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HITECHCLO
(High Technologies for Protective Military Clothing)

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number) This report presents the results of a survey of promising high technology applications to protective military clothing which, at the time of the study were neither in the U.S. military inventory nor in the final stages of development or procurement. The report makes recommendations on the application of technologies which appear to have early utility within the Naval Services.			

PREFACE

This report presents the results of a survey of those technologies that could be used in the development of more effective military protective clothing for the Naval Services. The survey was conducted within industry and agencies of the Government outside of the Department of Defense.

Care was taken not to duplicate the efforts of those activities responsible for researching, developing, and testing military clothing and equipment.

Many unique technologies were examined. This report concentrates on those few which seemed most promising for naval applications.

Special thanks are extended to Mr. Ben Friedman and Mr. Allan E. White of the Office of Naval Research for their support and guidance. More than a hundred individuals, representing dozens of firms and agencies contributed their time to describe and define concepts and technologies that could be used in protective military clothing. It is impossible to cite all their names here, but their assistance, nonetheless, is greatly appreciated.

I.

EXECUTIVE SUMMARY

The objective of this research was to inventory and assess new technologies in protective military clothing. Of those hundreds of technologies surveyed and studied, the one that appears to have the best potential for quickly improving operational effectiveness is the liquid cooled garment (LCG).

The LCG appears to offer a relatively inexpensive means of combating heat stress. There are two basic LCG configurations. One relies on a chiller unit to which the individual is tied by an umbilical cord. This option reduces weight and relieves the individual from having to recharge the system frequently (batteries and ice) but reduces mobility by tying the wearer to the chiller unit. The second option provides greater mobility by freeing the individual from an umbilical tie to a fixed unit. The mobility is paid for in weight (the entire unit with ice cartridges is about 8 pounds) and the requirement to change batteries and ice packs (about every two hours).

The LCG, as currently configured in several models, also may have potential as a liquid heating garment (LHG) given an appropriate, lightweight, durable, safe heating source. The adaptation of the LCG to an LHG implies a research and development effort.

It is recommended that the Naval Services evaluate the LCG as an item of protective clothing in environments conducive to generating heat stress. It is further recommended that the potential for the conversion of the LCG to an LHG be studied as an item of protective clothing in cold.

II.

THE PROBLEM

The objective of this research was to inventory and assess new technologies not currently in standard use in the Naval Services for application to protective military clothing. While care was taken not to duplicate the efforts of those agencies which are charged with researching, developing, testing, and evaluating protective military clothing, some such duplication was inevitable. Generally, these RDT&E activities proceed from a detailed statement of a specific requirement and a search for specific solutions. This survey, on the other hand, started with a comprehensive recognition of the complex problems of protective clothing and searched for technologies which could have utility for the Naval Services.

An individual operating in extreme hot or cold conditions is in a position similar to that of an astronaut. Both must survive and function in an extremely alien and hostile environment. Both require special life support systems. For a variety of reasons, technology has made a greater contribution to the survival and operational effectiveness of the astronaut than the individual sailor or marine.

Before examining some of the more promising technologies the effects of heat and cold on the individual should be briefly described.

COLD

Man is comfortable when the ambient temperature is 85° to 88° F and is at a disadvantage in ambient temperatures under 75° F. He functions well only when his internal temperature is within a 97° to 102° F range. This vulnerability dictates that when he is in a cold environment, he must compensate with the infusion of heat or insulation through clothing or the protection of shelter. He has been variously classified as a tropical, subtropical or at least a warm-temperate animal. He is classed as a homeotherm; that is, displaying a constant internal body temperature of 98.6° F. However, temperature gradients do exist from one internal area to another when the physical equilibrium is upset. The surface or skin temperature of man generally is 8° to 10° lower than internal temperatures. It takes an extreme temperature differential, as high as 30° at the extremities, before cold starts to draw down on the temperature of the body core.

Exposure to extreme cold can produce hypothermia, a condition that may lead to loss of consciousness, heart failure, and death should deep body temperatures fall to 75°.

The body's first physiological reaction to cold occurs in the cutaneous blood vessels. They constrict when exposed to lower temperatures so that less blood will be exposed to the cold, therefore protecting the vital organs at the core of the body. This constriction of surface blood vessels in cold may even raise internal body temperatures.

In the simplest terms, the problems of cold in military operations range from the problems of survival (which concern maintenance of life or the trauma of death from hypothermia or other cold-induced casualty) to relative comfort (a degree of physical well-being in the proper performance of difficult tasks).

An independent researcher has described the current U.S. cold weather ensemble as "antiquated and poorly designed."¹ It is basically the same clothing that was used in the Korean War.² It was in the Korean War in November-December 1950 that fully one-third of a division (7,338 men) fell victim to cold-related casualties.³ On 28 November

¹Jeffrey C. Barlow, "NATO's Northern Flank: The Growing Soviet Threat," The Heritage Foundation Backgrounder, 1 May 1979.

²1st Lt. Steven J. Lynn, "Its About Time the Corps Redesigned Personal Gear," Marine Corps Gazette, July 1979, p. 53 and Major Danny Cross quoted in Navy Times, 24 September 1979, pp. 21, 26.

³Major Sean Leach, "Can-Do Won't Do in Norway," Marine Corps Gazette, September 1978, pp. 53,54.

alone there were 250 casualties of the cold in this division.⁴ The 1979-80 experience in cold weather environments confirm that even peacetime cold weather casualties can be extremely high. While most such incidents remain undocumented, they do take place. A well-trained British Royal Marine company in Norway in early 1980 required hospitalization or evacuation of about 10 percent of company strength. Fifty Army Special Force troops training in temperatures at -40° F suffered unit trauma that found several hospitalized for months following amputation of extremities.⁵ Cold weather operations can be equally as hazardous in such operational milieus as a carrier deck in the North Atlantic. About 90 percent of cold weather casualties never return to combat duty and the average hospital stay is between 53 and 82 days.

Protecting naval personnel from the traumas of cold weather while insuring a high level of combat efficiency is obviously not exclusively a problem of clothing. Nevertheless, clothing is an extremely important consideration. The principal problems with the current issue of cold weather

⁴Lt. W. S. Dial, MSC, USN, "Aspects of Cold Weather Medicine," Bureau of Medicine and Surgery Report 024-10, January 1979, p.1.

⁵Cdr R. D. Chaney, MC, USN, "Medical and Safety Considerations of Cold Weather Training," Naval Medical Research Institute, Bethesda, MD 20014.

clothing are: (1) it is excessively heavy, (2) it is excessively bulky, (3) it does not ventilate excess body heat and moisture well, (4) it does not provide sufficient protection to the extremities.

HEAT

The human body comfort range is $93^{\circ} \pm 3^{\circ}$ F skin temperature with a relative humidity at the surface of less than 100% (no liquid on the skin). For a variety of reasons (activity, insulation, ambient temperatures or combination of these effects) skin temperatures may rise above 96° F and liquid will be produced as perspiration causing discomfort. Man, at rest, will produce about 70 kilocalories of heat per hour. During periods of rigorous activity this heat production will increase five or ten times. The core of his natural cooling system is the eccrine gland, an extremely efficient mechanism of a simple coil and duct that can pump 40 times its weight in moisture. These 3 million glands resident just below the surface of the skin can produce about 10 quarts of sweat daily. The evaporation of this sweat cools the individual. Unevaporated sweat, however, incurs a penalty, is useless, causes discomfort, takes energy to produce, and requires replacement through water intake.

Comfort is the state which exists when there is a balance between the body's production and venting of heat and the environment. When impermeable or even semi-permeable garments are worn, there is a tendency to disequilibrium which results in higher body temperatures, more moisture on the skin surface and discomfort or heat casualties. A severe example of clothing inhibiting the natural cooling functions of the body is the chemical, biological, and radiological protective garment. These suits, which are essentially heat traps, can be highly uncomfortable, depending upon activity levels and ambient temperatures, since they inhibit the venting of excess heat and humidity.

There are many options for reducing the impact of cold on the physiology of man through protective clothing. There are few options for reducing the effect of heat. Once non-essential clothing is removed and once steps have been taken to shield the body from radiant heat, there are few options left. The removal of clothing, development of very lightweight fabrics, and setting up barriers against radiant heat are generally passive measures of protection. More active cooling adjuncts to military protective clothing will probably be required before any meaningful progress can be made in this area.

COMMERCIAL APPLICATIONS

The following facts highlight some of the problems of identifying and transferring commercial (or non-DOD) clothing technology to the Naval Services:

- First, most commercial products are not much more effective than military products. The civilian concept for cold weather gear is based on the layering system as well. The same problems of overheating and evacuation of body vapors exist as do problems of bulk.
- Second, some of the best insulating materials used in civilian and non-DOD clothing are not adaptable to the all-weather requirements of the military. Goose down, for example, is an extremely effective, lightweight insulator. When it gets wet, however, it loses its insulation value and has a low recovery index when dried out. The Services have compromised using a part waterfowl, part polyester batting material in sleeping bags (for example) which are less likely to be permanently damaged when water soaked.
- Third, the Services do incorporate commercial and non-DOD items when they demonstrate superior quality (e.g., the experimentation with Goretex and pile fabrics and closed foam mats). However, the

DOD test, evaluation, and development process is slow and there is the problem of using large inventories of stocks in warehouses before issuing new technology clothing.

- Fourth, the requirements of the military are distinct from the sportsman and others routinely subjected to heat and cold. The military requires much more durable, lighter and flexible clothing. It must be durable enough to stand up to the rigors of tactical operations which are more demanding than outdoor sports or typical outdoor work.⁶ An infantryman's clothing must be lighter because he must carry an extraordinarily heavy load over and above his clothing.

⁶Based on Edholm and Lewis reports; in contrast to the majority of civilians who are committed to cold weather environments (to include explorers) who spend no more than 3 to 10 percent of each day out of shelter, soldiers are routinely out of doors 10 to 15 percent of the day and in tactical situations 25 to 30 percent. See Edholm and Lewis, "Man in Polar Regions," Handbook of Physiology, 1964, pp. 435-446.

III.

THE SURVEY

Industries, government activities and individuals who were contacted in search of applicable technologies are listed in Appendix 1. There were over forty such contacts which extended from several day visits (e.g., NASA, Lyndon B. Johnson Space Center) to short telephone calls and letters (e.g., International Harvester). Detailed records of each of these contacts are available in the project leader's records. Some of the many technologies studied are also listed in Appendix 1. A few of the more significant are discussed in the following chapter.

As should be expected, this survey produced more than information on clothing technologies. We believe that in visits across the country and to Europe there were exchanges of information and provocative discussions that stimulated interest in solving problems related to clothing in hot and cold operational environments. The survey also elicited opinions on the state of the DOD clothing technology programs, some of which are cited below:

- There appeared to be a consensus that the Department of Defense protective clothing RDT&E community was staffed with an extremely competent group of scientists and technicians and that, in

general, funding support for their work was adequate.

- Generally outside the DOD RDT&E community, and often within, concern was expressed that the over-all DOD system inhibited the generation and acceptance of new clothing technologies in a timely, cost effective, and responsive manner.⁷
- The fact that there are large stocks of antiquated protective clothing in DOD warehouses tends to inhibit any sense of urgency upon the part of commanders to demand better clothing for their units.
- Technologies exist which are not in widespread use within DOD, that could provide better, cost effective⁸ protective garments for the Naval Services.

⁷An example was the 1981 complaint by a Marine commander on the lack of progress made in providing an effective, comfortable chemical, biological, radiological (CBR) protective ensemble. One could cite a statement of Dr. Ralph Goldman and Major Robert Joy that "an intensive development program was started in 1960 to improve the 'CBR ... uniform'." At this writing, 22 years later, there is very little progress from such intensive development evident in the field. (Major Ralph J. T. Joy, MC and Ralph F. Goldman, PhD, "Microenvironments, Modern Equipment and the Mobility of the Soldier," Stress in the Military Climate, 22-24 April 1964, Walter Reed Institute of Research (Washington, D.C.).

⁸Cost effectiveness in this context can be easily measured in industrial type environments (e.g. the military warehouse) they are not so easily quantified for the tank driver, mechanized infantryman, or carrier deck crew.

IV.

TECHNOLOGIES

The technologies studied are divided into the following categories for purposes of this report:

- ° Exotic textiles, fabrics, and materials
- ° Advanced designs
- ° Heating mechanisms
- ° Cooling mechanisms

EXOTIC TEXTILES, FABRICS, AND MATERIALS

There were a number of exotic textiles, fabrics, and materials found in this search. There are, undoubtedly, others that are being developed in textile and clothing laboratories that are not ready for the market. The following is a citation of some of the more significant technologies studied in this effort.

- ° Hydrophobics. There can be little doubt that the water impermeable-vapor permeable materials that have been developed have valuable application to military clothing and must be considered a breakthrough in protective clothing technology. The benefits to be derived from these materials are that they can produce effective water repellent garments without a buildup of body moisture which can be dangerous in cold-wet climates.

These technologies are not new, they have been available commercially for years yet are not in general use in the U.S. military. It would appear the reasons that these materials are not used more extensively within the Department of Defense are economic. The materials are relatively expensive and there are large stocks of clothing still on hand for issue that would be replaced by such technologies. There does not seem to be any sense of urgency for replacing these stocks with more effective, more expensive clothing.

The best known water impermeable, vapor permeable material is Gortex produced by W. L. Gore and Associates. A similar product is Klimate manufactured by Kenyon Piece Dyeworks, Incorporated. A third option that should be considered was reported on as long ago as 1950 by a team from the U.S. Army Quartermaster Research Laboratory and Goodyear Tire and Rubber Company. The results of their experimentation⁹ with chloroprene indicated that they had developed a coated fabric which was waterproof and simulated uncoated fabrics in vapor transmission

⁹Reported in Rubber Age, Volume 66, No. 4, January 1950.

and wearing comfort. Management of the Aldan Rubber Company of Philadelphia has resurrected this experimental effort and informed commercial and government activities of its existence.¹⁰

The application of these technologies to military clothing appears obvious particularly in cold-wet climates. There may also be applications for the development of more comfortable toxicological resistant materials using these technologies or using a polyisobutylene with the 1950 Goodyear Rubber technique.¹¹ Experimentations exist which indicate that the use of these materials in garments can produce an effective wind breaker as well.¹²

- Densely Packed Fibers. The high insulation, low loft (i.e., thickness) materials such as Thinsulate (by 3M), Sontique (by Dupont), and Webril R (by Kendall) may have military application for cold weather clothing in those instances where reduction

¹⁰George E. Martin, Aldan Rubber Company letter of 23 October 1981, on file in ATAC.

¹¹Ibid

¹²Unpublished documentation furnished by W. L. Gore and Associates on file at ATAC.

of bulk in clothing is a major concern. The Thinsulate and Sontique microfiber materials are not typical synthetics like a polyester fiberfill, nor are they natural fibers such as down. Webril R is a nonwoven cotton microfiber. Inch for inch of thickness, these materials are alleged to be about twice as warm as any other clothing insulation (to include the finest down). However, if one can assume that the loft (bulk) of down is not a significant disadvantage, the higher insulation values of down and synthetic fiberfills give them significant insulation advantages over the new materials.

Very tightly woven cotton fabrics such as those produced for NASA for use in its biological isolation garment (BIG) for the astronaut provide a three to five micron filter which may have application for chemical warfare protective ensembles.

- Flame Resistant Materials. NASA's developmental efforts have produced or encouraged the production of a number of flame-resistant materials. The Federal Emergency Management Agency (National Fire Data Center) has also done important work in the area of flame-resistant materials and fire-fighting ensembles.

The nonflammable Fluorel compounds are examples of such exotic materials. The Fluorel mill stock can be foamed, molded, or extruded. It can be controlled as a paste, coating or spray solution to produce nonflammable materials in a bottom ignition (vis-a-vis flame at the top of the material) 100 percent pure oxygen atmosphere. Because of the widespread effort within and outside of the Department of Defense in developing and testing flame retardants and because of the highly technical nature of the efforts, this line of survey was not pursued to any significant degree in this research.

• Phase Change Materials. The feasibility of the use of heat sink materials capitalizing on solid-liquid phase change to control temperatures has been studied by NASA. The simplest example of such a phase change material is water which from its solid state of ice is capable of absorbing heat and (in the process of cooling other bodies) changes to the liquid state. There are other, more exotic materials which could have application such as the paraffins which have a very wide range of melt points. These paraffins could have application to cold and

warm weather climate garments. However, having surveyed the relevant literature¹³ and discussed potentials with thermal engineer¹⁴ it appears that water has most of the properties desired for use in a heat sink with few of the problems associated with the more exotic materials.

- Temperature Controlled Garments. The components (fibers, fabrics, design) for "temperature controlled garments" probably exist or are being developed in commercial laboratories. It appears to be a long way off, however, before these components are integrated into clothing that will cool the microclimate in periods/areas of high temperature and heat the microclimate in periods/areas of cold. It is not too far-fetched to speculate, however, that in the future there could be protective clothing that would be conditioned for wear by placing them in a heated humidor or cold storage prior to donning, which would

¹³For example, A. P. Shlosinger, W. Woo, C. Cafaro, and E. W. Bentill "Technology Study of Passive Control of Humidity in Space Suits," NASA, NSL 65-87-3 of September 1965. And, Shlosinger and Woo "Feasibility Study of Integral Heat Sink Space Suit Concepts," NAS 2-2102, NSL 65-87-2, May 1965.

¹⁴For example, meetings with B&K Engineering of Towson, Maryland, and Dynatherm of Cockeysville, Maryland. Records of discussions are on file at ATAC.

effectively heat or cool the wearer over an extended period once it was worn. DuPont's interest in such materials has been reported.¹⁵

- Piles. Synthetic piles such as those developed and manufactured by Patagonia (Great Pacific Ironworks) are highly recommended for use in undergarments in cold weather by mountain climbers. These piles not only have very high insulation values but wick moisture away from the body and dry very quickly once wet.¹⁶
- Reflective Materials. Metallized fabrics in cold weather clothing systems have been extensively studied by the Army at NATICK.¹⁷ A commercial manufacturer, North Face, of Berkeley, California has attempted to include aluminized fabric in sleeping bags but has found that there is an excessive level of noise in the "crinkle" of the

¹⁵Gabrille Wise, Baltimore Sun, 21 October, 1980.

¹⁶One synthetic fiber pile material is polypropylene. A Norwegian manufacturer, Helly Hansen, is a major producer of this material as a first layer (underwear) of cold weather clothing. Another "hydrophobic" material which has been developed using vinyon and acrylic fibers is "thermolactyl" marketed by Damart of New Hampshire.

¹⁷See, for example, "Insulating Effectiveness of Metallized Reflective Layers in Cold Weather Clothing Systems," U. S. Army Research Institute of Environmental Medicine Report No. T 2/98, April 1978.

material, that it tends to wash out in laundering, and wear off with prolonged use. The value of the reflectives in cold climates is to retain the biological heat otherwise lost through radiation. In hot climates the reflectives can be used to shield against solar or artificial radiation. In theory, military applications are obvious, but no off-the-shelf technologies were found in this research that appeared to offer promise of early use of reflectives in military protective clothing.

Dr. Norman R. S. Hollies, formerly of the Gillete Research Institute and currently with the University of Maryland, has indicated in discussions that he believes that reflective materials have great potential, particularly in cold weather clothing, and that continued research in this area should be productive.¹⁸

ADVANCED DESIGNS

Possibilities for new designs of protective clothing using new or existing materials are limitless. Major S. N. Allen at the Marine Corps' Development Center has, for example, designed a cold weather field jacket that offers many advantages in maximizing insulation and venting excess

¹⁸Telecon of 17 November 1981 and meeting of 2 October 1980 with Dr. Hollis.

heat. Innovative use of zippers and velcro fasteners offer many possibilities in improving the effectiveness of cold weather clothing. Relatively simple designs as placement and construction of pockets can increase clothing effectiveness significantly. Such innovations as placing light terminals at the finger tips of gloves using fiberoptics (a NASA development) can be a boon to the operator of mechanisms with complex, sometimes difficult to read control panels. Also produced by NASA was a glove equipped with fingernails that has potential for substantially improving finger dexterity.

The Norwegian headover, a tube-like scarf that can be slipped over the head, while an old design for the Norwegian, was new to the U.S. when seen at the 1980 Anorak Express Exercise. The senior commander for the Marine forces participating in the exercise (the Commanding General FMF Atlantic) was so impressed with the simplicity and effectiveness of the design that he had sufficient numbers purchased to have each of his Marines equipped with the headover for the next phase of the operation.

A classic example of quality design is the standard U.S. issue extreme cold weather vapor barrier boot, which is constructed of a double layer of rubber with an air space between layers which provides effective insulation. Commercial double layer leather boots with an ensolite liner

are advocated by some as an alternative to this heavier rubber thermal boot.¹⁹ The leather boot has some advantages, but for overall waterproofness and warmth the standard issue U.S. extreme cold weather boot is superior. The jogger's bra, developed at Houston University, is another example of innovative design that has been proven to be highly effective.

Innovative designs that were found in this research were considered to be either of slight consequence to the military, or already well known or insufficiently advanced in concept or evaluation.

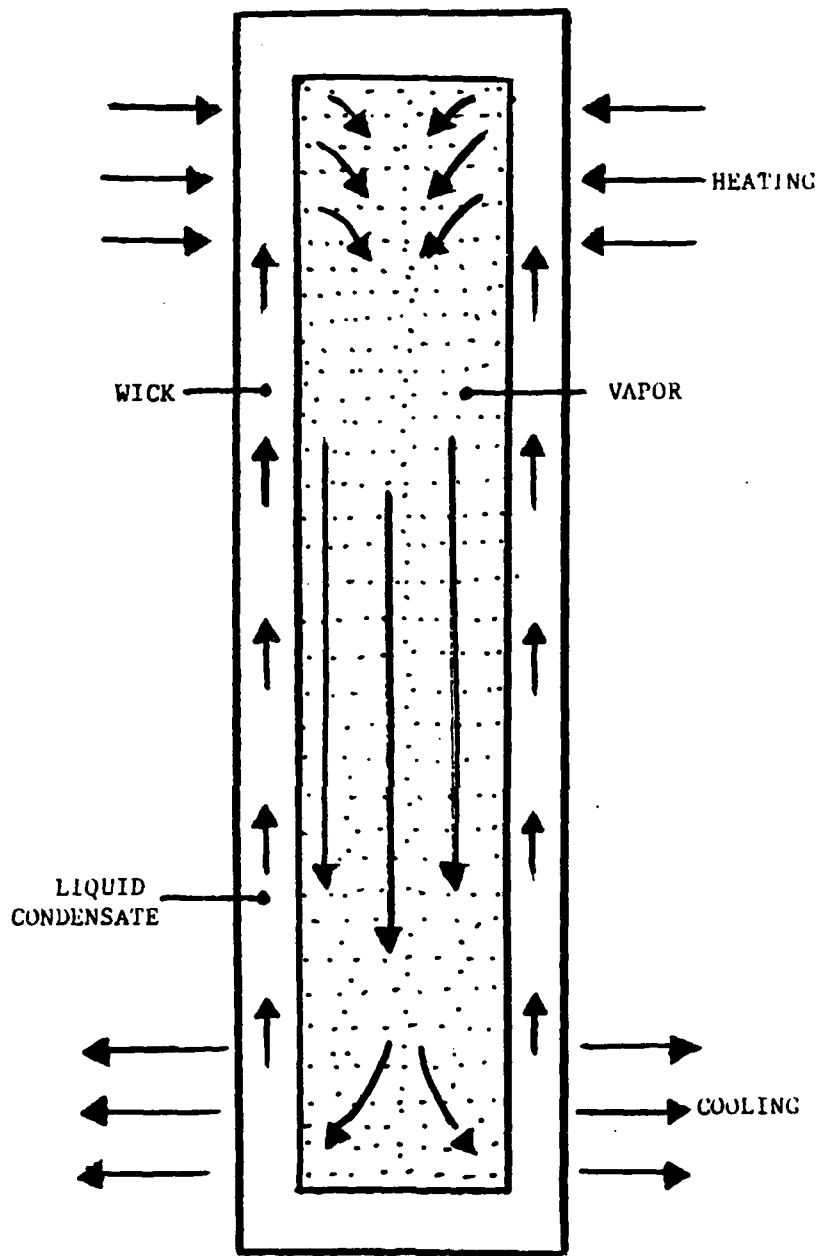
HEATING MECHANISMS

The mechanism investigated most thoroughly for this research was the heat pipe. The heat pipe has recently been developed for widespread industrial and military hardware applications. Examples are: evacuation of heat from missile electronics; heat recovery from electronic components to heat living/office spaces and thermal controls.

The heat pipe has a very high thermal conductance capability to the point where it is a near isotherm, efficiently transforming heat from one environment to another. It operates on either a capillary or osmotic cycling of fluid (water is as effective as more

¹⁹E.g., The Herman Survivor boot.

sophisticated fluids) that goes through a vapor, fluid transformation in an evaporation-condensation closed cycle system. The tubing for a heat pipe may be flexible which opens up possibilities for incorporation into clothing ensembles. (See Figure 1.)



Source: Dunn and Reay, Heat Pipes, 1976, op. cit.

Figure 1 THE HEAT PIPE

Introduction of the heat pipe into protective clothing could be for the purpose of (1) evacuating heat from the microclimate (the space under an individual's clothing) or (2) transferring heat from heat surplus areas (e.g., under arms, around the chest) to heat deprived areas (e.g., the feet and hands). Applications of this technology to both high and low temperature environments (under an impermeable chemical warfare suit or in a cold weather ensemble) are obvious.

The only functional heat pipe devices used in protective clothing found in this research were developed by NASA in experimental work for space suit temperature control. A. P. Shlosinger describes a heat pipe "thermal switching" device composed of flexible tubing. The system was designed to transmit heat from the skin of an astronaut to the external surface of the space suit.²⁰

The heat pipe technology was discussed in detail with at least a dozen expert sources such as NASA, Hughes, B&K thermal engineers, Dynatherm engineers, and NATICK laboratories. The consensus appears to be that the technology may have application for some special requirements (military

²⁰A. P. Shlosinger, "Study of Passive Temperature and Humidity Control Systems for Advanced Space Suits," TRW, Report No. 06462-6006-RO-00; AD # is CR 73720, November 1968. And, A. P., Shlosinger "Heat Pipe Devices for Space Suit Temperature Control," TRW, Report No. 06462-6005-RO-00, Accession Number is N69-38491, September 1968.

space activities) but is unlikely to be cost effective or practical for more general applications (the infantryman).

Electrically heated gloves and socks are available commercially and could have application to military clothing when the weight and resupply of the elements of power pack are not important considerations.²¹ The Catch-22 to this generality is that in environments where weight and resupply are not inhibiting, alternative, more efficient heating devices are usually available. Progress is being made in developing lighter, longer lasting batteries that are safe enough to be worn.²²

Heating the hands and feet may cause some undesirable physiological responses. Excessive heating may trigger a phenomenon where the body will become colder as the feet become warmer. Physiologist Alan C. Burton has written:

"In our work on electrically heated boots, we found it was impossible to maintain subjects in thermal comfort for any length of time if excess heating was given to the feet ...

²¹P&S Sales of Tulsa, Oklahoma, for example, offers an electric sock which the manufacturer claims can operate on a single D-cell alkaline battery (one per sock) to produce sufficient heat to warm the foot "for hours even in the coldest weather".

²²Interviews with U.S. Department of Energy technical personnel on the subject of energy storage devices, 2 October 1980.

Peripheral vasodilation results and as a consequence the deep body temperature falls, until eventually the subject is very cold indeed."²³

Advanced batteries were discussed with Department of Energy scientists and there appear to be good prospects for the emergence of new products that would be relatively low cost, with good cycle and service lifespans, that have good energy efficiency of reasonable size and weight. However, no breakthrough in technology is on the shelf for military application.

Portable pocket sized heaters were studied. The technologies were all decades old. One such warmer that used a liquid fuel is lit off at a wick. The flame is blown out and the glowing combustion generates temperatures 130° to 140° at the surface for a period of about six hours. The liquid used is toxic, flammable, and burns with an oil odor.²⁴

A one-time use chemical warmer consisting of a plastic bag of "chemical sand" that is kneaded to break an internal envelope to mix two elements was found. The manufacturer

²³Alan C. Burton, "The Pattern of Response to Cold in Animals and the Evaluation of Homeothermy," in Temperature: Its Measurement and Control in Science and Industry, Vol. 3, Part 3, Ed. J.D. Hardy, p. 359.

²⁴The trade name of the liquid warmer is "Jon-E-Warmer".

claims that a two-minute kneading followed by a ten minute chemical reaction cycle will produce 20-24 hours of warmth. In practice, the efficiency of the warmer drops significantly after four or five hours.²⁵

A third heater that burns solid fuel sticks is also available but did not receive an enthusiastic endorsement by its users.²⁶

Some years ago, Dr. Lamberson of the University of Pennsylvania did seminal work on a small propane heater to be used in diving suits. There are individuals in the clothing research community who still have some enthusiasm for the concept. However, Dr. Lamberson indicates no confidence that the technology is worthwhile pursuing as an individual garment heater.

COOLING MECHANISMS

The problem of cooling the microclimate (or reducing the excessive buildup of heat within the microclimate) is a great deal more vexing than that of heating. The human metabolic system naturally generates considerable quantities of heat as a by-product of physical exertion. In cold climates one approach to the avoidance of extreme discomfort

²⁵For the chemical warmer it is "Shake-n-Warm".

²⁶The solid fuel warmer was named "A-Line".

or injury is to conserve this body heat through insulation. Over millenia man has been fairly successful in finding efficient insulators for clothing. In hot climates the effectiveness of insulators against the environment are less efficient. Clothing and shelter can protect the individual to some extent from solar radiation. However, over the millenia man has reduced his work output to accommodate to high temperature, a luxury the fighting man may not be able to afford.

Protection from hyperthermia for the individual performing vigorous tasks in a high temperature, (and possibly high humidity) environment may be achieved through convection and/or conductance (with radiation a secondary consideration). Convection cooling is accomplished by the movement of air over a body that is covered by moisture (sweat or artificially induced moisture). Conductive cooling can be achieved by the transfer of heat from the skin surface to the environment through a medium that is in direct contact with the surface of the skin.

Figure 2 is a picture of an evaporative/convection cooling system found in this research. The system is evidently effective in cooling under circumstances where the restrictive movement caused by an umbilical cord tied to a fixed installation can be tolerated and where sufficient

FIGURE 2

CONVECTIVE COOLING SYSTEM



Courtesy of ENCON Manufacturing Company, Houston, Texas

sweating or artificial moisture can be accepted to produce evaporation. The physical principle involved in this system is the vortex tube that is a simple tee mechanism that separates hot air from cooler air producing a cool air input 6 to 60 degrees below the compressed air supply.

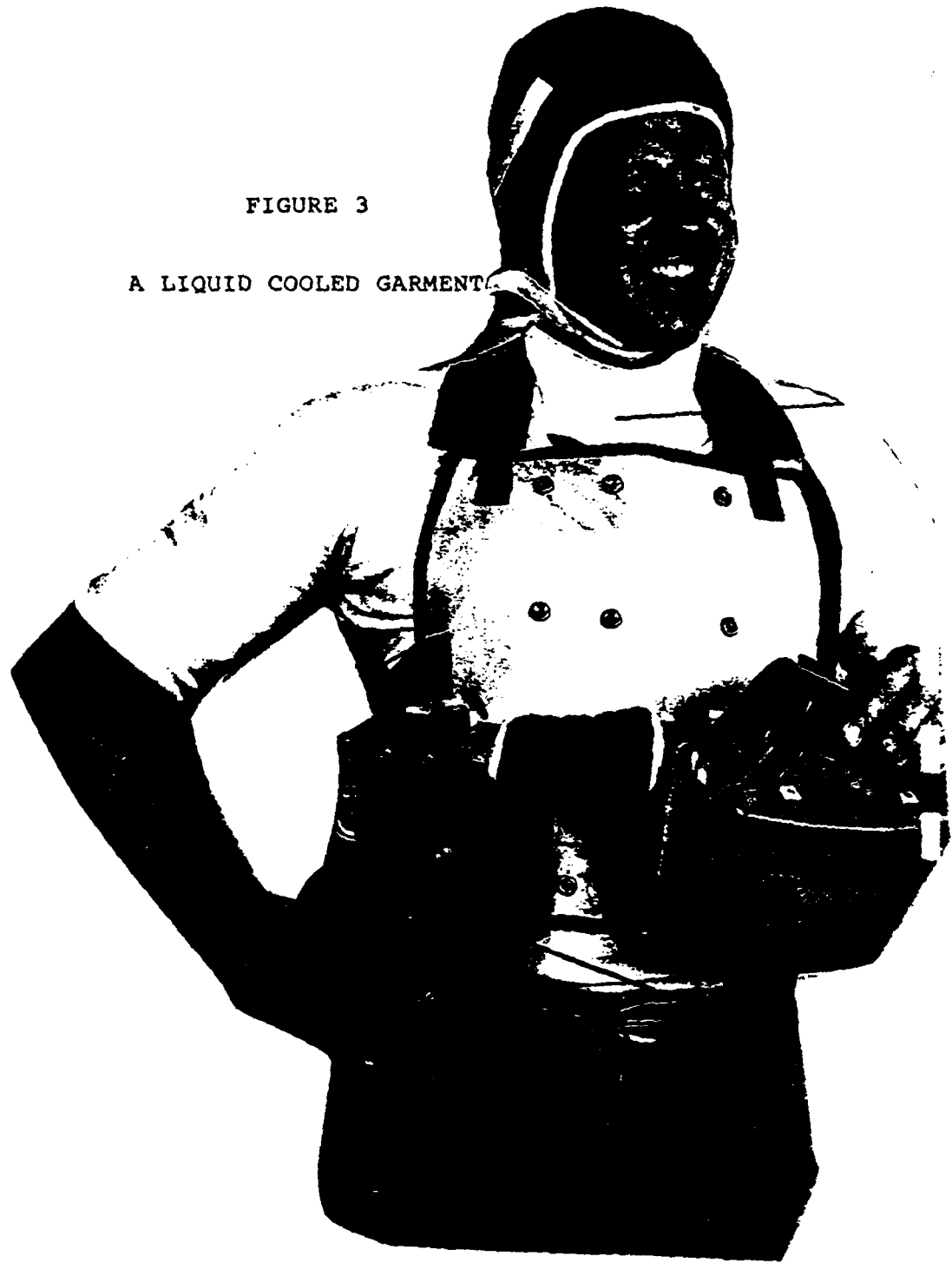
Conductive cooling may be accomplished to some degree through the use of the heat pipe.

The most promising technology for cooling, or for any other protective clothing purpose, that has been uncovered during this research is the liquid cooled garment (LCG). The LCG conducts heat from the body by passing a chilled liquid in a convoluted routing of a tube across the body surface.

The LCG, originally developed for NASA comes in either a mobile, ice heat sink unit configuration (See Figures 3 and 4) or a configuration using a large chiller unit into which the individual is tied with an umbilical cord. Two major LCG systems were found in this research. One is sponsored by the Army R&D Command, NATICK, the other (shown in Figures 2 and 3) by a California firm, Life Support Systems Incorporated (LSSI). While the NATICK LCG was seen, discussed and worn during this research, LSSI was more responsive to providing detailed information and the bulk of the data assembled is on this LSSI ensemble. No comparisons were made of the relative merit of these two systems. The

FIGURE 3

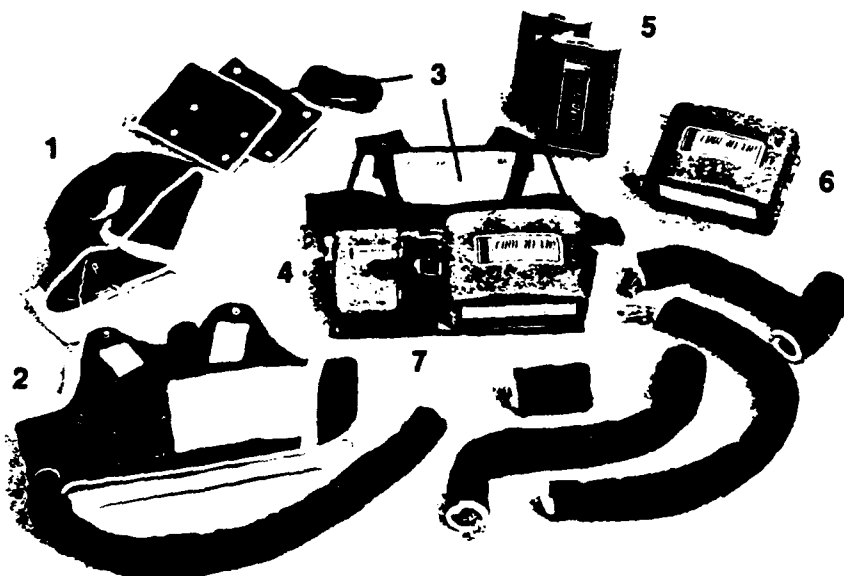
A LIQUID COOLED GARMENT.



Courtesy of Life Support Systems, Inc, Mountain View,
California

FIGURE 4

A LIQUID COOLED GARMENT COMPONENTS



Garments

- 1 Headliner:** Padded — for efficiency completely compatible with all head gear. Cooling capacity — up to 200 Btu/hr. Weight — 6 oz.
- 2 Vest:** Insulated for efficiency. One size fits all. Cooling capacity — up to 400 Btu/hr. Weight — 1 lb. 11 oz.
- 1&2 Head Vest:** Most effective configuration for high heat loads. Cooling capacity — up to 800 Btu/hr. Weight — 2 lb.
- 3 Suspension System:** Single systems may be belt mounted. Weight — 12 oz. Modular suspension system provides superior comfort and weight distribution. Single or dual cartridge system may be used. Weight — 15 oz.

Cooling System — The cooling system consists of two modules.

- 4 Control Display Unit:** Contains 6 VDC hermetically sealed pump motor, reservoir, low indicator, ON/OFF switch, and temperature control. Weight — 2 lb. 6 oz.
- 6 Heat Exchanger Unit:** Rugged insulated case — contains the replaceable cooling cartridge. May be paired for maximum cooling or duration. Weight — 1 lb. 2 oz.
- 7 Power Supply:** Rechargeable or throwaway 6V batteries. Rechargeable battery, 2 hour duration between charges. Weight — 1 lb. 14 oz. Throwaway battery — up to 6 hours duration. Weight — 14 oz.
- 5 Cooling Cartridge:** Ice cartridge — 1 quart. Weight 2 lb. 10 oz. System duration up to 2 hours without replacement of cartridge.

Courtesy of Life Support Systems Incorporated, Mountain View, California

results of a theoretical LCG versus forced air and natural air cooling analysis done by LSSI appears in Figure 5.

There is little hard data available on the performance of the LCG in a military environment. Data that is available is positive and promising.²⁷ The advantages and disadvantages of the LCG as a cooling mechanism appear to be as follows:

ADVANTAGE

• The system appears to be effective in reducing the danger of heat stress. It appears to reduce water requirements to replace liquid lost through sweating, and create a more hospitable environment for increased job proficiency.

DISADVANTAGE

• Increased comfort productivity and reduction of the dangers of hyperthermia is gained at the cost of additional weight in the mobile (heat sink) model of about 13 pounds.²⁸ The requirements to recharge or replenish batteries imposes a logistic burden.

²⁷One test by the 9th Infantry Division High Technology Test Bed Program indicated that LCG clad soldiers in a tank required 37 times less water intake in a hot environment than the soldier without the LCG.

²⁸12 pounds if an expendable rather than a rechargeable battery is used.

° The ice, heat sink configuration permits the wearer to be independent of an umbilical attachment to a fixed chiller unit with its power source.

° The LCG appears to have application (with or without the CBR ensemble) to a wide range of military personnel to include the tank crew, the APC infantry and crew, the LVT passenger, the heavy equipment engineer, the warehouseman, the flight deck standby fireman, the helicopter crewman, the shipboard crewman operating in non-airconditioned spaces, etc.

° The chiller configuration limits mobility.

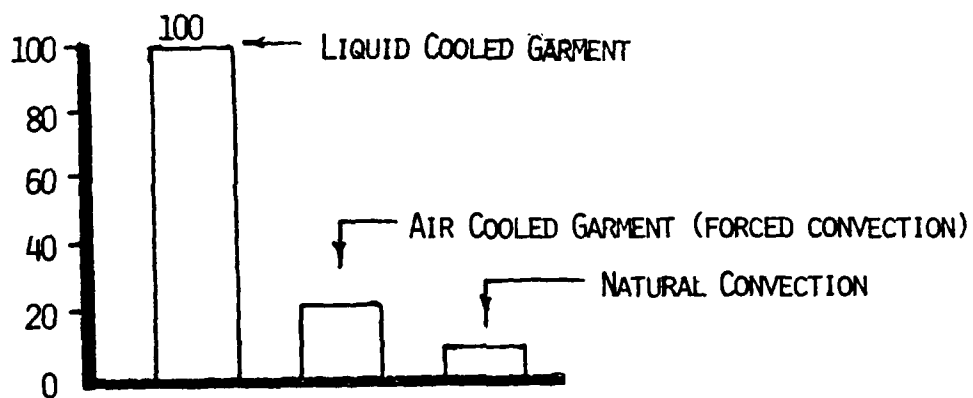
° In its current configuration the LCG does not appear to have universal application to all military. It appears to have limited application for the dismounted infantryman and any other operational environment where weight of the ensemble, cost and battery resupply/recharging could be a problem.

- The chiller configuration permits prolonged, uninterrupted operation.

- The portable ice heat sink configuration is limited to a maximum of two hours operation on a single cooling ice cartridge and on a single battery charge.

FIGURE 5

RELATIVE HEAT TRANSFER EFFICIENCIES



Note: Data is contained in LSSI materials and was not evaluated or confirmed in this research.

The LCG appears to have utility for the Naval Services in a wide range of applications. It demonstrates good potential for increasing productivity and effectiveness among those who may be equipped with the garment. It has potential for reducing health hazards and increasing comfort in otherwise intolerable conditions. The LCG should be cost-effective. Since there are no identical micro-climate cooling systems in the naval inventories, it does not replace a like item. There is, therefore, no requirement to queue in the first-in, first-out supply system for delivery to the fleet and supporting units. There are good prospects for further development of the garment. Using the same ensemble it is conceivable that a liquid heating garment could be developed using warm rather than cold water. A resurrected propane heater might be worthwhile considering to generate the heat for a mobile system.

V.

CONCLUSIONS AND RECOMMENDATIONS

CONCLUSIONS

- There were a large number of technologies found in this research which had application to military protective clothing for the Naval Services.
- These technologies ranged from the very exotic to the very simple, from the off-the-shelf to long-range development variety, from relatively expensive to relatively inexpensive.
- Of all technologies found, the liquid cooled garment appears to have the most promise for early application, high return for investment, and far reaching impact on military effectiveness for the Naval Services.

RECOMMENDATIONS

- That the liquid cooled garment be evaluated for use by the Naval Services.
- That the garment be tested with naval or combat engineers and aboard an aircraft carrier in areas where heat is considered to be a problem for personnel.
- That the garment be tested in a variety of mobile (ice cartridge) and chiller (umbilical cord) configurations.

- That the potential for developing a liquid heating garment from the components of the LCG with a heat source (such as the propane heater) be studied.

APPENDIX 1

CONTACTS MADE AND TECHNOLOGIES DISCUSSED

<u>CONTACTS</u>	<u>TECHNOLOGIES</u>
Albany International Research Company (Dedham, Mass.)	Fabric research programs
Aldan Rubber Company (Philadelphia, Pa.)	Vapotex
Angelica Company (St. Louis, Mo.)	Biological isolation garment/Barbac
Arctic Enterprises, Inc. (Thief River Falls, Mn.)	Cold weather clothing design
ARPA Cybernetics Technology Office (Arlington, Va.)	Heat pipes/phase change materials/chemical and biological protective garments/casualty isolation bags/Goretex
B&K Engineering (Towson, Md.)	Heat pipes/paraffins as phase change materials
Brooks Air Force Base (Brooks AFB, Texas)	LCG/
Celanese Corp	PBI/Fibrefill
Comfort Products (Aspen, Colo.)	Heated handwear
Cotton Incorporated (New York, N.Y.)	Cotton insulating fabrics
Department of Energy (Washington, D.C.)	Energy packs
Duracell (Fairfield, Conn.)	Energy packs
Dupont (Wilmington, Del.)	Sontique
Dynatherm Corp (Cockeysville, Md.)	Heat pipes

Early Winters (Seattle, Wa.)	Chemically heated handwear
Wigwam Mills, Inc. (Sheboygan, Wis.)	Heated footwear
Encon Manufacturing Co. (Houston, Tx)	Air ventilated garments/ air delivery systems
Federal Emergency Management Agency (Washington, D.C.)	Fire protective suits/ Goretex/neoprene/Nomex Kevlar
Gillette Research Institute (Rockville, Md.)	Reflective materials/ physiology and psychology of hyperthermia/thermal transfers
Headquarters Marine Corps (Arlington, Va.)	Soldier's load/packs/ biological & chemical protective garments
W. L. Gore & Assoc. (Elkton, Md.)	Goretex
Helly-Hansen (Moss, Norway) (Dublin, Ireland)	Cold weather clothing, designs and materials/ chemical and biological protective garments/fire resistant materials
Norman Hollies Consultant (College Park, Md.)	Reflective materials
Hughes (Culver City, Ca.)	Thermal diode heat pipe
ILC Industries (Dover, De.)	LCG/chemical and bio- logical protective garments
Institute of Textile Technology (Charlottesville, Va.)	Cotton fabrics
International Harvester (Elk Grove, In.)	Solimide high performance foams

Kendall (Boston, Ma.)	Webril R nonwoven cotton fabric
Kenyon, Corp. (Kenyon, R.I.)	Klimate
Life Support Systems (Mountain View, Ca.)	LCG/air ventilated garment
Marmot Mountain Works Ltd (Grand Junction, Colo.)	Cold weather clothing design
Marine Corps Development Center (Quantico, Va.)	Cold weather clothing and equipment/heat generators
Massachusetts Institute of Technology (Cambridge, Mass.)	Insulating fabrics
Minnesota Mining & Manufacturing Co. (Washington, D.C.) (St. Paul, Minn.)	Thinsulate
NASA Johnson Space Center (Houston, Tex.)	Design innovations/LCG/ LHG/battery packs/HEPA filters/silicone heated fabrics/blue ice /reflective fabrics
National Zoo (Washington, D.C.)	Polar bear physiology
North Face (Berkeley, Ca.)	Cold weather clothing design/reflective materials
Panasonic	Battery packs
Matthew I. Radnofsky Consultant, (Houston, Tex.)	Design innovations/ Vapotex/Texalite/ liquid cooled garments (LCG)/liquid heat garments (LHG)/VORTEX "T" tube/ PBI/polyimides/biological isolation garment/ Preox/Triaxial weaves/ Liteaflex/Teflon coated Beta cloth/Fluorel/nickel

	chromium steel cloths/ aluminized fabrics/ Nomex/Durette/THPOH/ biological and chemical protective garments
Walter Reed Army Institute of Research (Washington, D.C.)	Hypothermia related physiology
Patagonia (Ventura, Ca.)	Pile fabrics
Synergy Works (Oakland, Ca.)	Vapor barrier suit
Tenbe Co. (Atlanta, Ga.)	Liteaflex/solimedes
University of Pennsylvania School of Environmental Medicine (Philadelphia, Pa.)	Propane heaters
Valley Corporation (Houston, Tex.)	Air packs
U.S. Army Natick Laboratories (Natick, Mass.)	Design innovations/LCG/ Thinsulate/Sontique/heat pipes
U.S. Army Research Institute of Environ- mental Medicine (Natick, Mass.)	Physiology of heat and cold/metallized reflective layers/energy packs/ Goretex systems design
U.S. Army Training and Doctrine Command (Fort Lee, Va.)	Chemical & biological protective clothing
USMC Senior Medical Officer Office (Arlington, Va.)	Cold weather clothing/ hyperthermia/hypothermia

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