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THERMAL PROTECTION OF DIVERS

Patrick F. Dowland
Royal Navy

INTRODUCTION

The U.S. Navy is directing development efforts toward achieving a capability to dive and work at depths to 1000 ft in water temperatures down to 29° F. Whatever the depth or duration of dive, in all but the warmest sea temperatures the diver must have thermal protection to prevent impairment of his mental and physical performance by cold. The aim is to achieve a "steady state" where:

1. Deep body temperature is constant around 99° F.
2. Mean weighted skin temperature is constant around 94° F.
3. The power input to achieve steady skin and deep body temperatures is constant within narrow limits.
4. The diver is subjectively comfortable.

This condition can be expressed by:

$$\begin{pmatrix}\text{Metabolic}\\ \text{heat}\end{pmatrix} + \begin{pmatrix}\text{Suit heat}\\ \text{replacement}\end{pmatrix} = \begin{pmatrix}\text{Respiratory heat}\\ \text{loss}\end{pmatrix} + \begin{pmatrix}\text{Suit heat}\\ \text{loss}\end{pmatrix}$$

It has been shown that metabolic heat production exceeds respiratory heat loss at depths shallower than 600 ft and in seawater temperatures above 40° F. The diver therefore can be kept in thermal balance by the use of insulation alone. But at very deep depths, the situation is reversed and some method of heating the inspired gas is necessary. The amount of heat required to compensate for heat loss is a function of the water temperature, the depth, the gas mixture breathed, and the effectiveness of the insulation.

SUIT HEAT LOSS

The Wet Suit

The wet suit, probably the most widely used suit today, is usually made of foamed neoprene. The suit is normally made to the user's measurements, and only a small quantity of water is allowed to enter, which is quickly warmed by the body. Heat loss thus depends on the insulating properties of the material.

Foamed neoprene is subject to compression under pressure and becomes less and less effective with depth (fig. 14-1, 1-11), In addition, when this material is placed in a helium-rich environment under pressure, the nitrogen and oxygen diffuse out of the neoprene and are replaced with helium at a pressure equal to that of the chamber; the neoprene re-expands to about 65 percent of its original thickness.

When the diver enters the water, the helium outgasses; when he returns to his personal transfer capsule (PTC) or habitat, however, there is no re-expansion, since the pressure in the suit cell equals that of the habitat.

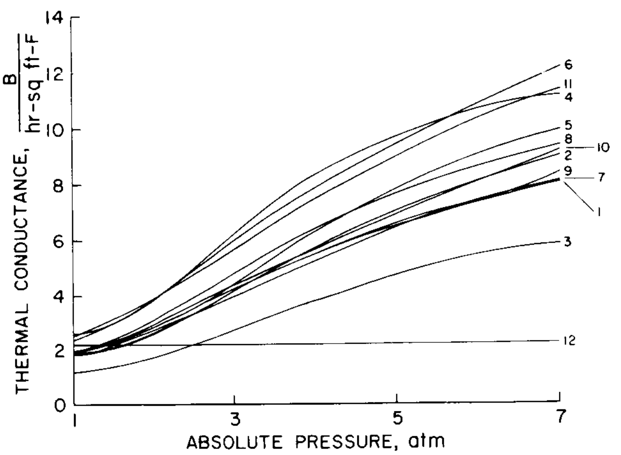

Figure 14.1 *Conductance of wet suit materials in comparison with noncompressible material (1-11 foamed neoprene, 12 incompressible material).*

Since this process is repeated with each excursion, the diver ends up with a suit of very poor insulating quality. In fact, at 600 ft, the insulation is about one quarter of that at the surface. For this reason, the conventional wet suit is unsuitable for deep diving.

The Dry Suit

A dry suit usually keeps the diver dry, and minimizes heat loss by providing an insulating air gap and an undersuit between the diver and the water. A constant volume regulation system has to be provided to maintain the air gap and reduce the possibility of squeeze.

During a dive from a habitat or PTC in a helium environment, the air trapped in the suit is replaced by helium, which greatly reduces the thermal insulating properties. It would be logical, therefore, to replace the gas layer with a nitrogen/oxygen mixture or carbon dioxide. However, nitrogen will contaminate the atmosphere, and carbon dioxide is unsatisfactory at deep depths and cold temperatures.

The dry suit then has certain advantages over the wet suit:

1. The diver is kept dry, a big advantage in deep diving on return to the PTC.
2. The insulation tends to remain constant with depth.
3. The diver can alter his insulation by increasing or decreasing his undergarments.

Incompressible Suits

Suits made of incompressible materials are under development. The material is made of glass microspheres held together by polymerized mineral oil and coated with a rubber type material on either side. Some manufacturing difficulties still exist, and suits constructed of this material tend to be slightly heavy on the surface, but development has been encouraging and recent swimming trials have been favorable.

Such suits will improve the thermal protection of divers operating below about 100 ft (fig. 14.1, 12), but this material alone is inadequate in deep depths where supplementary heat is required. It is as an insulative covering over some form of heating undergarment that this material will come into use in the field of deep diving. However, before it is acceptable for such a purpose, tests of flammability and toxic off-gassing are needed.

SUIT HEAT REPLACEMENT

Hot water has been the primary means of heat replacement. By this approach, the suit and power source must be considered together and the following requirements taken into account:

1. The diver must not be burned; water temperature in the suit must not rise above 110° F.
2. The diver must be kept warm; 1.2 kWh is required with present insulation but as much as 3.4 kWh may be required.
3. The diver must have freedom of movement with no bulky equipment or heavy umbilical.

4. There must be no off-gassing to contaminate the environment or disclose the diver's position on clandestine operations.
5. The diver must be protected in case of system failure. He must have time to return to his base of operation before he freezes.
6. The diver must not be electrocuted; electrical hazards must be known.
7. The diver must not be subjected to radiation hazards.

No system that fulfills all these requirements has yet been accepted into service.

The most widely used system is the open-circuit hot water suit supplied through an umbilical with water heated by an oil-fired boiler on the surface (fig. 14.2). The suit is made of open-cell neoprene and contains perforated tubes that distribute the water over the diver's body. Controls on the suit allow the wearer to control the flow to the upper and lower parts of the body or to dump to the sea at the suit inlet. When the system is fully open, the diver is kept in a bath of hot water. Temperature controls and fail-safe arrangements are fitted to the boiler (fig. 14.3) to prevent excessively hot water from getting to the diver.

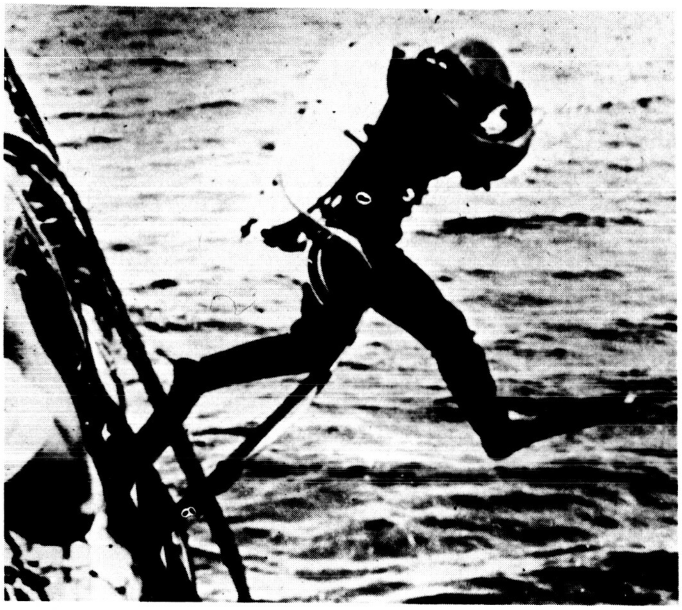

Figure 14.2 *Open circuit hot water suit in wide use at present.*

This suit is extremely comfortable to work in and has been used effectively in the open sea at depths to 850 ft in 40° F water and at depths of 1100 ft in 29° F water in hyperbaric chambers. The system is extremely wasteful of energy, however, and suffers from the serious shortcoming that should the hot water supply be interrupted, the diver is immediately exposed to ambient water temperatures, which in extreme conditions can incapacitate him within 1 min. Although now used in deep diving, this system is considered more effective in depths above 300 ft.

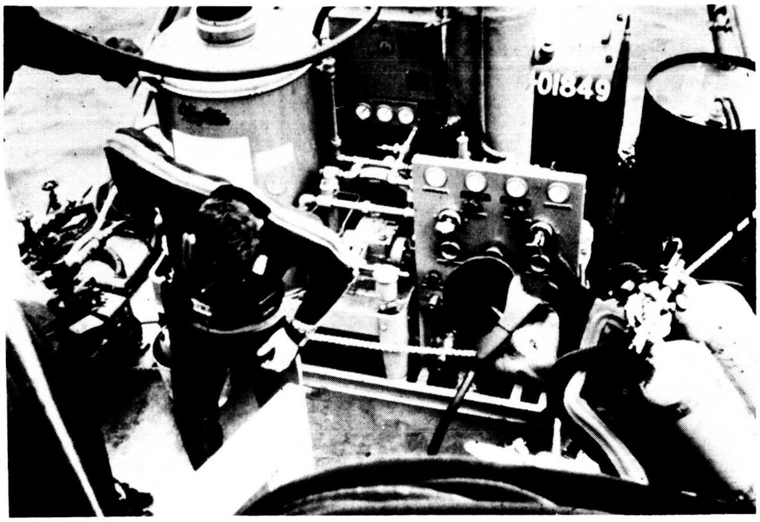

Figure 14.3 *Surface installed boiler for use with open circuit hot water suits.*

It is believed that a closed-circuit hot water system will give a more efficient solution to the problem of operating at greater depths. If such a system can be provided with a heat source carried by the diver, the excessive heat losses in the umbilical between the boiler and the suit can be minimized. As far as is known, only three closed-circuit suit designs exist.

In the Apollo suit, water is passed through small diameter tubes covering the diver's body. This undergarment was tried under both wet and dry suits, but the distribution of the tubes and their comparative inflexibility caused diver discomfort. Another suit is being tested in which the heated water passages are built into the entire suit surface, leaving virtually no areas unheated and permitting circulation of the heating fluid over a maximum body area (fig. 14.4) at a very low pressure. This suit is being used under a dry suit at the present time; however, it is hoped to weld an incompressible covering to it to provide ease of donning and maximum insulation.

Figure 14.4 *Closed circuit hot water undersuit at present under trial.*

The third suit being tested is an adaptation of the open-circuit suit described in which the water enters and exits at the waist area.

Closed-circuit suits can be supplied with hot water from boilers at the surface, mounted on the PTC or habitat, or carried by the diver. The surface boiler is widely used, and many ideas for PTC/habitat and diver-carried heat have been examined but most do not yet meet the requirements previously outlined.

The systems most worthy of consideration to provide a long-term solution to the problem of diving in very low temperatures are those using isotopes, electrical power, the latent heat of crystallization or salts, or heat pumps. However, none of these systems are sufficiently developed to permit conclusive evaluation of their potential.

The two heaters selected for trial are in the laboratory test stage. (It is hoped to evaluate these at depth in 29° F water in the fall of 1971.) The first of these heaters (figs. 14.5 and 14.6) works on the principle of the controlled oxidization of magnesium chip fuel charges and the transfer of the accompanying heat to a water loop connected to a closed-circuit suit. The oxygen flow to the combustion zone is controlled so that the desired heat output is achieved. The heat generated by the oxidization process is transferred to the water loop by a heat exchanger jacketed around the

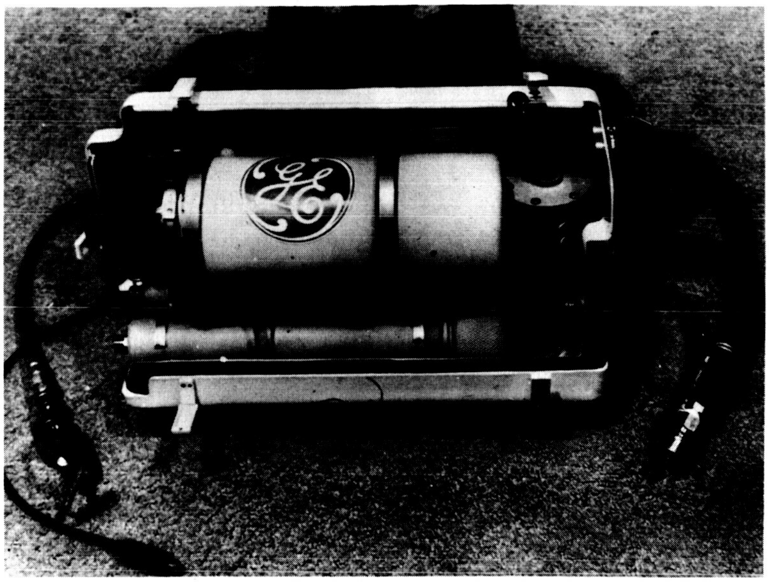

Figure 14.5 *General Electric CONOX diver carried boiler.*

combustion chamber. The heated water is circulated by an efficient pump powered by rechargeable nickel-cadmium batteries. The pump employs a magnetic coupling between the pump and motor to eliminate problems associated with sealing shaft penetrations.

The system is designed to automatically maintain a diving suit outlet temperature of between 95° and 100° F. A total of 6 kWh of thermal energy is provided to the diver swimming at 850 ft. The heater case weighs 35 lb in air and fits under the breathing apparatus on the lower part of the diver's back. The oxygen bottle fits in the harness assembly on the abdomen of the diver.

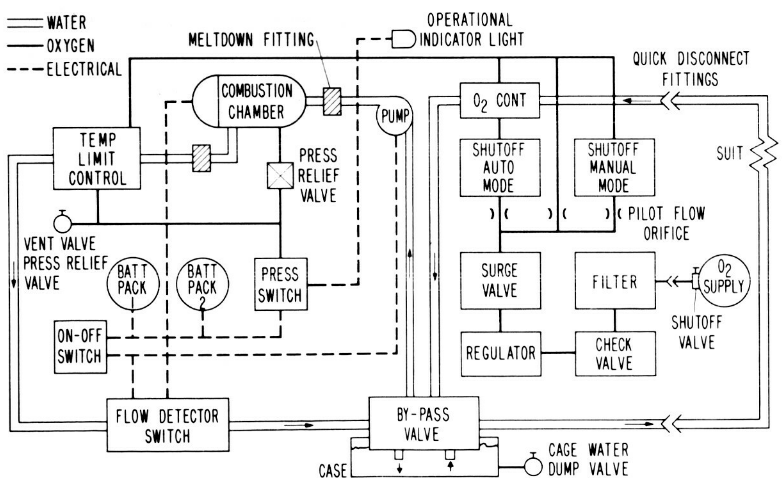

Figure 14.6 *Schematic of CONOX heater.*

The other heater under trial (fig. 14.7) uses the chemical energy stored in discrete sealed packages of solid fuel and solid oxidizers known as heat sticks. Initiated by an electrical impulse, these stable chemicals break down and recombine exothermally. The resulting reaction produces only heat as a by-product. Up to 8000 Btu are stored in a thermal surge, metallic salt reservoir at a constant temperature. A pump circulates water around the molten salt and through the loop suit. The

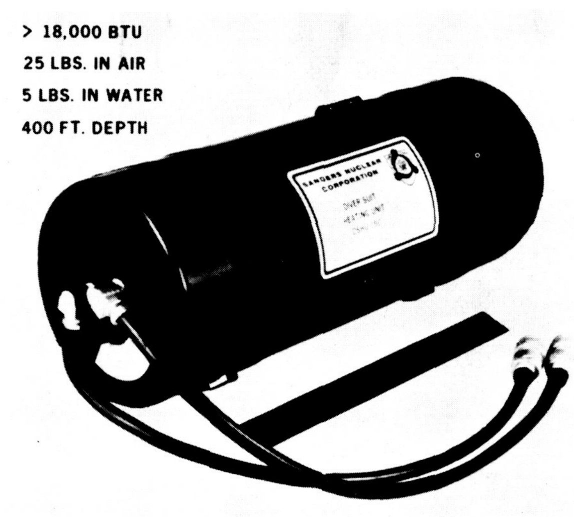

Figure 14.7 *Sanders nuclear chemical heater.*

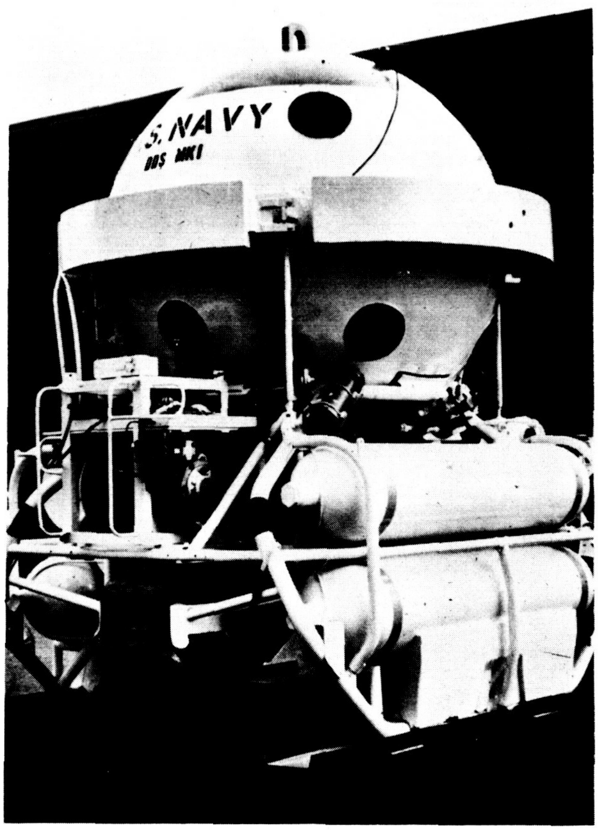

Figure 14.8 *Mark I Mod 10 deep dive system personnel transfer capsule.*

heating operation can be interrupted and restarted at any time and is designed to provide heat for 6 hr in 30° F water temperature. The heater weighs 25 lb in air and may be fitted to the breathing rig as required.

RESPIRATORY GAS HEATING

Work carried out last year at the Navy Experimental Diving Unit in Washington, D.C., has confirmed the need to heat the gas breathed by the diver at depths below 600 ft and temperatures below 40° F. Dives conducted in 1000 ft at 29° F water have confirmed that the carbon dioxide absorbent carried on existing breathing apparatus must be heated to maintain the endurance of the equipment. These problems are being overcome by using the hot water provided to the diver's suit to also heat the breathing equipment. The methods used for doing this are crude and hastily fabricated, but pressure chamber tests in 32° F water at 850 ft have been successful and it now remains to clean up the design.

Whether the diver-carried power sources now under trial can accept this additional loading has yet to be determined and depends on the final design of the equipment insulation package and the suit to be used.

PTC HEATING

Whatever suit and boiler combination is finally chosen for a safe dive, the divers in the PTC (fig. 14.8) must be kept adequately warm on their way to and from the work site and when waiting to enter the water.

Tests of the Mark I Deep Dive System PTC showed that a heat input of 1620 Btu is required for each degree of temperature differential to be maintained over and above ambient. Insulation of the Mark I DDS PTC was achieved by cementing electrical heating elements to the outside of the PTC using a cement with a high heat conductance (fig. 14.9). The hull is then insulated with just over 1 in. of syntactic foam. The electrical heating elements are contained in copper tubing. In the event of a short circuit, each element is protected so that no shock hazard to the divers is possible.

This method of providing heat to the PTC has several advantages. No extra space is required inside the PTC. If power should fail, the hull takes several hours to cool down so that divers will have heat for a considerable time. If it is required that the power to the heating elements be used for other services, it can be diverted for considerable periods of time without great degradation to the heating system. This system has been completely successful in tests at sea.

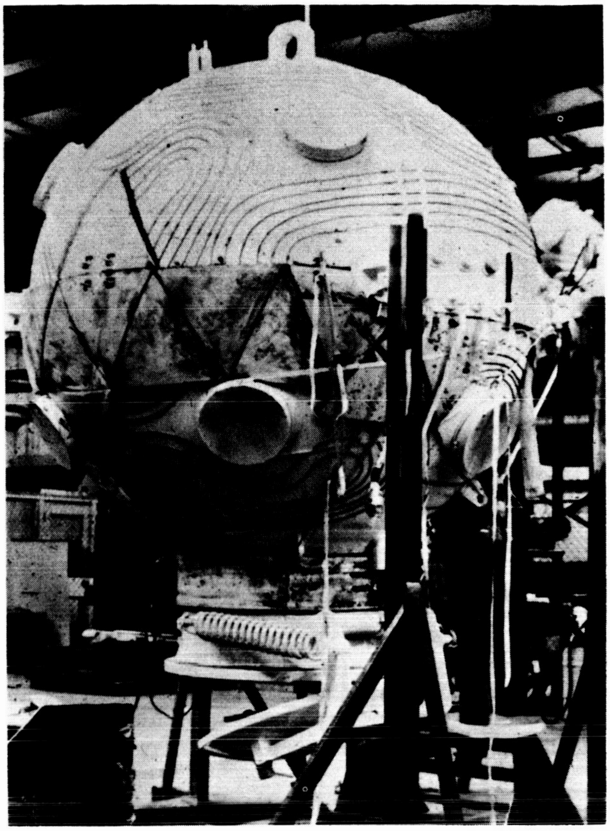

Figure 14.9 *Heating elements cemented to Mark I PTC before receiving the insulative shell.*

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