaris dacron-cotton, cover-all, nylon socks, and one pair of sweat socks. (Fig. 5). The British Mark VII SEIS was donned and thermistor and ECG lead continuity was confirmed (Fig. 6). The subjects remained fully dressed for thirty minutes before entering the environmental chamber. The suit's vest was inflated with compressed air, and the subject entered the water to his neck level without gloves and with his hands beneath the water. After three minutes, the time normally required to flood, pressurize, and escape to the surface, the subject donned his gloves and the remainder of the suit was inflated with CO_2. The subject was then free to move about the pool (Fig. 7). One hospital corpsman closely observed each subject. Continuous ECG and temperature data were monitored (Figs. 8 & 9). Subjective comments were elicited from the volunteers and recorded periodically (Fig. 10).

At the termination of a test, the suit was deflated and moved to an adjacent rewarming area (Fig. 11). The room contained a pool of water heated to 110°F. When the condition of the subject was deemed satisfactory, the subject undressed, voided, and was re-weighed. A post-exposure medical examination was made, and post-trial questionnaire completed (Fig. 12). The subjects were then released to their corpsmen.

Fig. 4. PRE-IMMERSION QUESTIONNAIRE

(To cover preceding 24 hours before immersion)

SUBJECT No.....

(a) **Food Eaten:**
- Dinner.
- Snack.
- Supper.
- Breakfast.

(b) **Estimation of Fluids Taken:**
- Breakfast.
- Mid-morning coffee.
- Dinner.
- Afternoon coffee.
- Supper.
- Late night.
- Early morning.
- Beer, wines/spirits—
  - morning.
  - evening.
- Other fluids.

(c) **Activities prior to immersion:**
- Sports or other strenuous activity.
- Time spent.

(d) **Other information:**

Signature.....

TABLE III

ANTHROPOMORPHIC MEASUREMENTS
(Kg., Cm.)

		SUBJECT			
		D	H	G	L
1.	Weight (Kg.)	82.5	75.0	76.0	67.0
2.	Stature	170.5	168.5	178.5	173.4
3.	Acromial Ht.	138.1	137.1	145.4	141.6
4.	Radial Ht. (Elbow)	107.1	106.5	111.4	107.2
5.	Stylion Ht. (Wrist)	85.7	80.0	87.7	86.4
6.	Dactylion Ht. (Fingertip)	63.6	61.5	66.7	68.4
7.	Trochanteric Ht. (Waist)	96.9	97.3	107.0	100.7
8.	Gluteal Furrow Ht.	76.5	79.6	85.4	81.7
9.	Chest Depth	24.7	25.7	23.3	22.3
10.	Chest Breadth	37.6	32.5	31.0	30.6
11.	Wrist Thickness	5.8	5.7	5.7	5.6
12.	Elbow Thickness	6.8	6.7	6.9	6.3
13.	Knee Thickness	10.3	9.3	11.0	10.1
14.	Ankle Thickness	7.5	6.2	7.6	7.2
15.	Foot Length	26.9	26.0	26.3	24.4
16.	Foot Breadth	10.4	8.6	9.0	9.5
17.	Chest Circ.	110.3	95.9	93.3	88.2
18.	Waist Circ.	91.2	91.1	86.8	81.8
19.	Hip Circ.	99.7	96.8	98.4	88.6
20.	Triceps Skinfold	0.9	0.9	0.7	0.5
21.	Subscapular Skinfold	1.2	1.2	0.9	1.0
22.	Sitting Ht.	90.4	85.6	90.2	87.4
23.	Buttock Knee Lgth.	59.2	59.2	62.9	61.7
24.	Hand Lgth.	19.1	18.6	18.9	17.1
25.	Hand Breadth	8.5	8.0	7.5	8.1
26.	Head Lgth.	19.2	19.4	17.9	18.1
27.	Head Breadth	16.5	15.0	15.2	15.3
28.	Diacromial Breadth	47.1	43.5	45.3	43.2
29.	Age (Years)	27	29	23	20

The four subjects were exposed to the conditions shown in Table V, until one of the following limitations occurred:

1. Unfavorable subjective response.
2. Rectal temperature 95°F or 103°F.
3. Skin surface temperatures lowered to unacceptable limits (46°F).
4. Cardiac arrythmias.

All testing was terminated after 12 hours, if the above conditions had not caused earlier termination.

TABLE V

SUMMARY OF ENVIRONMENTAL CONDITIONS

WATER TEMPERATURE (F°)	AIR TEMPERATURE (F°)	WIND VELOCITY MPH
29	10	20
44	32	20 *
60	45	20 *
90	85	still

* 2 experiments (4 men each)
(1) motivated (exercise, harrassment)
(2) non-motivated (limited exercise, no harrassment)

TABLE IV

SUMMARY OF PRE, POST WEIGHT AND URINE SPECIFIC GRAVITY DATA

Environmental Conditions	Subject	Weight		Urine Specific Gravity	
		Pre	Post	Pre	Post
A. 29, 10, 20 (Motivation)	D	178.8	177.2	1.080	1.100
	H	162.9	160.9	1.022	1.005
	G	171.2	171.1	1.016	1.010
	L	149.0	147.0	1.020	1.016
B. 44, 32, 20 (Motivation)	D	177.0	175.0	1.005	1.005
	H	162.0	159.0	1.018	1.005
	G	165.5	164.0	1.015	1.015
	L	144.0	143.0	1.020	1.005
C. 60, 45, 20 (Motivation)	D	174.0	173.0	1.030	1.029
	H	162.0	161.0	1.005	1.005
	G	164.0	161.0	1.025	1.025
	L	146.0	140.0	1.015	1.015
D. 44, 32, 20 (No-Motivation)	D	178.0	175.0	1.014	1.011
	H	164.7	163.2	1.010	1.010
	G	163.0	160.0	1.028	1.020
	L	146.0	146.0	1.020	1.020
E. 60, 45, 20 (No-Motivation)	D	178.0	175.3	1.009	1.007
	H	161.0	156.0	1.020	1.019
	G	164.0	162.5	1.027	1.023
	L	147.0	145.7	1.019	1.019
F. 90, 85, still (No-Motivation)	D	175.5	172.0	1.019	1.015
	H	162.0	158.0	1.015	1.015
	G	167.0	162.0	1.028	1.020
	L	144.0	142.0	1.009	1.010

Fig. 5. Subject Instrumented and Wearing a Standard Polaris Cover-All.

Fig. 6. British Submarine Escape Immersion Suit with Thermistor and EEG Leads Emerging Through Neck Area.

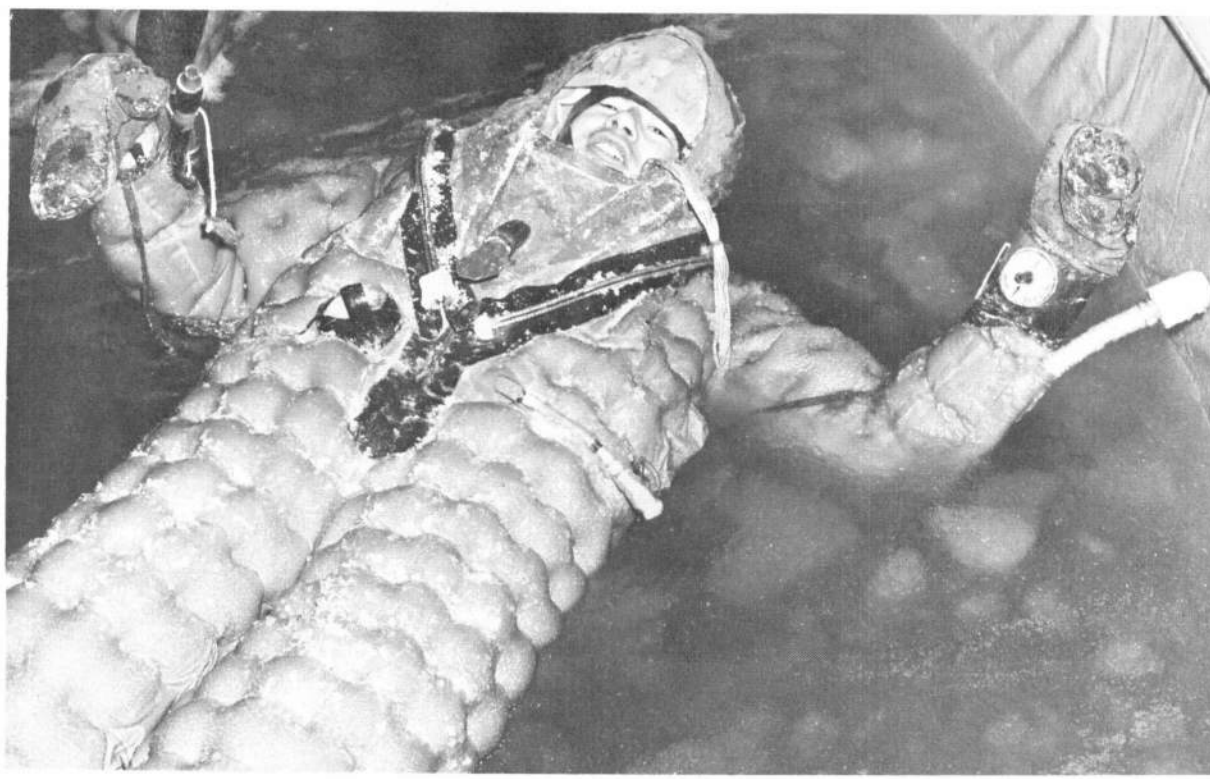

Fig. 7. Fully Inflated British Submarine Escape Immersion Suit in 29°F Water, 10°F Air and 20 MPH Wind.

Fig. 8. Right—Automatic Temperature Monitoring System; Left—"Max" Cart, Mobile Intensive Care and Emergency Life Support System.

Fig. 9. Investigators Reviewing the Temperature Record and Observing the ECG Monitor.

Fig. 10. ESCAPE AND EXPOSURE SUIT EVALUATION

SUBJECT OBSERVATION CHRONOLOGY

Area	Time
HEAD	
FACE	
NECK	
SHOULDER	
BACK	
UPPER ARM	
LOWER ARM	
HAND	
FINGERS	
PELVIC AREA	
GROIN	
THIGHS	
LOWER LEG	
FEET	
TOES	
DEFACATION	
URINATION	
SUIT LEAKS	
LEAK LOCATION	
SUBJECT FEELINGS	

FIGURE 12

POST-RUN QUESTIONNAIRE

SUBJECT No._____

1. SUIT
   - (a) Did you have any difficulty in putting the suit on?
   - (b) While waiting for the run to start, did you experience any discomfort and were you sweating?
   - (c) Did you have any discomfort in the before you inflated the suit?
   - (d) Did you have any difficulty in inflating the suit?
   - (e) Did you have any difficulty in removing the mitts from their stowage and/or in putting them on?
   - (f) Were you comfortable once the suit was inflated?
   - (g) Did the suit require readjustment — if so, how often?
   - (h) Did the suit leak?
2. PERSONAL
   - (a) Did you pass any urine during the time you were in the water, if so, how many times?
   - (b) Was there any difficulty in passing urine?
   - (c) Have you any comments to make on the effectiveness of the suit?
   - (d) What, if any, complaints do you have regarding personal comfort or distress?

Signature _____

Fig. 11. Subject Being Rewarmed After an Experiment with Observers and Physician Present.

RESULTS

Shortly after the tests began, a difference in the attitude of the pairs of subjects was observed. One pair usually moved actively and spoke frequently. The other pair was relatively passive and talked very little. At first, the exposure times attained appeared to correlate with this general attitude. Therefore, it was decided to maintain morale as high as possible in all subjects under all conditions and then repeat two of the conditions without this stimulation.

Type I experiments (motivation stimulation through exercise and general harrassment):

A. 29°F water, 10°F air, 20 MPH wind.

All four subjects sustained two hours of exposure or more before the experiment was terminated. In all cases objective extremity temperature data forced termination of the run.

The following exposure times were attained:

SUBJECT:	D	H	G	L
Time (Hours)	3.3	2.9	2.2	2.5

Four temperature areas showed a significant decrease in all experiments, and these areas together with the mean weighted skin temperatures (MWST) and mean body temperature (MBT) are shown in Tables VI-IX and represented in Figures 13-16.

TABLES VI-IX

29°F WATER, 10°F AIR, & 20 MPH WIND
(MOTIVATION)

SUBJECT D

TABLE VI

HOURS	CORE	TOE	LOW BACK	FINGER	MWST	MBT
0	986	710	901	756	882	950
1	984	563	805	756	786	917
2	998	574	770	599	772	923
3	988	531	673	551	745	902
3.3	984	518	539	541	734	900

SUBJECT H

TABLE VII

HOURS	CORE	TOE	LOW BACK	FINGER	MWST	MBT
0	963	707	942	764	918	947
1	1001	508	495	611	764	920
2	997	496	729	626	772	921
3.0	997	498	806	639	799	929

SUBJECT G

TABLE VIII

HOURS	CORE	TOE	LOW BACK	FINGER	MWST	MBT
0	991	754	928	763	900	960
1	997	537	787	605	783	925
2	978	503	599	610	760	904
2.2	961	501	570	625	758	901

SUBJECT L

TABLE IX

HOURS	CORE	TOE	LOW BACK	FINGER	MWST	MBT
0	978	669	908	629	850	934
1	987	509	773	527	771	914
2	995	491	745	512	767	918
2.5	994	478	677	476	758	914

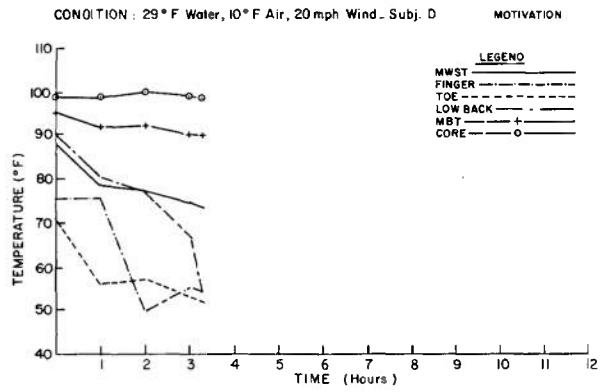

Fig. 13. Motivated Subject D exposed to 29°F water, 10°F air, 20 MPH wind.

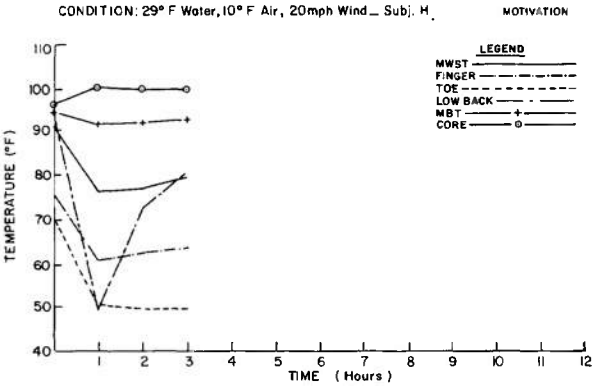

Fig. 14. Motivated Subject H exposed to 29°F water, 10°F air, 20 MPH wind.

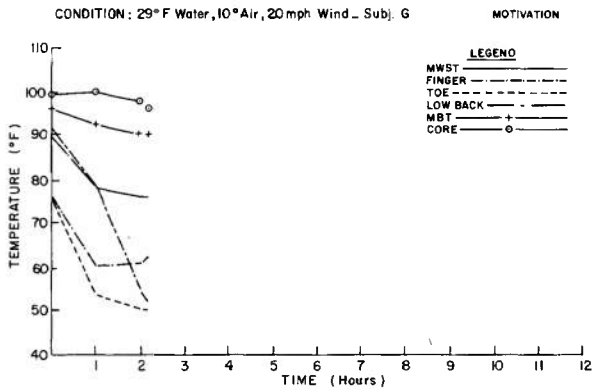

Fig. 15. Motivated Subject G exposed to 29°F water, 10°F air, 20 MPH wind.

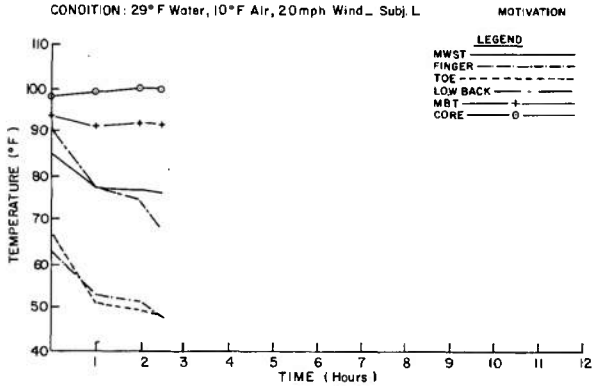

Fig. 16. Motivated Subject L exposed to 29°F water, 10°F air, 20 MPH wind.

B. 44°F water, 32°F air, 20 MPH wind.

All four subjects completed at least 4.5 hours of exposure before the experiment was terminated. Three subjects were taken from the water because of low extremity temperatures. The fourth man experienced stomach cramps and low back pain following approximately eight hours of exposure.

The following exposure times were attained:

SUBJECT:	D	H	G	L
Time (Hours)	8.2	7.1	4.5	4.8

The same four temperature areas showed a decrease in all experiments and these values are shown in Tables X-XIII together with the MWST and MBT. This tabular information is represented in Figures 17-20.

TABLES X, XI

44°F WATER, 32°F AIR, & 20 MPH WIND
(MOTIVATION)

SUBJECT D

TABLE X

HOURS	CORE	TOE	LOW BACK	FINGER	MWST	MBT
0	979	788	872	571	831	929
1	988	629	656	610		
2	995	585	758	604	833	940
3	990	572	763	593		
4	989	576	643	618	776	917
5	987	607	586	601		
6	987	592	810	653	812	928
7	986	590	634	629		
8	985	594	723	639	794	919
8.2	983	561	644	622	792	917

SUBJECT H

TABLE XI

HOURS	CORE	TOE	LOW BACK	FINGER	MWST	MBT
0	993	704	942	719	849	947
1	100	653	839	661	829	942
2	1007	606	647	699	802	938
3	1006	620	797	768	831	947
4	1001	589	790	614	833	944
5	998	588	548	556	760	918
6	991	544	717	575	788	921
7	990	535	703	594	777	918
7.1	990	538	738	585	772	916

TABLES XII, XIII

44°F WATER, 32°F AIR, & 20 MPH WIND
(MOTIVATION)

SUBJECT G

TABLE XII

HOURS	CORE	TOE	LOW BACK	FINGER	MWST	MBT
0	991	722	909	664	845	941
1	993	603	568	618		
2	996	550	681	621	791	920
3	982	535	706	605		
4	974	529	726	619	785	889
4.5	942	545	701	536	776	867

SUBJECT L

TABLE XIII

HOURS	CORE	TOE	LOW BACK	FINGER	MWST	MBT
0	995	653	829	539	848	951
1	993	618	863	499	841	940
2	100	539	894	521	850	950
3	999	514	911	497	846	947
4	990	492	909	486	765	914
4.8	992	485	892	485	816	931

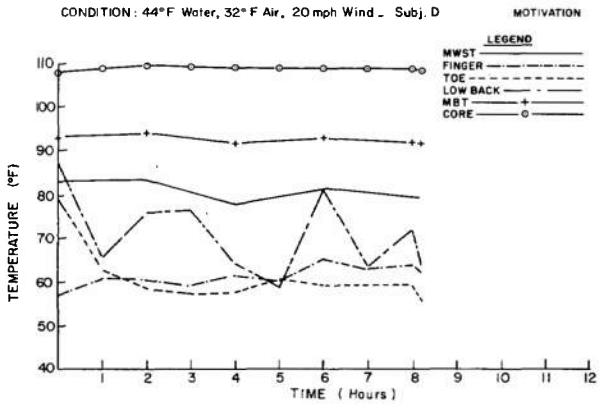

Fig. 17. Motivated Subject D exposed to 44°F water, 32°F air, 20 MPH wind.

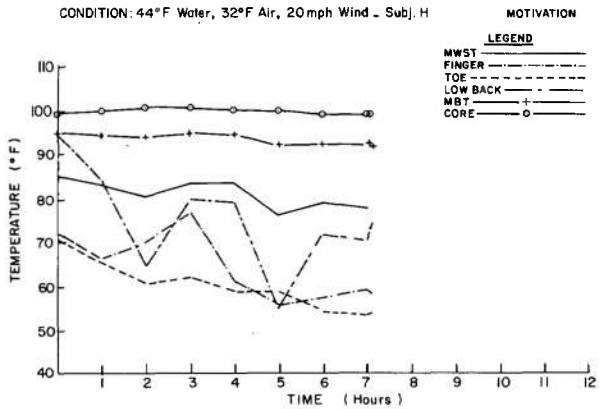

Fig. 18. Motivated Subject H exposed to 44°F water, 32°F air, 20 MPH wind.

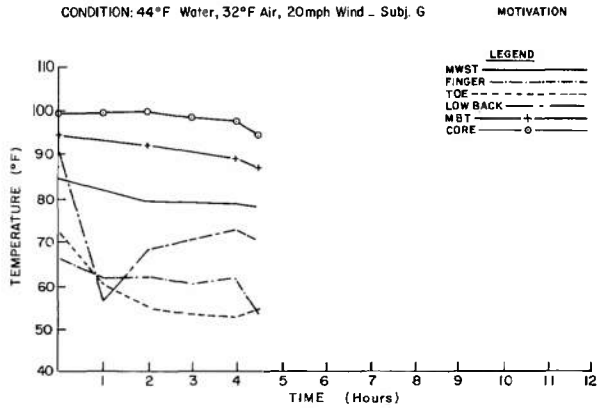

Fig. 19. Motivated Subject G exposed to 44°F water, 32°F air, 20 MPH wind.

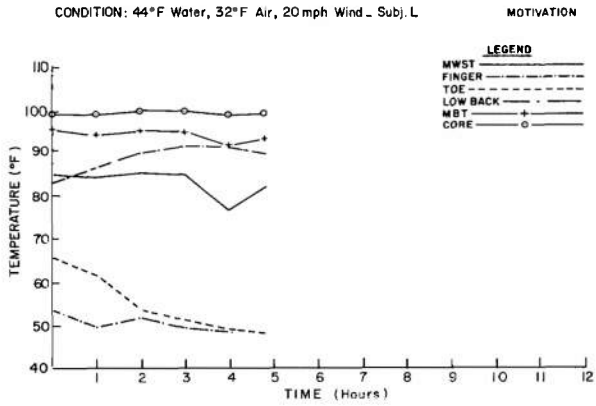

Fig. 20. Motivated Subject L exposed to 44°F water, 32°F air, 20 MPH wind.

C. 60°F water, 45°F air, 20 MPH wind.

All four subjects completed at least six hours of exposure before the experiment was terminated. Three subjects comfortably completed twelve hours of exposure. The fourth subject displayed a rapid decrease in core temperature together with a confused appearance, some vertigo, and finally extreme nausea during the rewarming period. The following exposure times were attained·

SUBJECT:	D	H	G	L
Time (Hours)	12.0	6.1	12.0	12.0

Four temperature areas showed a decrease in the experiments and these temperature changes are displayed in Tables XIV-XVII together with the MWST and MBT. This numerical data is represented in Fig. 21-24.

TABLES XIV, XV XVI, XVII

60°F WATER, 45°F AIR, & 20 MPH WIND
(MOTIVATION)

SUBJECT D

TABLE XIV

HOURS	CORE	TOE	LOW BACK	FINGER	MWST	MBT
0	969	906	881	772	913	949
1	978	764	890	610		
2	986	715	920	611	878	949
3	981	707	903	627		
4	983	705	891	715	871	945
5	983	703	901	766		
6	982	705	894	702	882	948
7	986	701	887	637		
8	987	771	892	707	893	955
9	986	774	891	699		
10	985	734	902	627	890	952
11	981	717	912	645		
12	975	712	906	623	900	949

SUBJECT H

TABLE XV

HOURS	CORE	TOE	LOW BACK	FINCER	MWST	MBT
0	982	836	925	945	934	965
1	986	685	789	668		
2	985	647	765	645	841	936
3	981	619	822	635		
4	979	601	838	633	837	931
5	972	593	851	617		
6	961	989	855	626	842	920
6.1	952	588	847	623	839	916

SUBJECT G

TABLE XVI

HOURS	CORE	TOE	LOW BACK	FINGER	MWST	MBT
0	981	923	944	948	940	966
1	984	818	929	672		
2	992	756	930	698	855	945
3	984	799	929	696		
4	984	711	912	629	877	947
5	984	679	923	629		
6	981	656	926	610	858	939
7	985	644	938	603		
8	978	621	904	624	874	942
9	977	617	934	602		
10	975	605	933	583	869	939
11	969	603	937	543		
12	967	606	924	621	858	930

SUBJECT L

TABLE XVII

HOURS	CORE	TOE	LOW BACK	FINGER	MWST	MBT
0	981	710	928	641	884	948
1	982	636	854	588		
2	983	607	884	562	843	935
3	982	590	899	548		
4	984	588	900	536	822	929
5	982	592	889	533		
6	981	584	901	536	827	929
7	983	586	898	535		
8	978	580	911	534	845	933
9	975	573	916	536		
10	974	569	920	537	840	928
11	971	553	924	522		
12	976	555	919	522	839	929

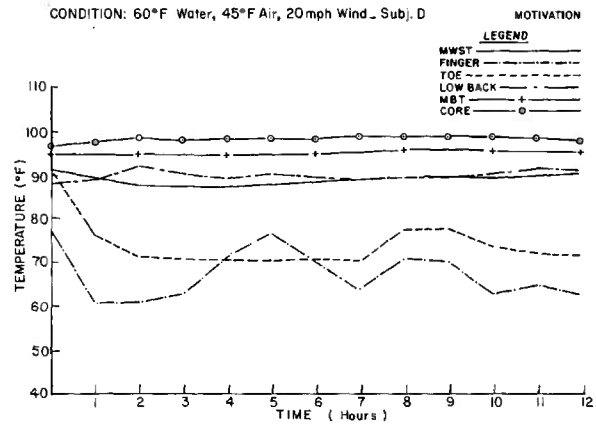

Fig. 21. Motivated Subject D exposed to 60°F water, 45°F air, 20 MPH wind.

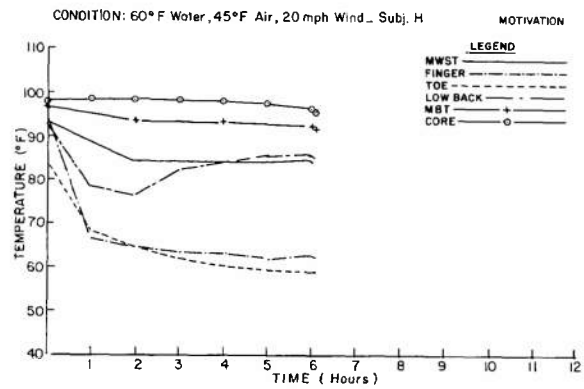

Fig. 22. Motivated Subject H exposed to 60°F water, 45°F air, 20 MPH wind.

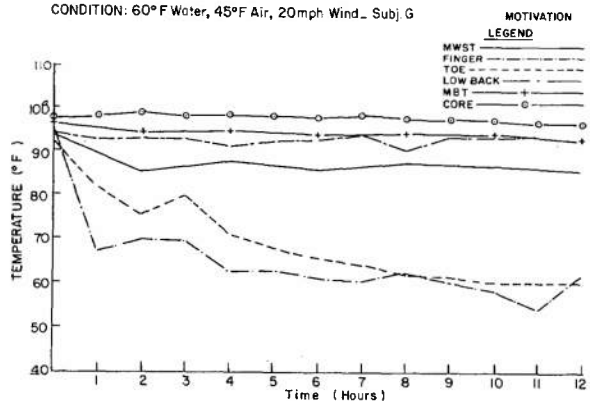

Fig. 23. Motivated Subject G exposed to 60°F water, 45°F air, 20 MPH wind.

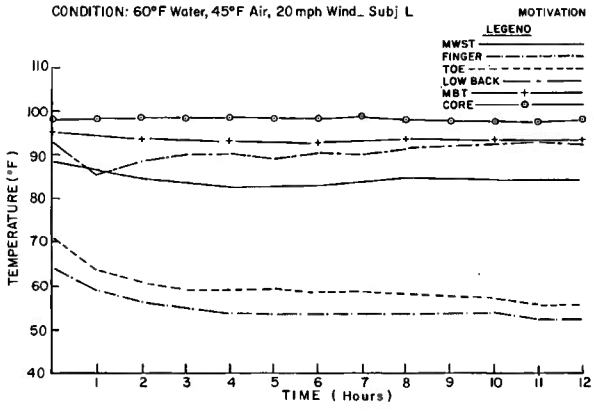

Fig. 24. Motivated Subject L exposed to 60°F water, 45°F air, 20 MPH wind.

Type II experiments (subjects observed but not harrassed or influenced to exercise):

A. 44°F water, 32°F air, 20 MPH wind.

All subjects completed at least 2.3 hours of exposure before the experiment was terminated. Two men were taken from the water because of low objective extremity temperature readings. Subject G complained of pain at a previously (incurred) fracture site 2.8 hours into the exposure. The fourth man completed the twelve hour limit time of exposure.

The following exposure times were attained:

SUBJECT:	D	H	G	L
Time (Hours)	12.0	2.3	2.8	2.9

A decrease in the fourth temperature areas previously described was seen and these changes are shown in Table 18-21 together with the MWST and MBT. This numerical information is represented in Fig. 25-28.

TABLES XVIII

44°F WATER, 32°F AIR & 20 MPH WIND
(NO MOTIVATION)

SUBJECT D

TABLE XVIII

HOURS	CORE	TOE	LOW BACK	FINGER	MWST	MBT
0	987	960	914	919	922	964
1	987	773	850	633		
2	986	659	842	593	820	930
3	985	640	872	566		
4	985	619	876	620	833	933
5	983	607	873	589		
6	984	595	872	605	836	934
7	982	596	876	589		
8	982	585	878	577	829	930
9	985	583	885	588		
10	984	577	883	623	828	931
11	985	574	885	611		
12	984	571	894	598	827	931

TABLES XIX XX. XXI

44°F WATER, 32°F AIR & 20 MPH WIND
(NO MOTIVATION)

SUBJECT H

TABLE XIX

HOURS	CORE	TOE	LOW BACK	FINGER	MWST	MBT
0	995	653	829	539	801	929
1	1001	561	887	725	838	946
2	992	504	854	586	805	929
2.3	993	497	852	573	802	921

SUBJECT G

TABLE XX

HOURS	CORE	TOE	LOW BACK	FINGER	MWST	MBT
0	995	819	956	909	931	973
1	991	675	935	670	841	940
2	986	613	903	574	820	930
2.8	985	584	875	501	804	924

SUBJECT L

TABLE XXI

HOURS	CORE	TOE	LOW BACK	FINGER	MWST	MBT
0	993	704	942	719	919	967
1	991	610	873	528	839	941
2	987	526	843	495	823	931
2.9	983	496	844	494	817	914

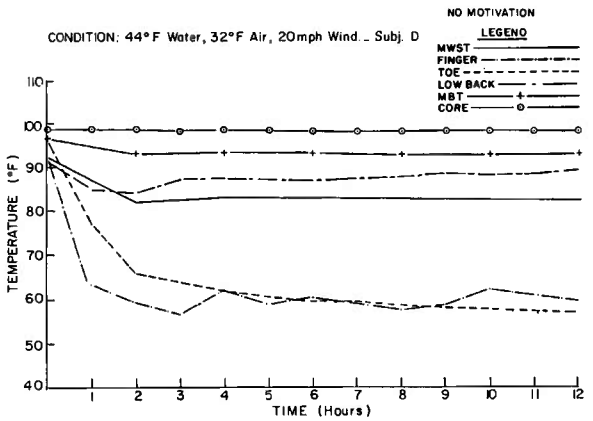

Fig. 25. Unmotivated Subject D exposed to 44°F water, 32°F air 20 MPH wind.

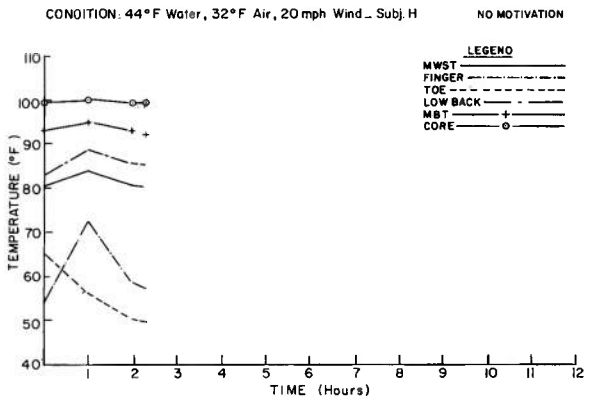

Fig. 26. Unmotivated Subject H exposed to 44°F water, 32°F air 20 MPH wind.

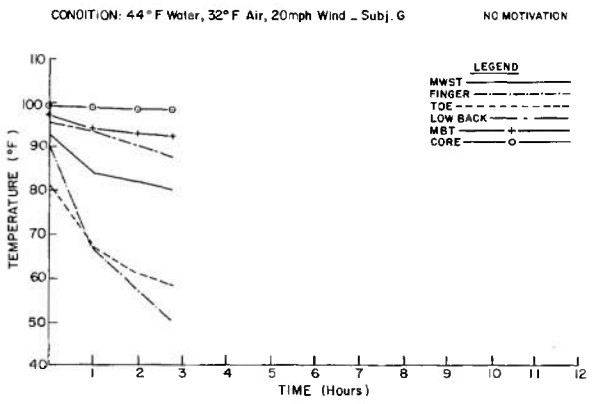

Fig. 27. Unmotivated Subject G exposed to 44°F water, 32°F air 20 MPH wind.

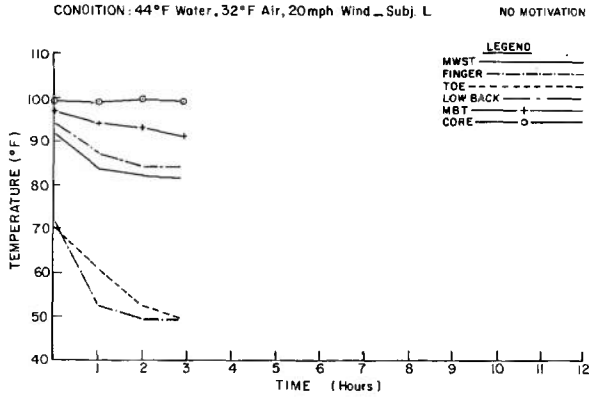

Fig. 28. Unmotivated Subjert L exposed to 44°F water, 32°F air 20 MPH wind.

B. 60°F water, 45°F air, 20 MPH wind.

All subjects completed at least 5.2 hours of exposure before the experiment was terminated. Two men completed the twelve hour limit. Subject G was taken from the water because of severe back pain unrelated to temperature. Subject L experienced low extremity temperature for several hours and was removed from the water.

The following exposure times were attained:

SUBJECT:	D	H	G	L
Time (Hours)	12.0	12.0	10.0	5.2

Four temperature areas showed a significant decrease in all experiments and these temperature changes are shown in Table XXII-XXV together with the MWST and MBT. This numerical data is represented in Figs. 29-32.

TABLES XXII, XXIII

60°F WATER, 45°F AIR, & 20 MPH WIND
(NO MOTIVATION)

SUBJECT D

TABLE XXII

HOURS	CORE	TOE	LOW BACK	FINGER	MWST	MBT
0	982	681	918	846	900	954
1	985	632	897	630		
2	985	634	846	608	835	934
3	984	624	791	565		
4	981	611	886	579	813	924
5	981	598	886	581		
6	981	594	892	597	840	933
7	980	589	887	596		
8	983	602	889	613	836	933
9	981	609	880	564		
10	981	608	883	631	840	933
11	984	619	892	610		
12	983	614	874	601	840	934

SUBJECT H

TABLE XXIII

HOURS	CORE	TOE	LOW BACK	FINGER	MWST	MBT
0	988	691	937	900	893	955
1	986	656	931	678		
2	984	620	915	645	871	945
3	985	600	836	632		
4	986	585	872	588	835	935
5	985	571	880	581		
6	984	565	861	571	816	927
7	985	551	784	630		
8	984	548	776	576	815	927
9	986	544	829	574		
10	990	540	823	559	823	933
11	986	549	934	575		
12	984	548	852	599	827	931

TABLES XXIV, XXV

60°F WATER, 45°F AIR, & 20 MPH WIND
(NO MOTIVATION)

SUBJECT G

TABLE XXIV

HOURS	CORE	TOE	LOW BACK	FINGER	MWST	MBT
0	984	765	923	787	802	922
1	988	585	875	676		
2	988	572	849	658	848	940
3	989	564	850	550		
4	991	571	857	598	846	942
5	991	561	839	543		
6	991	547	913	560	851	943
7	993	545	730	531		
8	998	559	801	554	803	932
9	998	604	846	604		
10	100	611	857	543	800	933

SUBJECT L

TABLE XXV

HOURS	CORE	TOE	LOW BACK	FINGER	MWST	MBT
0	994	681	937	640	841	942
1	981	589	917	553		
2	981	577	915	541	822	927
3	980	554	928	527		
4	974	538	925	515	823	923
5.2	977	525	926	503	772	908

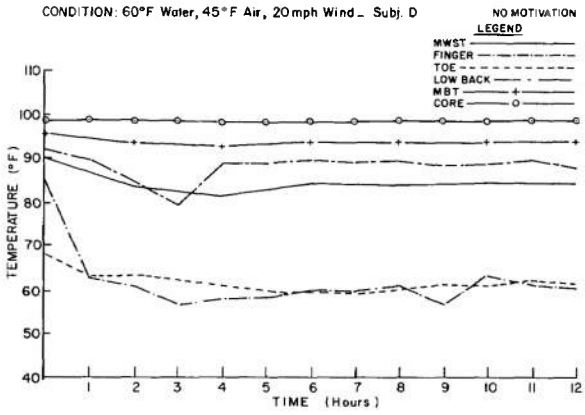

Fig. 29. Unmotivated Subject D exposed to 60°F water, 45°F air, 20 MPH wind.

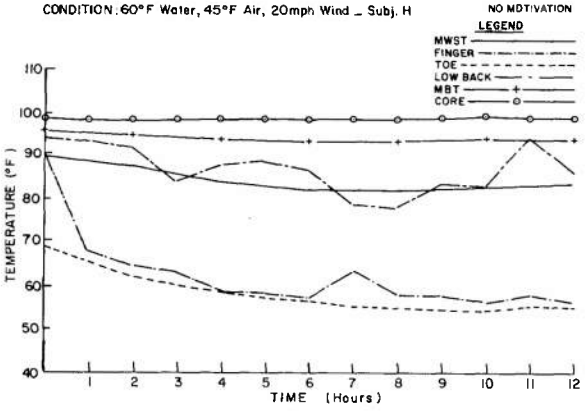

Fig. 30. Unmotivated Subject H exposed to 60°F water, 45°F air, 20 MPH wind.

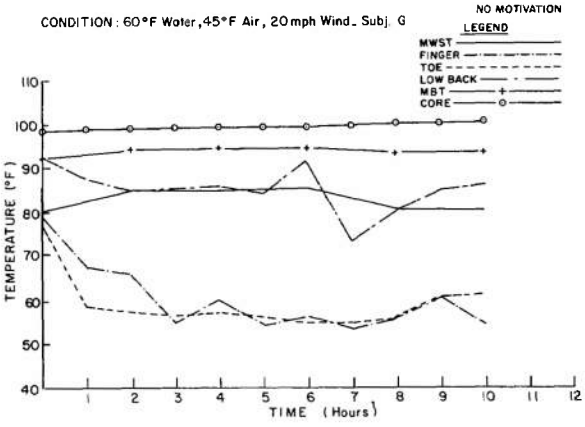

Fig. 31. Unmotivated Subject G exposed to 60°F water, 45°F air, 20 MPH wind.

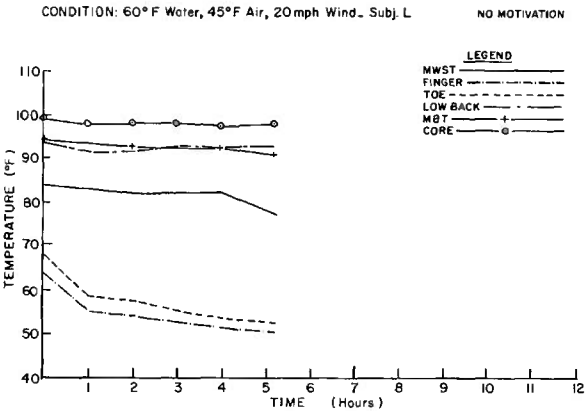

Fig. 32. Unmotivated Subject L exposed to 60°F water, 45°F air, 20 MPH wind.

C. 90°F water, 85°F air, still.

All four subjects completed the experimental time limit of twelve hours.

The four temperature areas represented previously will be displayed for the sake of comparison. The small temperature changes are shown in Tables XXVI-XXIX together with the MWST and MBT. This numerical data is represented in Figures 33-36.

TABLES XXVI, XXVII

90°F WATER, 85°F AIR, & STILL WIND
(NO MOTIVATION)

SUBJECT D

TABLE XXVI

HOURS	CORE	TOE	LOW BACK	FINGER	MWST	MBT
0	979	923	951	910	938	964
1	980	969	939	970		
2	983	974	930	976	953	972
3	985	972	927	934		
4	988	975	922	931	948	974
5	987	972	923	977		
6	991	974	922	944	946	978
7	989	973	922	935		
8	984	971	924	945	944	970
9	982	960	915	918		
10	990	954	935	912	944	974
11	996	961	957	911		
12	995	935	938	910	946	978

SUBJECT H

TABLE XXVII

HOURS	CORE	TOE	LOW BACK	FINGER	MWST	MBT
0	995	899	912	947	920	969
1	989	969	953	927		
2	987	960	937	961		
3	986	964	932	964		
4	986	964	927	915	970	980
5	984	953	927	936		
6	983	928	938	918		
7	983	912	956	919		
8	987	932	965	950	943	971
9	987	899	936	895		
10	987	913	945	895		
11	988	902	916	894		
12	988	918	925	894	949	974

TABLES XXVIII, XXIX
90°F WATER, 85°F AIR & STILL WIND
(NO MOTIVATION)

SUBJECT G

TABLE XXVIII

HOURS	CORE	TOE	LOW BACK	FINGER	MWST	MBT
0	991	935	979	908	986	988
1	1002	982	975	918		
2	995	981	956	922		
3	997	976	947	950		
4	1001	970	947	924	959	986
5	992	953	950	908		
6	995	917	945	913		
7	991	929	944	920		
8	986	941	940	953	959	976
9	986	914	938	905		
10	999	910	928	912		
11	1001	909	923	916		
12	994	903	925	890	927	971

SUBJECT L

TABLE XXIX

HOURS	CORE	TOE	LOW BACK	FINGER	MWST	MBT
0	990	885	908	902	915	964
1	983	968	967	973		
2	986	965	930	956		
3	983	965	922	977		
4	980	955	919	945	936	964
5	980	942	918	940		
6	979	909	912	914		
7	978	904	911	941		
8	976	904	903	931	923	957
9	978	904	909	924		
10	978	903	910	918		
11	984	903	899	914		
12	980	932	903	847	923	960

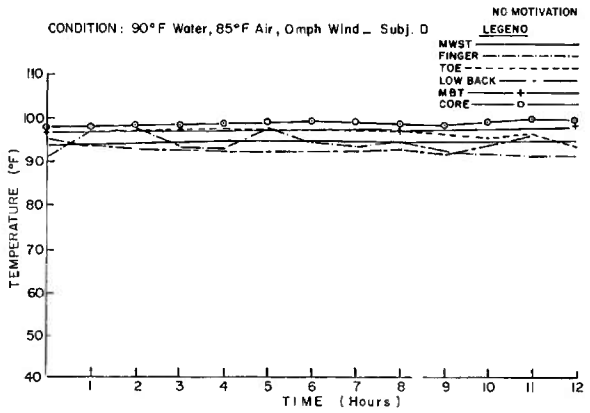

Fig. 33. Unmotivated Subject D exposed to 90°F water, 85°F air, 0 MPH wind.

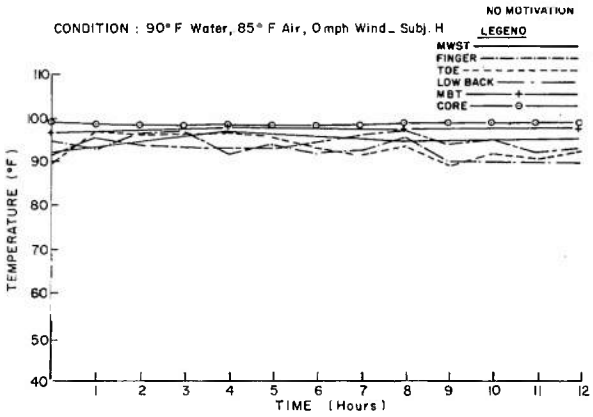

Fig. 34. Unmotivated Subject H exposed to 90°F water, 85°F air, 0 MPH wind.

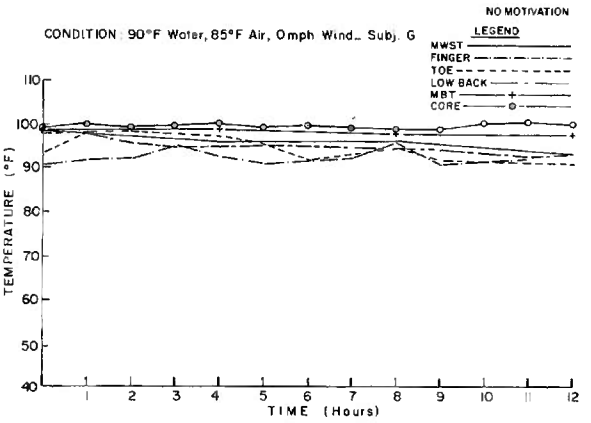

Fig. 35. Unmotivated Subject G exposed to 90°F water, 85°F air, 0 MPH wind.

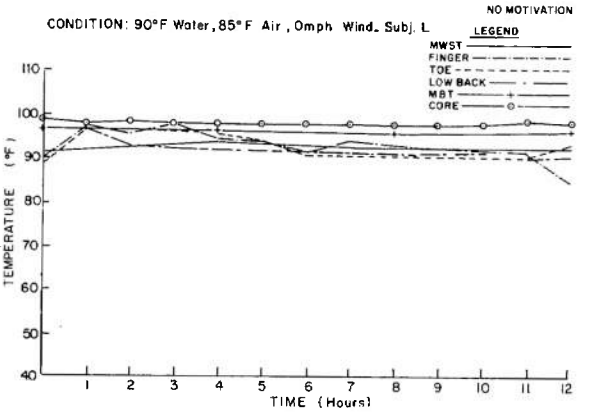

Fig. 36. Unmotivated Subject L exposed to 90°F water, 85°F air, 0 MPH wind.

Subjective comments collected during the course of the project noted as follows:

1. Upon entering the water, the right cuff frequently admitted water which usually pooled in the low back area.

2. The glove-suit interface was inadequate. This permitted water to enter around the wrist and to pool inside the gloves.

3. The extremities of some suits would not inflate. Others only twisted the extremity during inflation producing pain and discomfort.

4. A snorkel type device would be desirable in a high sea. This would enable maintenance of water-tight integrity around the head area.

5. In 29°F water, the gloves usually became stiff, uninflatable, and were difficult to don.

DISCUSSION

The primary purpose of this project was to determine the performance and survival time provided by the British Mark VII Submarine Escape Immersion Suit under specific environmental conditions.

A twelve hour limit was placed on exposure times because of the following restrictions:

1. The same subjects participated in all experiments.

2. The subjects occasionally participated in two trials within a single week.

3. The subjects who volunteered to participate performed their normal shipboard duties as well.

4. A twelve hour exposure would provide adequate information from which extrapolation to theoretical end-points could be made.

The critical question to be answered was, what point in time will permanent damage occur to extremities and when will death supervene? The most sensitive tissue in each man under each condition was chosen as the limiting tissue. Permanent tissue damage would be expected with approximately one hour exposure at 40°F.

The decrease in core temperature for each condition was calculated and extrapolated to 86°F, the theoretical end-point or death. It is at this temperature that most individuals become unconscious, may drown, and in many cases display cardiac irregularities.[5]

Estimating the exposure times, which would produce permanent tissue damage, was accomplished by calculating the rate of temperature change during the late, stable portion of the temperature curve. Extrapolation of the time-temperature curve to a point of 40°F plus an additional exposure of one hour at this temperature provides the projected endpoint.

Survival times were calculated from the rate of core temperature change. Using the value from the highest core temperature reading to the value at the termination of the experiment, extrapolation to the predetermined endpoint of 86°F was made. Because this rate of change usually increases at temperatures below 95°F, valid endpoints are difficult to project. Table XXX shows the results of these calculations and the termination times for each experiment under each condition.

When the extrapolated tissue damage times and critical core times from the two motivation experiments were compared with the no-motivation experiments, it appears that tissue damage will occur sooner in the no-motivation experiments. However, the drop in the critical core temperature, appears to occur earlier in the motivation experiments. In the motivation experiments a high exercise level and desire to stay warm seems to maintain peripheral circulation. This contrasts with the no-motivation experiments where minimal exercise and stimulation took place. In the former case, with more exercise, a higher percentage of the blood is shunted to the periphery for its protection. While in the latter, with less exercise, more blood remains centrally to protect the core temperature.

The glove-suit interface was inadequate. Water consistently penetrated the glove and right cuff. This naturally detracted from the exposure time. Objective temperature measurements in the lower extremities, particularly the larger toe, caused early termination of many tests. Urinating presented difficulty which was usually overcome by partial deflation of the suit. Pain and cold in the back area were noted. The suits frequently needed reinflation after a few hours in the water. In a high sea, a snorkel to aid breathing and keep the hood water tight would be desirable. The suit size presented difficulty. The men found the head area tight, especially over the ears; they were unable to get their shoes into the feet. Therefore, sweat socks had to be substituted for shoes.

The British experiments estimated tissue damage and survival exposure time by extrapolation. The same pattern has been followed in our study. The British used a temperature of 47°F as their tissue damage endpoint and 95°F as their critical core temperature. Their test program specified less severe environmental conditions (41°F water, 58.6°F still air) and indicated that the hands and feet would begin to suffer after about six to twelve hours. Under sim-

ilar conditions (44°F water, 32°F air, 20 MPH wind) in our subjects we predict a range of 10-20 hours. The British further indicated that in 41°F water many men would probably have died within twelve to eighteen hours. Our tests indicate a range of eight to twenty four hours survival. Neither of these studies has adequately considered the effects of fatigue, lack of food and water, or psychological distress over prolonged exposure periods.

CONCLUSIONS

1. The British Mark VII SEIS suit would probably eliminate the immediate exposure casualties that might be expected from men entering cold water.
2. Considering the rates of temperature change over the times observed, the extremities of the most sensitive men would probably be damaged after about:
   a. 5 hours at 29°F water, 10°F air, 20 MPH wind.
   b. 10 hours at 44°F water, 32°F air, 20 MPH wind.
   c. 24 hours at 60°F water, 45°F air, 20 MPH wind.
   d. 24 hours at 90°F water, 85°F air, still.
3. The critical core temperature (86°F) would occur in the most sensitive men after about:
   a. 6 hours at 29°F water, 10°F air, 20 MPH wind.
   b. 12.5 hours at 44°F water, 32°F air, 20 MPH wind.
   c. 24 hours at 60°F water, 45° air, 20 MPH wind.
   d. 24 hours 90°F water, 85°F air, still.
4. Considering the total problem of submarine escape followed by survival on the surface, the Mark VII SEIS concept represents a reasonable approach to the problem of escape from a bottomed submarine.

RECOMMENDATIONS

The British Submarine Escape Immersion Suit answers the immediate problem of submarine escape and surface protection. Therefore, it is recommended as an interim escape and survival mode. Phase II studies which include determination of compatibility of the British Mark VII SEIE with U. S. Navy escape trunks and procedures should be initiated immediately. If the extremity areas of the suit could be improved and slightly more overall thermal protection added, the exposure time of the suit could be extended to meet original project criteria. Appropriate anthropomorphic measurements are necessary so that the final suit configuration and size are consistent with the human envelope range of U. S. Navy submariners.

ACKNOWLEDGEMENTS

The authors wish to acknowledge and cooperation shown by the Commanding Officers of the USS Sea Owl (SS405) and USS Sea Robin (SS407) and the men under their command who volunteered to act as test subjects. The facilities and equipment of the Aerospace Crew Equipment Department were invaluable, and we are grateful for the assistance of the Departmental Staff. HMC R. R. Lavoie, HM1 M. J. Cipriano, and HM2 J. Fifield worked long and hard to maintain both equipment and cordial relations with the test subjects.

TABLE XXX

SUMMARY OF EXPOSURE TIMES OF MEN WEARING THE BRITISH MARK VII SEIS NECESSARY TO PRODUCE TERMINATION OF THE EXPERIMENT, TISSUE DAMAGE AND DEATH AT THE VARIOUS ENVIRONMENTAL CONDITIONS

Environmental Condition	(1) Termination of Experiment (2) Tissue Damage (3) Death	Subject Time (hours)				Range (hours)
		D	H	G	L	
A. 29, 10, 20 (Motivation)	(1)	3.3	3.0	2.2	2.5	(2.2-3.3)
	(2)	7.0	5.8	9.1	5.1	(5.1-9.1)
	(3)	12.2	24	5.6	>24	(5.6-24)
B. 44, 32, 20 (Motivation)	(1)	8.2	7.1	4.5	4.8	(4.5-8.2)
	(2)	20.7	18.7	9.5	10.3	(9.5-20.7)
	(3)	> 24	> 24	8.2	> 24	(8.2-24)
C. 60, 45, 20 (Motivation)	(1)	12.0	6.1	12.0	12.0	(6.1-12.0)
	(2)	23.6	> 24	> 24	> 24	(24)
	(3)	> 24	18.5	> 24	> 24	(18.5-24)
D. 90, 85, still (No-Motivation)	(1)	12.0	12.0	12.0	12.0	(12)
	(2)	> 24	> 24	> 24	> 24	(24)
	(3)	> 24	> 24	> 24	> 24	(24)
E. 44, 32, 20 (No-Motivation)	(1)	12.0	2.3	2.8	2.9	(2.3-12)
	(2)	> 24	5.3	4.9	7.5	(4.9-24)
	(3)	> 24	12.5	> 24	> 24	(12.5-24)
F. 60, 45, 20 (No-Motivation)	(1)	12.0	12.0	10.0	5.2	(5.2-12)
	(2)	> 24	> 24	20.5	14.8	(14.8-24)
	(3)	> 24	> 24	> 24	> 24	(24)

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UNCLASSIFIED

Security Classification

DOCUMENT CONTROL DATA - R & D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY *(Corporate author)*

U.S. NAVAL SUBMARINE MEDICAL CENTER, Submarine Medical Research Laboratory

2a. REPORT SECURITY CLASSIFICATION

UNCLASSIFIED

2b. GROUP

N/A

3. REPORT TITLE

PHYSIOLOGICAL EVALUATION OF THE BRITISH MARK VII SUBMARINE ESCAPE IMMERSION SUIT (SEIS) DURING IMMERSION

4. DESCRIPTIVE NOTES *(Type of report and inclusive dates)*

Interim report on BuMed Work Unit

5. AUTHOR(S) *(First name, middle initial, last name)*

David A. HALL, LT, MSC, USNR, Joel J. NOBEL, LT, MC, USNR, and Mr. Louis J. SANTA MARIA

6. REPORT DATE	7a. TOTAL NO. OF PAGES	7b. NO. OF REFS
14 March 1968		12

8a. CONTRACT OR GRANT NO.	9a. ORIGINATOR'S REPORT NUMBER(S)
b. PROJECT NO. MF022.03.03-9027.03	SMC, SMRL REPORT NUMBER 514
c.	9b. OTHER REPORT NO(S) *(Any other numbers that may be assigned this report)*
d.	

10. DISTRIBUTION STATEMENT

This document has been approved for public release and sale; its distribution is unlimited.

11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY
	U.S. Naval Submarine Medical Center Box 600, Naval Submarine Base New London Groton, Connecticut 06340

13. ABSTRACT

This study determines the general performance and survival time afforded by the British Mark VII Submarine Escape Immersion Suit (SEIS), in 29°F. water, 10°F. air, and 20 MPH wind speed.

It was found that the British suit did not provide the 24-hour estimated survival time at the severe conditions listed above, and the four subjects were taken from the water after an average time of 2.8 hours of exposure. Damage to the hands and feet would probably occur between 5.1 and 9.1 hours. Death would probably occur after 5.6 to 24 hours of exposure.

Tests were also conducted in 90°F. water and 85°F., in still air. These tests indicated that no major problem will be encountered under these conditions.

The environmental conditions were then changed in a step-wise fashion from 29°F. water, 10°F. air, and 20 MPH wind, until 24-hour estimated survival time was obtained. At 44°F. water, 32°F. air, and 20 MPH wind, 24-hour survival may be predicted for most men, based on results in the limited number of subjects used in this investigation.

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Survival in cold water						
Submarine escape						
Submarine escape suits (British Mark VII) evaluation of						
Protective suits for submarine personnel						