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NAVAL SUBMARINE MEDICAL RESEARCH LABORATORY

SUBMARINE BASE, GROTON, CONN.

REPORT NUMBER 739

A REVIEW OF AVAILABLE HEATED WET-SUIT PROTECTION FOR DIVERS AND SWIMMERS

by

Frederick P. Rentz, LT MC USNR

Bureau of Medicine and Surgery, Navy Department
Research Work Unit MF099.01.01.10

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J.H. Baker, CAPT MC USN
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Transmitted by

Valentine David Galasyn

Valentine D. Galasyn
Commander, MC, U.S. Navy
Director, School of Submarine Medicine

Reviewed and Approved by:

Charles F. Gell

C.F. Gell, M.D.,D.Sc.(Med)
Scientific Director
NavSubMedRschLab

Approved and Released by:

JH Baker

J.H. Baker, CAPT MC USN
Officer in Charge
NavSubMedRschLab

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SUMMARY PAGE

THE PROBLEM

To review the currently available protective wet-suits for short, cold water swims or for long swims in moderately cold water. It has long been recognized that cold water limits the performance and endurance of divers and combat swimmers.

FINDINGS

Heated wet-suits are available which satisfy the requirements for most diving tasks. Further developments may include a device which would allow a free-swimming diver to remain for six to eight hours in 5° C water.

APPLICATION

This paper should be of interest to UDT, Seal and Marine Reconnaissance personnel, who are concerned with long diving evolutions, as well as to those concerned with deep diving and Arctic diving, where extremely cold water requires heat replacement.

ADMINISTRATIVE INFORMATION

The author prepared this paper in partial fulfillment of the requirements for qualification as a Submarine Medical Officer. His paper was selected for publication as a NavSubMedRschLab Report in order to make this material available to the Technical Library at the Laboratory, and for reference material at the School of Submarine Medicine.

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ABSTRACT

A review of current information concerning heat replacement wet-suits for divers is presented. The limitations of physiologic response to cold, aided by modern insulative garments, are defined, and the necessity for supplemental heat is demonstrated. Developments in electrically heated wet-suits and hot water suits are presented, as well as information concerning batteries, chemical heaters and radioisotope-fueled heaters.

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INTRODUCTION

One of the major obstacles remaining in man's exploration of the oceans is the limitation that chilling has imposed on divers. Although divers generally pride themselves in their ability to withstand cold stress, it is this capability and not duration of gas supply or simple fatigue from exertion which now limits the length of free-swimming dives and shallow underwater swims in cold water.

PHYSIOLOGY AND IMMERSION

At rest in still, warm air, the human body is in thermal equilibrium. In its simplest form the equation expressing this could be written:

Heat production = Heat loss

This can be expanded to show the various ways heat is gained and lost:

> Metabolic heat production plus muscular heat production = conductive-convective heat loss plus radiative heat loss plus respiratory heat loss plus heat loss through sweat and urine.

Since water has 25 times the thermal conductivity and 1,000 times the specific heat of air[5], conductive-convective heat loss is by far the greatest heat loss mechanism in water.[5] Although body temperature can be maintained over a span of 18°C to 52°C in air [21], long-term temperature stability for most nude subjects in water is possible only in the narrow temperature range of 35°C to 35.5°C[3]. The combined effects of cold, immersion, and accidentally-swallowed water can increase urine output up to three times the normal rate[6] with consequent additional heat loss.

Respiratory heat loss, of relatively lesser importance at shallow depths with oxygen or oxygen-nitrogen breathing mixtures, becomes approximately equal to the sum of metabolic and muscular heat production at a depth of 600 feet in 5°C water with helium-oxygen breathing mixtures.[13]

Basal metabolic heat production is generally taken to be about 40 kg-cal per hour per square meter of body surface area.[3,21] Although heat production can be increased 15 to 20 times the basal value by vigorous muscular activity[2,21], a more realistic figure for sustained swimming would be 200 to 300 kg-cal per square meter.[2] Heat production is generally measured as a function of oxygen consumption: 4.85 kg-cal per liter of oxygen consumed.

The magnitude of thermal losses varies with: (a) the temperature of the water, (b) the vasoconstrictive response of the skin, (c) the speed at which the water in contact with the skin is flowing, and (d) the effective natural insulation of subcutaneous fat.

Figure 1, from Craig and Dvorak[3], shows the large reduction in thermal

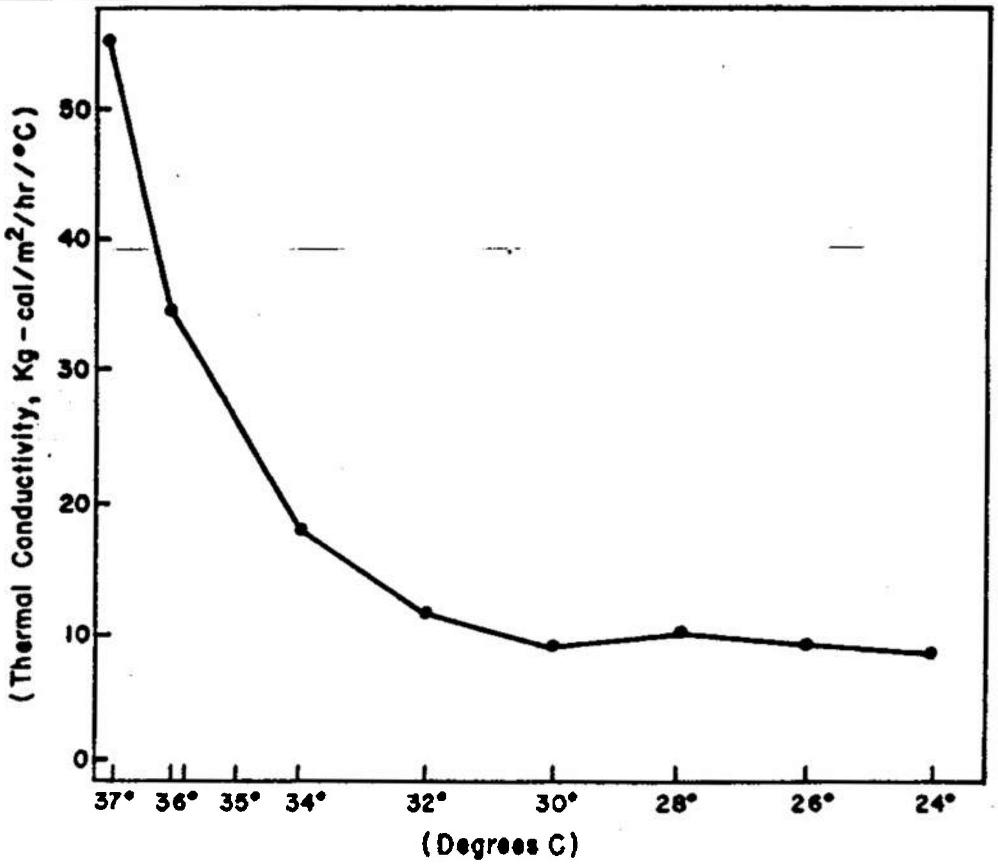

Fig. 1. Variation of skin conductivity with temperature (from Craig and Dvorak)[3].

conductivity of the skin with decreasing temperature. This is due in large part to vasoconstriction.

There is a great natural variation in thermal conductivity of the skin, ranging from 34 kg-cal per square meter per hour to 108 kg-cal per square meter per hour[6] in Beckman and Reeves' study. Generally, obese people with more subcutaneous fat tend to have lower thermal conductivities.

Although it would seem practical to offset thermal losses by exercising in moderately cold (35°C to 24°C) water, thereby increasing heat production, exercise actually accelerates the cooling by increasing the flow of water over the body (flushing).[22]

The CLO is a useful arbitrary measure of insulation, both natural and added. It is defined as 0.18°C per kg-cal per square meter per hour, or that insulation which allows 5.5 kg-cal per degree centigrade per square meter per hour to flow across a surface.[23] Figure 2 is a nomogram showing the effective CLO's for various temperatures and corresponding rates of heat loss (activity levels) of a nude subject. In a range of temperature from 10°C to 25°C, the effective insulation is roughly constant between 0.3 and 0.4 CLO. At 10°C the subject is performing exhausting work just to keep warm. One can infer from this nomogram that at 0°C the average man would be unable to sustain the required effort for more than a few minutes before

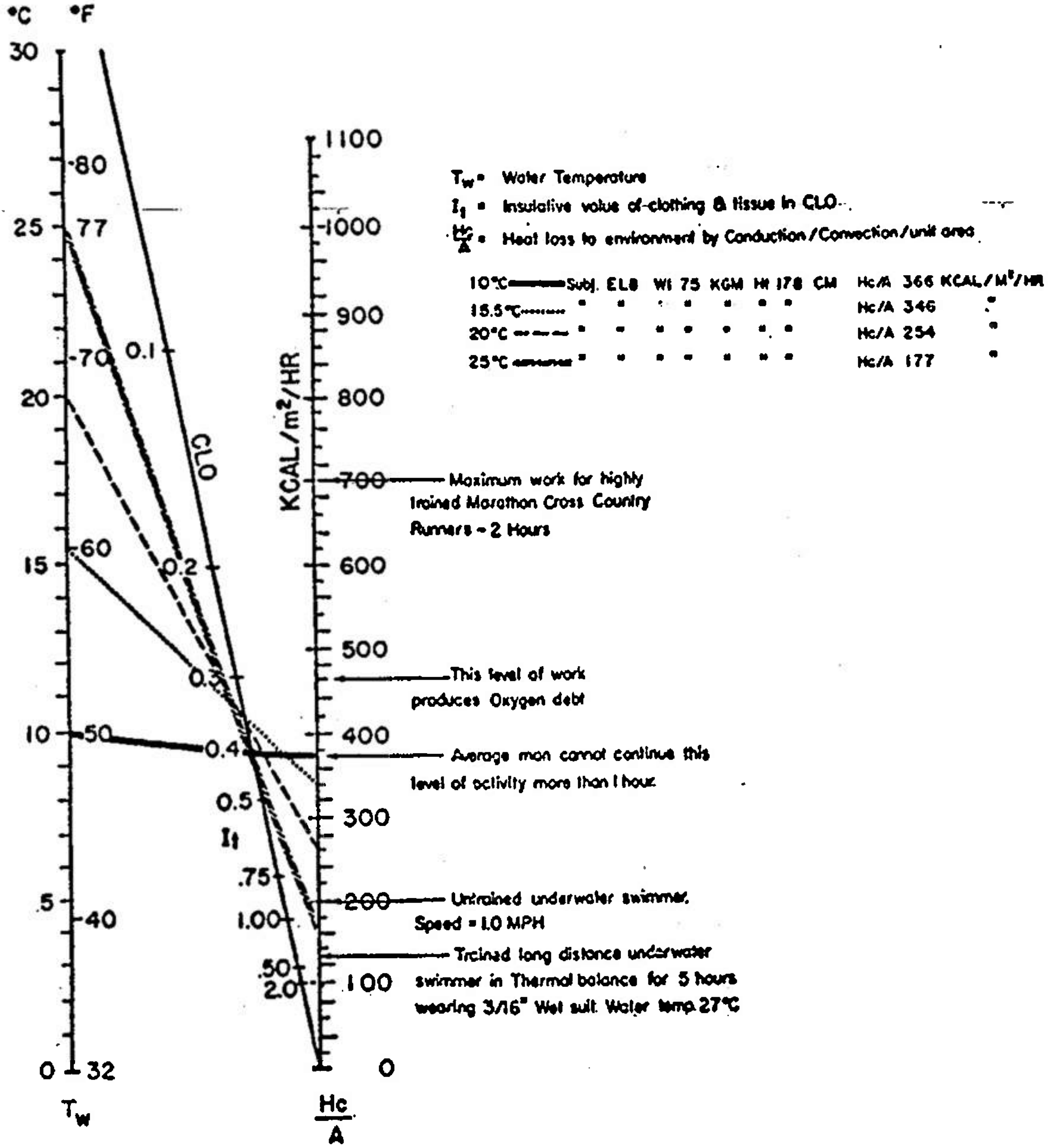

Fig. 2. Rates of conductive-convective heat transfer to water at various temperatures of one nude subject immersed to neck level (from Beckman)[2].

his core temperature would start to fall.

A certain acclimatization takes place with repeated exposure to cold.[26,27] The Ama divers of Korea show a slightly elevated basal metabolism over their non-diving sisters.[5] Highly-trained distance swimmers find that a layer of subcutaneous fat (caused by overeating) is a good protection against cold. This natural protection, however, is not sufficient to protect against extremes in cold or duration of exposure.

The consequences of heat loss are well documented, and are known first-hand by most people in the northern United States. Because of their high surface-to-volume ratio and their distance from the organs generating most of the metabolic heat, the extremities are first to suffer. Initially, an intense pain is felt in the extremities, followed by numbness, if the temperature is below 28°C.[3] Manual dexterity decreases because of loss of sensation and muscular weakness.[24,25] The surface temperature approaches that of the water, and permanent damage (various degrees of "immersion foot") will result with prolonged exposure.[22] In unprotected subjects at 10°C, a 50% loss of grip strength was found after only one hour of immersion.[1]

If conduction-convection to the surrounding water exceeds heat production, body temperature will fall with accompanying nausea, trunk muscle cramps, hypoglycemia, and headache.[6] If core temperature falls below 34°C, amnesia results.[1,8] In a 70-kg man, the unreplaced loss of only 407 kg-cal would result in a drop of 7°C in core temperature and unconsciousness, paralysis, and areflexia.[4,2]

DRY SUITS AND WET-SUITS

The traditional protective garment for the diver has been the dry suit. This has proven unsatisfactory for long missions because: (a) it generally leaks, and water destroys the insulative value of the underwear worn with it; (b) the effects of sweating and immersion diuresis saturate the underwear; (c) the necessary seals at wrists and face are uncomfortable to wear for any length of time.

Unicellular neoprene foam (UNF) wet-suits were first developed in the early 1950's.[10] Although polyvinylchloride wet-suits were evaluated at the Experimental Diving Unit in 1952, the UNF wet-suit was found to be superior and has remained the standard to the present time.[9] The wet-suit accomplishes two things: (a) it provides added insulation to retard heat flow, and (b) it retains a layer of water next to the skin which does not circulate, reducing convective losses.

Figure 3[2] it is evident that although the 3/16 inch UNF wet-suit provides approximately 0.63 CLO, a relatively large (around 300 kg-cal per square meter per hour) metabolic energy expenditure is still required just to maintain thermal equilibrium in 5°C water. If a swimmer were inmobile for any length of time, he would quickly lose heat.

Pressure has an adverse effect on the insulating qualities of the closed-cell UNF. At 50 feet the individual air-filled cells are compressed, and the insulative value is reduced to that of solid neoprene, 0.9 CLO per inch thickness,[8,10] Figure 4 shows the loss in insulative capacity with depth of a 1/4 inch, nylon-lined UNF wet-suit.

A partial solution to this problem has been an incompressible wet-suit made of glass microspheres in a matrix of polymerized mineral oil. So far, this design has proved to stiff and heavy to be practical.

The gas in the foam cells affects the insulating qualities of the material.

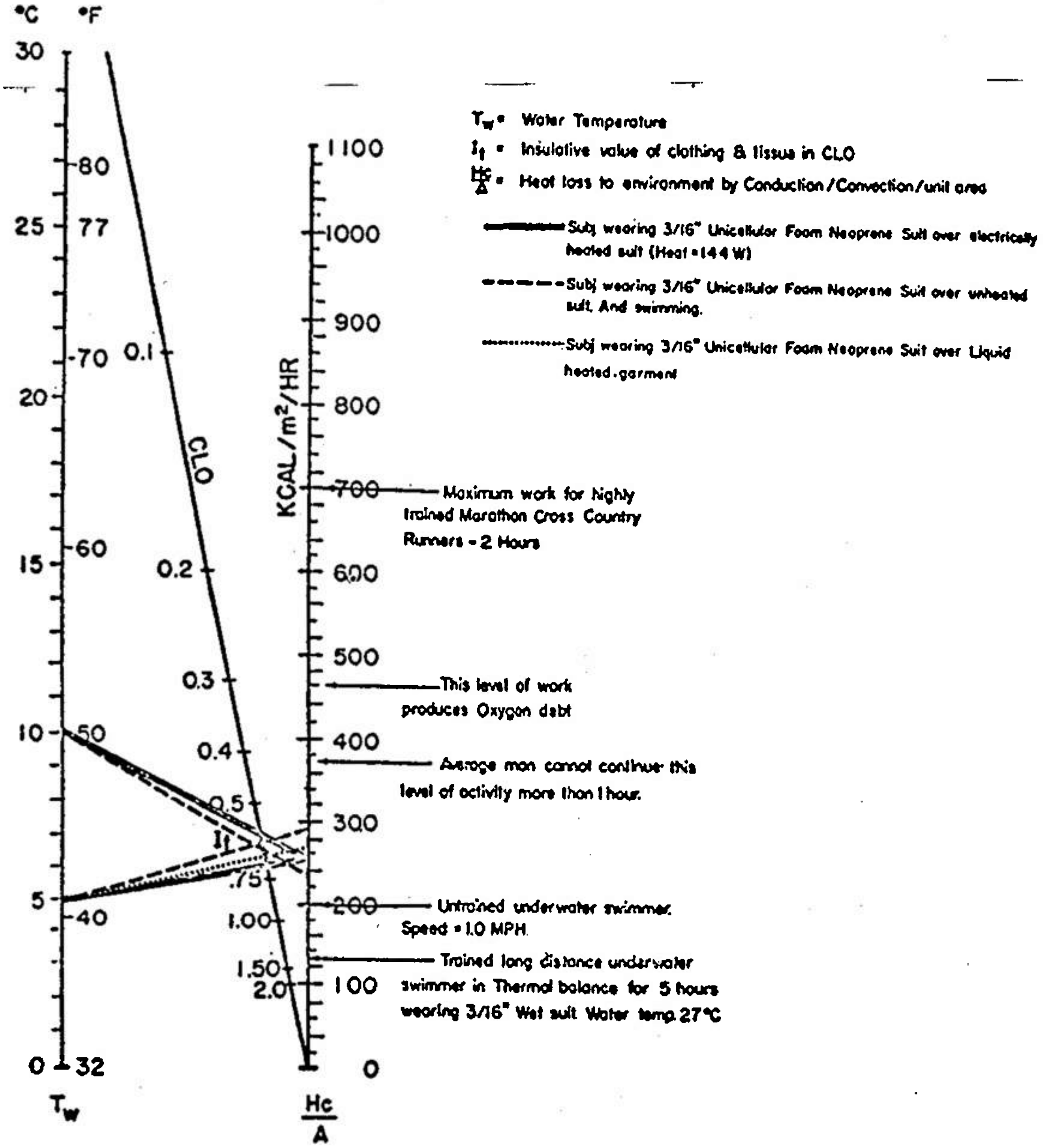

Fig. 3. Rates of conductive-convective heat transfer to water at various temperatures from submerged subject wearing various suit assemblies (from Beckman)[2].

Nitrogen and air are good insulators, carbon dioxide is better, and helium is poor. In a helium atmosphere, such as would be found in a deep habitat or a personnel transfer capsule, the UNF tends to become saturated with helium, further reducing its insulating qualities. Good results have been obtained from a wet-suit made of an inter-connected foam whose surfaces are impregnated

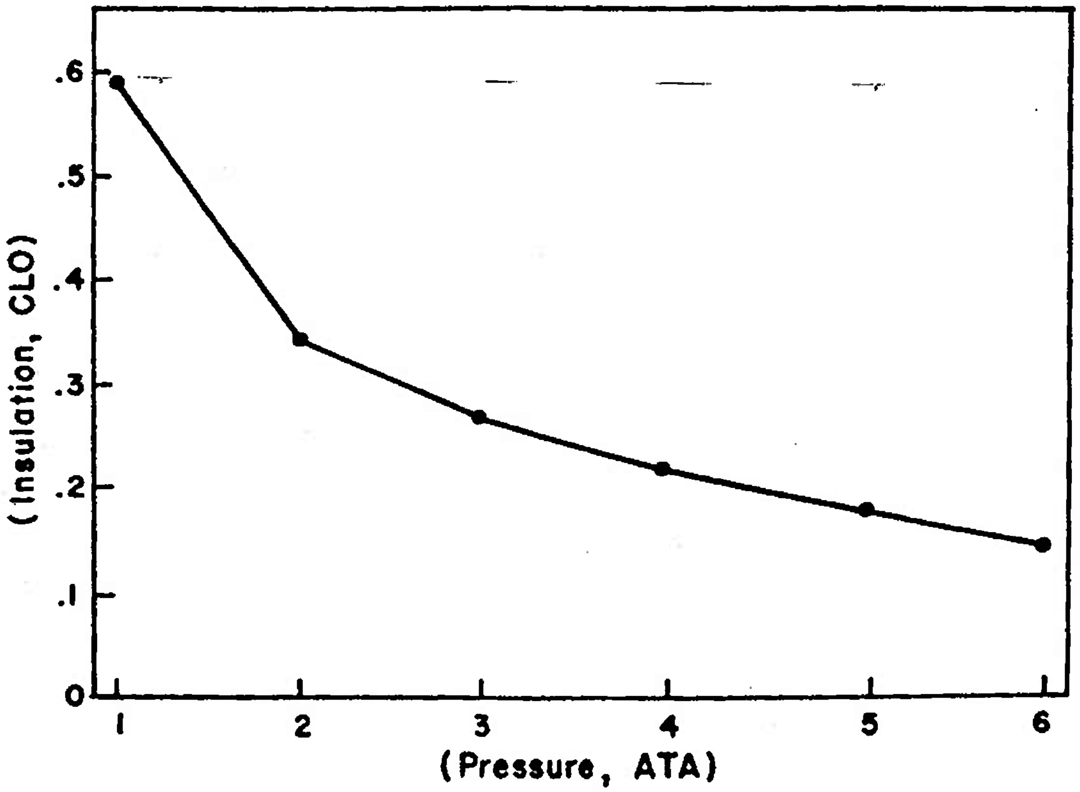

Fig. 4. Decrease in insulative value of a 1/4-inch wet-suit with pressure (drawn from Beckman)[2].

with rubber to prevent leaks. The foam is filled with carbon dioxide gas and pressure-compensated for depth. This suit must be protected from chafing, since a leak would destroy its insulation value.

In an attempt to insulate an immobile diver effectively, Beckman[2] clothed subjects in four UNF wet-suits, each 1/4-inch thick. The subjects were able to maintain core temperature for 5 hours at 5°C, but suffered painful chilling of the extremities. The positive buoyancy of the suit was 80 pounds, and the subjects were effectively immobilized by the bulky garment. Evidently, insulation alone is not sufficient to protect a diver from cold if he is expected to accomplish any useful work.

Thus, for long immersion in temperate water, or for shorter periods in cold water, heat must be supplied to the diver. Depending on insulation, activity of the diver, and water temperature, the amount of available heat must be from 535 to 1,115 thermal watts[2] or from 470 to 991 kg-cal per hour. (See Table I.)

Table I. Heat Required For Maintaining Comfortable Body Temperature of Diver When Wearing 3/16 Inch UNF Wet-Suit With Minimal Activity (From Beckman)[2]

Water Temp °C	Rate of Body & Respiratory Heat Loss (Kg-cal/m^2/hr)	Total Heat Loss/ Kg-cal/Hr	Heat To Be Replaced * (Kg-cal/hr)	Power Requirement of Suit if 60% Efficient	Power Requirement in Thermal Watts
15	200	386	286	470	535
10	240	463	363	650	754
5	300	579	479	800	928
0	360	695	595	991	1,115

*Total Heat Loss Less Basal Metabolic Heat of 100 Kg-cal/Hr

UMBILICAL SUPPLIED, HEATED SUITS

The most popular and simplest heated wet-suit has been the free-flooding, umbilical supplied, hot water suit. As shown in Figure 5[12], several perforated tubes distribute heated water from the umbilical to the interior of the UNF suit, where it circulates around the diver and passes to sea through the openings in the suit. This suit will protect a diver against the coldest water for any length of exposure time and is said to be quite comfortable to wear.[20]

The disadvantages, of course, are that the diver is tethered, and that the power requirements are quite high. In 5°C water, using a flow of two gallons per minute and an inlet temperature of 42°C, the diver alone will require 16,800 kg-cal per hour. The insulated umbilical loses an additional 1,500 kg-cal per hour per 100 feet of length. Since the suit inlet temperatures must not exceed 43°C if burns are to be avoided, these high power requirements must be supplied by pumping a high volume of water through the suit.[2,12]

A more efficient design is the Welson tubing suit (Apollo suit) or the Sanders Associates tubing suit, designed to be worn under UNF wet-suits. With these suits, the heating liquid is contained in a maze of tubing worn next to the skin, and it returns directly to the heating unit instead of being discharged into the sea. With the Welson tube suit under a single 3/16 inch UNF wet-suit in 5°C

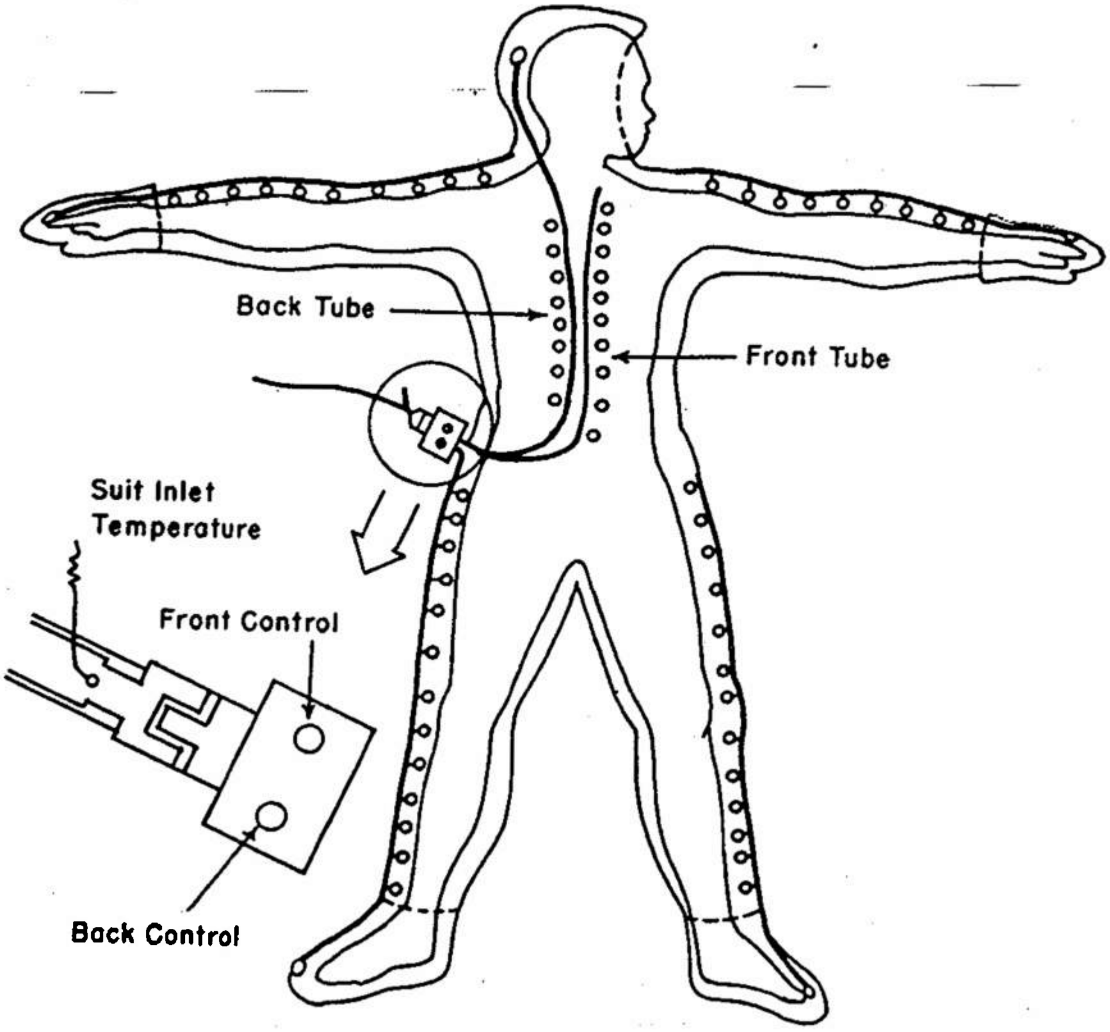

Fig. 5. Flow distribution pattern of open circuit water circulating suit. A thermister probe was placed close to the diver in the hot water umbilical to measure suit "inlet temperatures". (drawn from Bondi and Tauber)[12]

water, subjects at rest required 850 to 980 watts or 730 to 835 kg-cal per hour across the suit to maintain comfort.[15]

A third design would combine the simplicity and comfort of the free-flooding garment with the power economy of the tube-suit. Distribution tubes would discharge warm water into the suit, as with the free-flooding design. Rather than discharging the heated water to sea, however, it would be collected by another series of tubes and recirculated to the heater.[15]

ELECTRICAL POWER

The electrically heated wet-suit is a design which shown a great deal of promise. Even before World War II, there was an electrically-heated dry suit for the helium-oxygen hard-hat rig. Because of the dry suit's tendency to develop short circuits, open circuits, and "hot spots", however, it has fallen into disuse.[10]

The British (Vacuum Reflex Ltd., London) have developed an electrically-heated wet-suit for the U.S. Marine Reconnaissance Swimmers. It uses a finely knitted, resistance wire cloth sandwiched between two layers of UNF waterproofing, thermal insulation, and abrasion protection. This material is capable of stretching without breaking the resistance wires, a problem which plagued earlier attempts at a closely fitting, resistance wire garment.[8,10]

The previously mentioned carbon-dioxide charged wet-suit also incorporates a resistance wire network for heating. In use during Sealab II, it permitted a dive of nearly three hours without discomfort in 5°C water.[10] The mean thermal efficiency of this garment was found to be 74% as opposed to only 55% for the British suit. This is probably due to the fact that the resistance wires are close to the skin in the carbon dioxide charged suit, while the British design puts a layer of UNF between the resistance wires and the skin.[2]

Since chilling of the extremities is a limiting factor with even the best insulation systems, it would seem logical to provide electrically heated gloves and boots. In Reeves' study,[12] this approach was successful in preventing painful chilling of the extremities in 5°C water. Only 60 watts of power, 15 watts to each glove and boot, was required. The core temperature, however, fell just as rapidly as it had with no supplemental heating, and the experiment had to be terminated because of the subjects' painful abdominal and groin muscle cramps.

Electrically-heated suits may be supplied either by umbilical or by batteries carried with the diver. Since 25 to 30 pounds of lead weights must be carried to balance the buoyancy of a UNF wet-suit for cold water use, the substitution of an equivalent weight of batteries would impose no extra weight burden. Table II[8] compares the types of batteries currently being considered for use with heated wet suits. A 25-pound battery could provide 500 watts for 1-1/2 to 4 hours. Advantages of the sea-water battery are that the unit does not have to be pressure-compensated, and that instead of recharging, the anodes need only be replaced. A battery in use today uses silver-zinc cells and is rated at 28 volts and 1,000 watt hours.[20]

Table II. Comparison of Batteries for Heated Wet-Suits (From Beckman, Reeves, and Goldman)[8]

Battery	Watt hr/ lb	Watt hr/ 25 lb	Est. Cost	Charging
Mg-AgCl-Sea-Water	40-80	1,000-2,000	$500	Replace anode
Silver-Zinc	40-80	1,000-2,000	$450	10-30 cycles
Silver-Cadmium	30-60	750-1,500	$600	300-1,000 cycles

CHEMICAL POWER

Exothermic chemical reactions offer a potentially attractive energy source due to their low cost and their high energy per unit weight. (See Table III.) The high temperatures of these reactions, however, and the necessity of providing a means of transferring the heat to the diver make the complete system just as heavy and bulky as other systems, and certainly more complex than the electrically heated suit.

Oxidation of hydrocarbons on a catalytic surface offers a convenient and efficient means of obtaining energy. Burners operating on this principle are marketed for sportsmen as hand-warmers and tent heaters.

The oxygen requirements of these exothermic reactions are considerable. To completely oxidize a standard 400 gram cylinder of propane gas, liberating 4,780 kg-cal, ($C_3H_8 + 5\ O_2 \quad 4\ H_2O + 3\ CO_2$) requires 1,450 grams of oxygen, or 35 cubic feet, nearly the entire contents of the standard U.S. Navy open circuit breathing apparatus (180 scf of air, of which 37.8 scf is oxygen).

A unit presently under evaluation by the U.S. Navy (Aerospace Crew Equipment Laboratory, Naval Air Engineering Center, Philadelphia) uses heat from the catalytic combustion of hydrogen at 38°C. The hydrogen is obtained from the sodium aluminum hydride and water according to the reaction: $NaAlH_4 + 2\ H_2O \rightarrow NaAlO_2 + 4\ H_2 \uparrow$.[8]

Of the liquid fuels, gasoline appears to have the highest energy to weight ratio. Gaseous fuels are more concentrated, but must be stored under pressure in heavy cylinders.

An evaluation has been made of a garment employing the heat of crystallization of lithium nitrate trihydrate.[16] A triple-layered vest was fabricated with a layer of open cell polyurethane

Table III. Heat Liberated from Various Gaseous and Liquid Fuels (From Hodgman et al.)[11]

Fuel	Energy per weight
Kerosene	11.006 kg-cal/gm
Ethanol	6.456 kg-cal/gm
Gasoline	11.528 kg-cal/gm
Propane	11.961 kg-cal/gm
Methane	13.175 kg-cal/gm
Acetylene	12.000 kg-cal/gm
Calcium Carbide	2.960 kg-cal/gm (for liberated acetylene)
Hydrogen	29.150 kg-cal/gm
Sodium Aluminum Hydride	5.830 kg-cal/gm (for liberated hydrogen)

foam sandwiched between two layers of 1/8 inch UNF. The polyurethane was filled with the melted lithium nitrate trihydrate. In use the vest is heated to 40°C in a water bath to melt the salt. It is worn under a wet-suit and discharges its heat in an hour as the liquid crystallizes. The subjective responses of the divers who wore the vest were favorable, and it did keep their chests warm. The heat released, however, is only 71 kg-cal per kg of lithium nitrate trihydrate. A suit adequate to replace thermal losses would be unacceptably heavy and stiff.

NUCLEAR POWER

Radioisotope-fueled diver heaters also show promise as light-weight, durable, potent sources of heat. The ^{238}Pu unit tested by Bondi, Rawlins and Tauber[17] falls far short of this promise, however, and illustrates some of the problems associated with a unit of this type. Designed to provide only 420 thermal watts, the unit lost heat to the surrounding water, and delivered only 270 watts to the diver. Water coming through the unit was initially warm, but rapidly cooled to 31°C at 40 minutes. Within one hour in the 5°C water, the diver was cold and shivering.

The measured equivalent radiation dose to the diver was 100.3 mrem per hour, even with the stainless steel and water shielding, limiting his maximum usage of the unit to 30 hours per quarter or 50 hours per year. This is hardly desirable for a device designed to permit longer immersion times.

Sanders Nuclear Corporation[14] has proposed an isotope fueled heater which would generate 20,000 B.T.U for 6 hours (840 kg-cal per hour). So far, this heater has not been evaluated.

Table IV[2] compares several isotopes which could be used as power sources. In general, the gamma and neutron emitters, such as ^{238}Pu and ^{90}Sr require heavy shielding and/or reduced usage times. ^{170}Tm has an initial power density of 2 watts per gram and a low price, but its half-life is only 0.4 years. ^{171}Tm and ^{147}Pm have longer half-lives, but low initial power densities and high costs. A compromise appears to be ^{204}Tl with a four-year half-life, a moderately high power density, and a reasonable cost. A heating unit which would provide 1,000 watts would incorporate about 1.5 kg-cal of ^{204}Tl and costs around $100,000.

Table IV. Radioisotopes for use in Thermal Power Generators for Divers (From Beckman)[2]

Radioisotope	Symbol	Half Life (Years)	Initial Power Density (Watts/GM)	Present Cost ($ Per Watt)	Radiations
Plutonium	^{238}Pu	89.0	0.55	1000	Alpha, Neutron, Gamma
Thulium	^{170}Tm	0.4	2.0	20	Beta, Bremsstrahlung
Thulium	^{171}Tm	2.0	0.1	400-1000	Beta, Bremsstrahlung
Polonium	^{210}Po	0.38	141.0	780	Alpha, Gamma
Promethium	^{147}Pm	2.5	0.36	4900	Beta, Bremsstrahlung

Table IV. Radioisotopes for use in Thermal Power Generators for Divers (From Beckman)[2] (cont)

Radioisotope	Symbol	Half Life (Years)	Initial Power Density (Watts/GM)	Present Cost ($ Per Watt)	Radiations
Thallium	^{204}Tl	4.0	0.67	100	Beta, Bremsstrahlung
Curium	^{244}Cm	18.0	2.8	480	Alpha, Neutrons
Curium	^{242}Cm	0.45	121.0	17	Alpha, Neutrons
Cesium	^{137}Cs	30.0	0.2	21	Beta, X, (Gamma)
Cerium	^{144}Ce	0.78	25.0	1	Beta, X, (Gamma)
Strontium	^{90}Sr	28.0	0.93	20	Beta, X, (Gamma)

CONCLUSION

It is evident that heated wet suits are required for long underwater missions in temperate water and for short excursions in cold water. Several diver heating systems have already been developed and are in use, such as the free-flooding umbilical supplied suit and the battery powered, electrically heated suit. These are adequate for most underwater tasks today. A diver working from a personnel transfer capsule or a deep habitat is usually tethered for safety. An umbilical carrying heated water or electrical power would not be much added encumbrance. A combat swimmer could use the battery-powered suit for his free-swimming mission of two to three hours, drawing power from the larger, swimmer delivery vehicle battery during the longer trip to and from the area. Thus, he would not really be limited by the relatively short free excursion time permitted by today's batteries.

Improvements in these systems are to be expected, as well as eventual development of a successful, practicable, isotope-fueled heating unit. With their low cost and high energy-to-weight ratio, the combustion heating devices may soon achieve prominence. A system which will keep a free-swimming diver comfortable in cold water for periods of six to eight hours has yet to be perfected, and represents a challenge for future development.

BIBLIOGRAPHY

1. Frey, H., "Thermal Protection", Skin Diver, October and November 1967.
2. Beckman, E.L., "Thermal Protective Suits for Underwater Swimmers", Milit. Med., 132: (3) 195-209, March 1967.
3. Craig, A.B. and Dvorak, M., "Thermal Regulation During Water Immersion", J. Appl. Physiol., 21: (5) 1577-1885, September 1966.
4. Beagles, J.A. and Coil, E.F., "Divers' Body Heat Loss", Navy Electronic Laboratory, San Diego, California, Report 1408 of Project SR011-01-01, 10 October 1966.
5. Bullard, R.W. and Rapp, G.M., "Problems of Body Heat Loss in Water Immersion", Aerospace Med. 41: (11) 1269-1277, November 1970.
6. Beckman, E.L. and Reeves, E., "Physiological Implications as to Survival During Immersion in Water at 75 F.", Aerospace Med. 37: 1136-1142, November 1966.
7. Raymond, Lawrence W., "Physiological Mechanisms of Maintaining Thermal Balance in High-Pressure Environments", J. Hydronautics 1: 102-107, October 1967.
8. Beckman, E.L., Reeves, E. and Goldman, R., "A Review of Current Concepts and Practices Applicable to the Control of Body Heat Loss During Water Immersion", Bureau of Medicine and Surgery, Navy Department, Research Task No. MR005.13 - 4001.06.
9. Fulton, H.T. et al., "Preliminary Report on Protection against Cold Water", Bureau of Ships, Project No. 186012, Report No. 5-52, 1952.
10. Jenkins, W.T. and McCrory, W. W., "Protection of the Underwater Swimmer from Hypothemia", U.S. Navy Mine Defense Laboratory Report 324.
11. Hodgman, C.D. et al., Handbook of Chemistry and Physics. 42nd Edition, Chemical Rubber Company, Cleveland, Ohio, Pages 1926, 1932, and 1936, 1961.
12. Bondi, K. R. and Tauber, J. F., "Physiological Evaluation of a Free-Flooding Diver Heat Replacement Garment", Naval Medical Research Institute, Report No. 17 of Project MF12.524.014 - 1004.

13. Tauber, J.F., Rawlins, J. S.P. and Bondi, K.R., "Theoretical Thermal Requirements for the Mark II Diving System", Naval Medical Research Institute, Research Report No. 2 of Project M4306.02 - 6010B, August 1969.

14. Sanders Nuclear Corporation, Personal Communication of 6 May 1969.

15. Jackson, D.L., Tauber, J.F. and Rawlins, J. S. P., "Evaluation of the NSRDL Heater Pump Performance Characteristics and Reliability", Naval Medical Research Institute, Report No. 1 of Project M4306.02 - 6010B, 7 August 1969.

16. Hearst, P.J., "Chemical Heat Source for Wet Suits", Naval Civil Engineering Laboratory, Technical Note N - 998, November 1968.

17. Tauber, J. F., Rawlins, J.S.P. and Bondi, K.R., "Evaluation of a Diver's Thermonuclear Swimsuit Heater System", Naval Medical Research Institute, Report No. 3 of Project M4306.07 - 1003, February 1970.

18. Goldman, Breckinridge, Reeves and Beckman, "'Wet' versus 'Dry' Suit Approaches to Water Immersion Protective Clothing", Aerospace Med. 37: 485-487, May 1966.

19. Reeves, E., Stephens, M.P. and Beckman, E.L., "An Evaluation of the Foamed Neoprene 'Divers Wet-Suit' as a Survival Garment for Helicopter Aircrews", Naval Medical Research Institute, Research Report No. 7 of Project MF011.99 - 1001.

20. Rawlins, J.S.P. and Tauber, J.F., "Heated Suit Design and Evaluation Problems", Naval Medical Research Institute. Unpublished Paper.

21. Gayton, Arthur C., Textbook of Medical Physiology, W.B. Saunders, Philadelphia, Page 959, 1965.

22. Keatings, W.R., Survival in Cold Water, Blackwell Scientific Publications, Oxford, 1969.

23. Gagge, A.P., Burton, A.C. and Bazett, H.C., "A Practical System of Units for the Description of the Heat Exchange of Man with the Environment", Science. 94: 428-430, 1941.

24. Stang, P.R. and Wiener, E.L., "Diver Performance in Cold Water", Human Factors 12: 391-399, August 1970.

25. Bowen, H.M., "Diver Performance and the Effects of Cold", Human Factors 10: 445-464, October 1968.

26. Skreslet, S. and AArefjord, F., "Acclimatization to Cold in Man induced by Frequent Scuba Diving in Cold Water", J. Appl. Physiol. 24: 177-181, February 1968.

27. Keatings, W. R., "Swimming in Cold Water", Brit. Med. J. 1: 185, 19 April 1969.