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AD-A215936

SOME PRACTICAL ADVICE ON COLD WEATHER CLOTHING (U)

by

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TECHNICAL NOTE 89-21

PCN
051LC11

August 1989
Ottawa

ABSTRACT

Considerable research and development has been carried out on cold weather clothing at the Defence Research Establishment Ottawa. This paper explains, in laymens language, the practical knowledge gained in the course of this work. It deals in turn with the five elements of good winter clothing design, thickness, dryness, wind proofness, whole-body coverage and flexibility. It concludes with explanations of how breathable fabrics, wicking fabrics and aluminized materials work and how practical they are.

RÉSUMÉ

Une quantité considérable de recherche et développement a été effectuée sur les vêtements pour temps froids au Centre de Recherches pour la Défense Ottawa. Ce rapport explique de façon simple, les connaissances acquises lors de ce travail. Il traite également des cinq éléments importants pour le design de vêtements d'hiver, à savoir, l'épaisseur, la sécheresse des couches isolantes, l'imperméabilité au vent, la couverture du corps et la flexibilité. Il conclut par des explications sur la façon dont les tissus respirables, les tissus imbibants et les matériels aluminisés fonctionnent et discute de leur utilité pratique.

EXECUTIVE SUMMARY

There are five elements to good winter clothing design. First, the thicker the clothing, the greater the insulation. The thickness required for clothing depends on how hard one is working. A letter carrier who is walking continuously requires much less insulation than a security guard who stays in one spot. The second element is dryness. Any insulating material which is wet is no longer an insulating material. Thirdly, wind reduces insulation in several ways. It can remove the still air layer on the surface of the closing, compress the insulation, blow through the clothing to remove the insulating still air inside your clothing or blow through poor-fitting closures. Fourth, as much of the whole body should be covered by the same amount of insulation. Finally, the clothing should be flexible so that layers can be easily added or removed so that you avoid being either too hot or too cold.

Breathable fabrics allow water vapour through them, but not rain. They are much more expensive than conventional rainwear fabrics, so if you don't need waterproofness, don't pay the extra for it. Polypropylene and other thermal underwear fabrics claim to wick sweat away from the skin. No one has yet shown that these fabrics have any significant effect on warmth, coolness, wetness or dryness. Aluminized materials do reduce radiative heat loss from the body, but insulation yet requires still air layers to keep you warm.

Introduction

Many people spend several hours per day out in the cold and wind of the Canadian winter. This may be by choice in the case of hikers and skiers or as part of their jobs in the case of police, construction workers, or postmen. A few people spend all day and even overnight out in the cold. Foremost among these are soldiers and it is the army whom we at Defence Research Establishment Ottawa (DREO) are trying to help in our research and development work. However, the practical knowledge we have acquired on behalf of the military is applicable to other users of cold weather clothing. This paper is intended to make the most important parts of that knowledge available to the general public and the clothing and textile industries. It is directed primarily at the user rather than the producer but it may be helpful to industry in understanding what the user really needs.

I am frequently asked "What is the best insulation for winter clothing?" It is inspired by the belief that the best clothing is automatically that made from the best material. There is a widespread belief in what I call "Materials Magic". The disappointing answer is that it does not matter very much what clothing is made of. How it is made is much more important. Good designs, not magic materials, are the key to good clothing. There are five elements to good winter clothing design.

They are:

(1) Thickness
(2) Dryness
(3) Wind proofness
(4) Whole-body coverage
(5) Flexibility

I will deal with each in turn.

Thickness

The most important thing that clothing does is create a layer of air near the body and then keep it still. For heat to escape from the body, it first has to cross this air layer. Generally speaking, the thicker the air layer, the harder it is for heat to cross it. In other words, the thicker the clothing, the greater the insulation.

There are many ways of creating a layer of still air. A thin garment such as a shirt simply traps a layer of air underneath itself. Even though a shirt fabric is only about ½ mm thick, it can create an air layer as much as 5 mm thick. You can create thickness simply by wearing several layers of thin fabrics (undershirt, shirt, jacket, etc.) but this doesn't work all that well after the first couple of layers. The problem is that each additional layer tends to press the ones below it up against the body so that the air is squeezed out. To get more insulation for cold weather it is best to use fabrics that are thicker so that a layer of air is trapped within the textile itself. Knitted sweaters, pile liners and parkas filled with polyester batting or down and feathers all create air layers of thickness from a few millimeters to a few centimeters.

There is a lot of hoopla in advertisements and newspaper articles about some types of materials being better than others. It is usually claimed that because a certain fibre is very fine, or hollow, or natural, or the product of space age technology, that it does the best job of keeping air still. None of this is true. Pretty well all clothing materials do a very good job of keeping air still (as long as the wind doesn't blow through them). A 10 mm thick layer of clothing creates a 10 mm thick layer of still air no matter what the fibres are made of or what shape they are.

There are differences among insulating materials but they are quite subtle and really should not worry the average user. The differences are in the way different materials prevent heat loss by thermal radiation. (Thermal radiation is what you feel when you put your hand up to the fire. Anything that is warm radiates. Since our skin is warm, it radiates into the environment and loses heat. You cannot stop this kind of heat loss with an air layer; you need to put solid objects in the way. Textile fibres tend to stop radiation as well as trap air.) From a practical point of view all materials of the same thickness give about the same insulation. Insulation values for clothing can be quoted in the same way as for building insulation. A 10 mm thickness of clothing gives an RSI value of about 0.25. This is a typical value and there is some variation. Ten millimeters of wool blanket might have RSI 0.30 and 10 mm of down might have RSI 0.20. But give or take 20% they are all the same. The warmest garment will almost always be the thickest, not the one made of some magic material.

So how thick should clothing be? It depends on what the temperature is and how hard you are working. The basic idea is that as you work harder you produce more heat. You need to get rid of that heat or you will become too hot. But if you lose more heat than you produce, you will become cold. You therefore need to match your clothing insulation to your activity as well as to the weather. Without knowing exactly what a person does, I can't give accurate advice on how much insulation he should wear, so I've picked a couple of examples and made estimates of required clothing thickness.

The examples I've picked are those of a security guard who stays more-or-less in one spot and of a letter carrier who is constantly on the move carrying a load of a few kilograms. We can call these work rates light and moderate respectively. Obviously there are people who work harder than letter carriers but they probably do not keep a steady pace and it is more difficult to estimate their heat production. The security guard is probably producing about 150 Watts of heat, the letter carrier about 300 Watts. (Hard work would be 600 Watts or more, but you have to be quite athletic to keep this up for a whole working day.) Table I lists the clothing thickness for these two jobs at various air temperatures. These thicknesses are the total thickness of all clothing and trapped air layers on any part of the body. Ideally this same thickness should be worn over the whole body.

Dryness

The old mythology of clothing said that for warmth-when-wet, it had to be wool. The modern mythology says synthetics such as polyester and polypropylene are warm when wet. So will the real magic material please stand up! Both myths are precisely that. Any insulating material which is wet is no longer an insulating material. The reason is very simple.

We all know that when we wet our skin either with sweat or rain, the water evaporates. Evaporation takes heat and cools the skin. If we put water in our clothing and put the clothing next to our skin, the water evaporates. Evaporation takes heat and cools the clothing which cools the skin. It's that simple. It doesn't have much to do with water being a good conductor and replacing air which is a poor conductor. Unless you go swimming with your clothes on, you really don't replace much of the air with water. It does not matter what the fibres are made of or what shape they are. Wet clothing is cold clothing.

The only way to obtain insulation in wet conditions is to use a material which does not get wet. A closed-cell foam such as that used in a diving suit is about the only practical choice if you insist on soaking yourself. Otherwise all you can do is try to keep water out with either waterproof covers or water repellent finishes. Wool probably owes its warm-when-wet reputation to its natural water repellency and its hairy surface. Under mildly wet conditions such as a fine drizzle or a light spray from a sail boat bouncing over waves, a wool sweater won't get wet and will insulate. But don't expect this to work in a downpour.

The modern myth that synthetics are warm when wet certainly comes from the observation that synthetic battings keep their loft when wet. Down and feathers on the other hand turn into a wet soggy mess. Since insulation requires thickness, won't the synthetic be warmer than the down? Sure it will but warmer does not mean warm (-30°C is warmer than -40°C but it's still cold). The heat loss through a wet garment will usually be about three times the heat loss through the same garment when dry. So you need to wear three wet parkas to do the job of one dry one. Don't rely on magic materials to keep you warm in the wet, stay dry. If you do get wet, change. If you still insist on getting wet, wear a diving suit.

Windproofness

Everyone knows that a wind makes cold even colder and the weather reporters drive the point home by quoting windchill factors. The windchill factor is not very relevant to a clothed person but it does tell you something about exposed skin so it's worth considering.

Even naked skin has some still air stuck to it and so is insulated from the environment. The air layer that is held by friction to the skin is about 5 mm thick - when it isn't windy. What the wind does is to blow that insulating air layer away. As a result, the loss of heat from exposed skin is faster when it is windy than when it is still. When the weather office quotes a windchill of 2000 Watts per square metre, they are telling how fast heat is lost from exposed skin assuming the skin has a temperature of 33°C. Windchill does not strictly apply to skin which is at any other temperature. Actual skin temperatures are often much lower. The other way of quoting windchill is as an equivalent temperature. Here what is meant is the temperature at which, with no wind, the heat loss would be the same as with the actual temperature and actual wind. (Note that windchill tells you how fast skin cools not how far it will cool. If the air is 5°C, your skin can't cool lower than 5°C even if the windchill is -20°C.)

Just as there is a layer of still air stuck to exposed skin, there is a layer of still air on the outside of clothing. This is also blown away by the wind so even perfectly windproof clothing loses some insulation in the wind. The wind can do two other things to clothing though and these are usually much more important.

If there are holes in your outermost layer of clothing, the wind can penetrate and blow away the still air trapped inside the clothing. The wind can get in in two ways, either through small holes between yarns in the fabric or through the large openings in the garment itself where your head, arms, etc. poke through. To keep the still air inside your clothing, you have to stop both kinds of wind penetration. Neither is very difficult.

Some fabrics have substantial spacings between their yarns and let wind through easily. Others are tightly woven and let very little wind through. Still others are coated, usually to make them waterproof, and let no wind through at all. It is very easy to check a fabric for windproofness. Stretch the fabric tight across your mouth and try to blow through it. Try this with a variety of fabrics, your shirt, jacket and rainsuit for example. You can easily tell which ones let air blow through and which don't. If you can detect any air blowing through the fabric in this test, it isn't windproof.

Keeping wind out of large openings is a matter of design of closures. Storm cuffs or draw strings are required at the cuffs of trousers and jackets, at the waist or the hem of jackets and around the face opening of the hood. A scarf can do a good job of keeping wind out of neck openings.

Another thing that wind does is compress clothing, pushing it hard against the skin. With the thickness mostly gone, there is no insulation. This is most important where you are relying on thin fabrics and trapped air layers. It is particularly noticable on the legs when walking into the wind. The solution is to use thicker materials that don't compress and don't rely so much on trapped air layers.

With the right materials and good design in clothing, windchill should not be a factor.

Whole Body Coverage

It is only a slight exaggeration to say that the typical Canadian goes out into the cold with eight layers of clothing on his torso, a single thin pair of trousers, and no hat. This is about the same as insulating a house with eight inches of insulation in one wall, one inch in the other three walls and nothing in the ceiling. It's not a very efficient use of insulation. Heat loss is practically nothing in some places and very high in others. Total heat loss will be lower if we take the same quantity of insulation and distribute it evenly over the whole body or the whole house.

No one ever insulates a house so unevenly so why do people dress that way? There are many reasons. One is fashion. If hats are out, some people will freeze to death rather than die of embarrassment when seen wearing one. Another is convenience. It is very easy to throw on a coat but it takes a while to put on an extra pair of trousers. But I suspect the main reason is more basic. People will often say "My legs don't get cold...My arms don't get cold...My head doesn't get cold". What they mean is that their arms, legs and head don't feel cold. Since they don't feel the cold in these areas, they don't see any reason to insulate them.

The fact that we do not feel cold on our arms, legs and head is probably rooted in our biological make up. Man is a tropical animal and evolution has not equipped him for life in the cold. In the tropics, on a really cold day, the temperature may be 10°C. In order to keep himself alive in that frigid environment, man takes steps to protect the torso and the vital organs. He doesn't really care if arms and legs get cold. At 10°C, they can't freeze and permanent injury is unlikely. So he shuts off the blood supply to arms and legs (but not head) and keeps the heat in the torso where the important organs are. Since arms and legs can be allowed to cool, they are not very well equipped with temperature sensors. You can demonstrate this to yourself very easily. Get an ice-cube and touch it to various portions of your body, or better, someone else's body. An ice cube on the back produces a very much stronger cold reaction than on the forearm.

Even though we do not feel the cold on our arms, legs and head, we can still lose a lot of heat from them. All over coverage is essential if we are going to survive extreme cold for many hours.

Flexibility

If you know what the weather is going to be and what you are going to do, it is easy to put on the right clothing. By wearing enough thickness, but not too much, you can avoid being either too cold or too hot.

There is a minor problem that the weather forecast is not always spot on, but usually it's pretty close. If you are too cold, it's usually your own fault, not the weatherman's. A much bigger problem is that people rarely stay in the same place or keep doing the same thing for very long. We are constantly in and out of heated buildings or vehicles. We may have to work hard for a while, then stand around and wait for someone to catch up or a bus to arrive. If we dress to keep warm when we are outside and sedentary, we will be too hot when we work hard or when we go inside.

This is a classic problem with a classic solution. Dress in layers, add more layers when you are too cold, remove layers when you are too warm. Unfortunately, this is easier said than done. For example, suppose you go out on a cold, windy day wearing thermal underwear, trousers, shirt, sweater and a one-piece snowmobile suit. You find yourself quite comfortable while driving the snowmobile but it breaks down and you have to walk home. Now you are too hot. What are you going to take off? You don't want to take off your snowmobile suit since it is your only windproof layer. To take off an inner layer, you have to remove the snowmobile suit, remove a sweater or shirt, and put the outer layer back on, meanwhile exposing your upper body to the wind. Removing layers from the legs is even more difficult. Understandably, people are reluctant to go through all this and simply put up with the heat. They do their best to get rid of heat by opening zippers but this doesn't work very well. The result is profuse sweating and soaking wet clothing.

There are two points to be made here. One is that clothing should be easy to remove. So a two-piece suit makes more sense than a one-piece. Trousers should be loose enough to pull off over boots or have full length side zippers. The second point is that you should plan on removing outer clothing, not inner clothing. This means that your inner clothing should also be windproof (ideally it should be waterproof as well). At first the idea of windproof inner clothing may seem strange but it's not that difficult. Instead of wearing a sweater under a parka, wear a light weight windbreaker under a parka. If you are too hot, you can remove the parka and still have wind protection. The same can be done with fully zippered trousers if you can find lightweight windproof trousers to go underneath. Admittedly, making adjustments on the legs is much more difficult than on the upper body but if you do have to spend long periods out in the cold, the effort is well worthwhile.

Table I can be used as a guide to how much insulation you need in inner and outer clothing. Suppose you have a job which requires alternating between light and moderate work. At moderate work rates at -10°C you need about 10 mm thick clothing. Make your inner clothing this thick. During your light work periods you'll need about 20 mm. So if you have outer clothing that is also about 10 mm thick you can go back and forth from 10 to 20 mm total thickness by adding or subtracting that outer layer. Ideally, the outer clothing should cover the whole body but obviously taking outer trousers off and putting them on every half hour could be very inconvenient. For many people a long coat which covers most of the legs may be more practical - but it should have a hood.

This kind of system of adding or subtracting a whole outer layer can be very effective in making big changes in insulation to compensate for big changes in activity. But what about minor changes to take care of being a little too hot or a little too cold. A two-piece outer suit allows you to wear just the trousers or just the jacket. Zippers and vents can help a little and so can removing hats and gloves. All other things being equal, the clothing which gives more chances for adjustment is to be preferred. But don't expect these little things to be as effective as removing a complete layer.

Breathables, Wicking Fabrics and Other Hi-Tec Red-Herrings

Almost any catalogue of outdoor clothing contains glowing descriptions of the scientific miracles embodied in the latest wonder fibre or fabric. The general characteristic of these products is that they are very much more expensive than the traditional fabrics they replace. I would guess that the manufacturers claims for them are based more strongly on market research than scientific research. One or two are worth considering, though.

One of the few genuine advances in clothing in recent years is the development of fabrics which are waterproof but "breathable". "Breathable" is a poor word since it sounds like it refers to letting air in and out whereas it really refers to letting water vapour through. A better term is "water-vapour permeable", although it is a mouthful.

Almost all fabrics are breathable in this sense. They all have holes in them to let water vapour diffuse through. The ones that are not breathable are the fabrics which have been coated to plug the holes and stop the rain coming in. What technology has come up with over the past 10 or 15 years is a set of fabrics which are both waterproof and breathable. This is a real technological advance, not just marketing. So what? The question is do you need such a fabric and is it worth the cost?

First consider this. The only time you'll need a waterproof fabric is if you are going out in rain or wet snow. If your clothing is just for dry cold conditions you don't need waterproofing. What you need is a windproof fabric. Tightly-woven nylon or polyester fabrics, with no coating, are windproof, breathable and cheap. If you don't need the waterproof feature, why pay for it?

Second, if you do need waterproofing, ask yourself what is wrong with a normal non-breathable, coated fabric? Is the extra cost of a breathable fabric worthwhile? The marketing usually claims that these breathable fabrics will let you sweat and stay dry whereas you'll get wet in non-breathable fabrics. This may or may not be true depending on the conditions. At low temperatures it is quite untrue. No matter what your rainwear is made of, if you sweat into it at low temperature, you'll get wet. Even if your clothing isn't waterproof at all, if you sweat, you get wet. The reason is very simple.

When you sweat, the air close to your skin is at about 35°C and 100% relative humidity. If the air outside is 0°C, the temperature of the outermost layer of clothing is probably in the 0 to 10°C range. The situation is very similar to a cold beer removed from the fridge on a hot muggy July day in Southern Ontario. In a few minutes that beer bottle is covered by condensation and dripping wet. The same thing happens in clothing. There is warm moist air close to a cold surface so the clothing gets wet from condensation. It doesn't matter what the clothing is made of. It's the low temperature that causes the wetness, not the fabric.

Whether you sweat into a totally impermeable waterproof, into a breathable waterproof, or into a normal, permeable, non-coated fabric, at lower temperatures you'll get wet. Why then, go to the expense of a breathable waterproof. The answer is that in a normal waterproof, once you get wet, you stay wet. In a breathable you'll get wet but then dry - <u>slowly</u>. It will take many hours of drying to get rid of the water from one hour of sweating but the water will eventually get out. So if you are someone who has to keep on wearing the same clothes all day or for several days, a breathable waterproof is worthwhile. On the other hand, if you are only going to be out for an hour or two before you can come in and dry your clothes, the expense is probably not worthwhile.

Another product line that is supposed to dispose of sweat is polypropylene and other thermal underwear fabrics which "do not absorb moisture but wick sweat away". This is more difficult to make sense of. Usually the claims for these fabrics stem from a confusion of the motions of water vapour and liquid water. Lets tackle vapour first.

If you wear too much clothing and work too hard you will overheat and sweat. (The best solution to the problem is not to wear so much clothing. See section on flexibility.) What sweat is supposed to do is evaporate from the skin. The conversion of water liquid to water vapour takes up heat from the body. For this process to work, the vapour has to escape from the clothing taking its heat away with it. As noted earlier, there is a big problem in that water vapour is going to condense in cold clothing and escape only slowly. On top of that, there is a minor problem that textile fibres tend to absorb water vapour from the air. Wool and leather absorb a lot, cotton and nylon absorb a little, polyester, acrylic and polypropylene absorb almost none. To this extent, the claims for Hi-Tec underwear are technically correct. They do absorb less water vapour than the so called natural fibres. However, the quantity involved is rather small even for cotton. Also, the water that is absorbed by cotton would probably not get through the other clothing even if it were not absorbed. The claims may be technically correct but there's not much practical significance.

When we talk about wicking, we are dealing with liquid water. The term "wick" is a little obscure so most readers (and probably writers) of underwear advertisements do not understand the claims. Wicking refers to the motion of liquid along fine channels between the fibres in a textile. The wick in a candle or oil lamp transports molten wax or oil from a pool up to where the flame is burning. If you put a drop of water on a cotton undershirt or a paper towel, the drop spreads out over a large area. This is wicking. It is a process which is not very well understood scientifically although we are studying it and some aspects are clear.

In order to wick water in a fabric, you first have to get the water into the fabric. It has to be made of fibres which attract water to their surfaces. Next you have to provide long fine channels for the water to move along. The fabrics which wet easily are the traditional cottons and linens. The ones with long fine channels are generally fabrics made from continuous filament fibres such as polyester, nylon or polypropylene. Synthetic fibres, especially polypropylene, are repellent to water so they do not wet easily. So in order to make a really good wicking material, manufacturers put a finish on synthetic fibres to make them attractive to water and easily wetted. The result is a fabric which soaks up water like a sponge. Polypropylene fibres may absorb very little water vapour but polypropylene underwear absorbes a lot of liquid water. At least it does when it is new. That finish that makes polypropylene wet easily unfortunately washes out. After a few washes (perhaps just one) your miracle wicking fabric will not wick anymore. One the other hand, many cotton knits wick almost as well as polypropylene and keep on doing so till they wear out. They are also cheap.

This long technical discussion of wicking fabrics may be interesting (or maybe not) but does any of it matter? I think not. No one has ever demonstrated that wicking fabrics next to the skin have any significant effect on warmth, coolness, wetness or dryness. Many people claim that they feel more comfortable in polypropylene than in cotton (before or after washing, they don't say). But then anyone who pays $50 for a set of underwear is not likely to admit he's been taken. The scientific evidence to date says that if you sweat into cotton underwear, you have wet cotton underwear. If you sweat into polypropylene underwear, you have wet polypropylene underwear. The water will not wick away. It may be that you'll find one more comfortable, than the other, but neither one will be insulating if it's wet.

One last set of red herrings, "space-age, aluminized materials that reflect 80% of the body's heat back in". Forget them. At best they reduce radiative heat loss from naked skin. Insulation still requires that still air layer. (At least on earth it does. In space, you can use a vacuum instead.) Also, most textiles already do a pretty good job of reducing radiative heat loss. So what you gain from a reflective layer is only an increase in insulation of a few percent even when the aluminum surface is clean and dry. A few aluminized threads mixed into a wool sock won't even give you that few percent.

Putting It All Together

What I've tried to convince the reader of is that good winter clothing can be quite simple and straightforward. It depends mostly on design principles which are largely common sense. Part of a good design is picking the right materials but there are no magic materials which will turn poor clothing into good clothing. The actual design that you need will depend on the job you have to do. A good design need not be expensive. Ordinary, cheap, convenient garments can be put together to make an effective winter clothing system. Just bear in mind these five rules:

(1) Pick the correct thickness;
(2) Keep it dry;
(3) Make sure its windproof;
(4) Cover the whole body (or as much as is practical);
(5) Wear garments that can be taken off and put back on easily.

Otherwise, breathable waterproofs are useful for some, but Hi-Tec won't keep you warm.

TABLE I

Clothing Thicknesses Required for Light and Moderate Work at Various Temperatures

Temperature (°C)	Clothing Thickness	
	Light Work (mm)	Moderate Work (mm)
0	16	8
-10	21	10
-20	27	13
-30	32	16
-40	37	19

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SECURITY CLASSIFICATION OF FORM
(highest classification of Title, Abstract, Keywords)

DOCUMENT CONTROL DATA

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

1. ORIGINATOR (the name and address of the organization preparing the document. Organizations for whom the document was prepared, e.g. Establishment sponsoring a contractor's report, or tasking agency, are entered in section 8.)
Defence Research Establishment Ottawa
National Defence
Ottawa, Ontario K1A 0Z4

2. SECURITY CLASSIFICATION (overall security classification of the document, including special warning terms if applicable)
UNCLASSIFIED

3. TITLE (the complete document title as indicated on the title page. Its classification should be indicated by the appropriate abbreviation (S,C or U) in parentheses after the title.)
SOME PRACTICAL ADVICE ON COLD WEATHER CLOTHING (U)

4. AUTHORS (Last name, first name, middle initial)
FARNWORTH, Brian

5. DATE OF PUBLICATION (month and year of publication of document)
AUGUST 1989

6a. NO. OF PAGES (total containing information. Include Annexes, Appendices, etc.)
10

6b. NO. OF REFS (total cited in document)

7. DESCRIPTIVE NOTES (the category of the document, e.g. technical report, technical note or memorandum. If appropriate, enter the type of report, e.g. interim, progress, summary, annual or final. Give the inclusive dates when a specific reporting period is covered.)
TECHNICAL NOTE

8. SPONSORING ACTIVITY (the name of the department project office or laboratory sponsoring the research and development. Include the address.)
Defence Research Establishment Ottawa
National Defence
Ottawa, Ontario K1A 0Z4

9a. PROJECT OR GRANT NO. (if appropriate, the applicable research and development project or grant number under which the document was written. Please specify whether project or grant)
051LC11

9b. CONTRACT NO. (if appropriate, the applicable number under which the document was written)

10a. ORIGINATOR'S DOCUMENT NUMBER (the official document number by which the document is identified by the originating activity. This number must be unique to this document.)
DREO TECHNICAL NOTE NO. 89-21

10b. OTHER DOCUMENT NOS. (Any other numbers which may be assigned this document either by the originator or by the sponsor)

11. DOCUMENT AVAILABILITY (any limitations on further dissemination of the document, other than those imposed by security classification)

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DCD03 2/06/87

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14. KEYWORDS, DESCRIPTORS or IDENTIFIERS (technically meaningful terms or short phrases that characterize a document and could be helpful in cataloguing the document. They should be selected so that no security classification is required. Identifiers, such as equipment model designation, trade name, military project code name, geographic location may also be included. If possible keywords should be selected from a published thesaurus. e.g. Thesaurus of Engineering and Scientific Terms (TEST) and that thesaurus-identified. If it is not possible to select indexing terms which are Unclassified, the classification of each should be indicated as with the title.)

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THICKNESS,
MOISTURE CONTENT,
WINDPROOFNESS,
BREATHABLE FABRICS,
WICKING FABRICS,
ALUMINIZED FABRICS. (STW)

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