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Thermal Evaluation of Government of Canada Cold Weather Clothing and Indigenous Garments

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Thermal Evaluation of Government of Canada Cold Weather Clothing and Indigenous Garments

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Executive Summary

Government departments with operational requirements in the Arctic have commented that the typical clothing ensembles worn by their personnel are a limiting factor for successful operations in the north. Frostbite, hypothermia, and challenges with basic usability of equipment with bulky outerwear, are all example trials faced by personnel. Clearly, personnel conducting northern operations must be properly attired for their required tasks.

Indigenous Peoples provide leadership when it comes to protecting people from the elements in northern, often harsh, environments. Canada's northern residents have hundreds of years of successful development of clothing to protect themselves from the environment. This project brings together Indigenous Knowledge and western science in order identify the components of traditional clothing ensembles that are most suitable for operational activities in cold climates.

The overall objective of this project is to investigate the ability of Indigenous clothing to protect the wearer according to its construction and purpose, providing guidance for its use as harsh weather personal protective equipment. This will lead to increased personal safety and security in Arctic environments.

The four main tasks for the research project are:

1. Collaborate with crafting partners to determine the different types of garments to be evaluated, and procure garments from crafters located across northern Canada.
2. Measure the thermal protection provided by these garments using a thermal manikin.
3. Conduct interviews with the crafters, Hunter and Trapper Organization members, Coast Guard Auxiliary, and the Canadian Rangers to collect knowledge on relevant clothing types, preferences, garment care, and use. In addition, conduct interviews with Government of Canada staff with northern operational experience.
4. Perform a high level evaluation on the considerations of how garment construction, care, costs, and contracting may influence the ability of federal departments to purchase these examples of Indigenous clothing for incorporation into personal protective equipment, or uniforms, for their staff.

This report will focus on the second task.

Nineteen Indigenous-made garments were tested as part of this project, along with various garments used by Parks Canada and the Canadian Coast Guard, as part of their issued personal protective equipment kits for their staff. The garments were combined to create different clothing ensembles. The thermal insulation (clo value) of the various garments and ensembles were measured using a 23-zone submersible thermal manikin, NEMO, in the National Research Council of Canada's Thermal Measurement Lab. All tests were conducted in 4.0°C air while NEMO maintained a mean skin temperature of 40.0°C.

The larger Indigenous-made garments (e.g. parkas and pants), provided a high level of thermal protection equivalent to, and sometimes exceeding, that provided by garments used by Parks Canada and the Canadian Coast Guard. An ensemble composed entirely of Indigenous-made garments had the highest measured clo value out of all those tested, which would allow a physically active person to remain warm in -60.0°C air.

All of the Indigenous-made hand garments had higher clo values compared to the NRC standard base layer Gore-Tex mittens and Parks Canada mittens. Based on previous research not affiliated with this project,

we can deduce that the insulation provided by the Indigenous-made hand garments can help protect against frostbite for up to 180 minutes in -30.0°C air.

Similar to the hand garments, the Indigenous-made foot garments had higher clo values compared to the combination of NRC standard base layer neoprene boots and Parks Canada socks.

The Indigenous-made head garments (hats and neck warmers) had clo values similar to the base layer, and Parks Canada items. However, the lack of difference in clo values can be explained by dressing variations, and the compressibility of some garments. When examining the amount of power required to maintain its skin temperature, NEMO required less when wearing some Indigenous-made garments indicating that they provided more insulation compared to the base layer items.

Overall, the thermal evaluations showed that the Indigenous garments performed very well across a range of temperatures. Particularly at the extreme cold range, the clo value measured by these garments indicate that they would provide an excellent degree of protection in harsh environmental conditions. When compared to previously-posted requirements from Government of Canada Departments and Agencies on the Buy and Sell procurement site, the Indigenous clothing would meet or exceed the technical requirements, such as clo value, to be considered for inclusion as part of Government of Canada personal protective equipment kits.

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Definitions

Symbol or Acronym	Definition
T_A	Air temperature
clo	One clo is equal to the amount of insulation needed to keep a seated person comfortable in air at a temperature of 21°C, 50% or less relative humidity, with an air velocity of 0.1 $m \cdot s^{-1}$
TR_2	An estimate of the air temperature (°C) a person could wear the garment or ensemble and remain in a thermoneutral condition (heat loss is equivalent to heat gain). A TR_2 temperature rating is for a low level of physical activity, which is equal to a metabolic equivalent[1] of 2 (2 MET). A low level of physical activity is equivalent to a person walking very slowly (ASTM, 2016b).
TR_4	An estimate of the air temperature (°C) a person could wear the garment or ensemble and remain in a thermoneutral condition (heat loss is equivalent to heat gain). A TR_4 temperature rating is for a moderate level of physical activity, which is equal to a metabolic equivalent of 4 (4 MET). A moderate level of physical activity is equivalent to a person walking very fast (ASTM, 2016b).
STIV	clo values reported as standardized total thermal resistance (insulation). The standardized total insulation values account for the thermal insulation provided by both clothing and surface air layer around the manikin.

[1] One metabolic equivalent (1 MET) level of activity is equal to the amount of energy consumed, and heat produced, by a person who is lying down motionless.

1. Introduction

Human beings are homeothermic (also known as “warm blooded”) animals in that we attempt to regulate and maintain our deep body (core[2]) temperature regardless of the external environmental conditions. This regulation is achieved through balancing the amount of heat generated via metabolism, with the amount of heat lost to the external environment. When heat generated is equivalent to heat loss, the human body is in thermal balance, and should maintain a stable deep body temperature. While the human body has several physiological mechanisms to help regulate temperature, such as shivering and sweating, the most common way we do so is through the use of clothing. Depending on where we are, and what we are doing, humans will attempt to select a level of clothing that allows them to maintain a normal deep body temperature of approximately 37°C.

This technique of maintaining a normal deep body temperature through the use of appropriate clothing selection is seen often during normal day to day activities. When seated in an environment in 21°C air, a person will tend to be dressed in light clothing that covers their entire body (e.g. pants and a long sleeved shirt). If this same person was to step out of the office into -10°C air, they would put on extra clothing such as a winter parka in order to maintain their deep body temperature. At a different time of year, this same person may exit from an indoor environment into 30°C air, and possibly remove some clothing to increase heat loss so that their deep body temperature does not increase.

In addition to the external environment, another factor that can impact our deep body temperature is the level of physical activity a person is performing. A higher level of physical activity causes more body heat production compared to being stationary, thus requiring less clothing to remain warm. This phenomenon can be observed during sporting events where the stationary observers in the bleachers require more clothing to stay warm compared to the active athletes on the field. Both groups of people are in the same environment, but one group requires less clothing since their heat production is much higher.

Considering then both the impact that the external environment and the individual level of physical activity of a person can have on our ability to maintain a stable deep body temperature, it is therefore important to select the right level of clothing to allow humans to achieve the desired thermal balance (heat generated = heat loss). Decreases, or increases, in deep body temperature can result in discomfort in humans, and if they are large enough, harm or even death. Since both the external environment and physical activity level can change, so too will the clothing requirements. This means that the concept of “bad” clothing, from a thermal protection perspective, is inaccurate. All clothing can be useful in helping to achieve thermal balance, provided it is used in the appropriate environment for a given level of physical activity.

One environment that can be challenging in which to operate is the Canadian Arctic. This environment has extremely low temperatures, high winds, and precipitation. However, Indigenous Knowledge (IK) provides leadership when it comes to protecting people from the elements in Canada’s

[2] While it is common to use the term “core” when referring to body temperature measurements (e.g. “hypothermia is when core temperature drops below 35°C”), no accepted definition of where such an area begins and ends actually exists.

northern, harsh environments. Canada's northern residents have hundreds of years of successfully developing clothing to protect themselves from the environment.

Government departments and agencies with operational requirements in the Arctic have commented that the typical clothing ensembles worn by their personnel are a limiting factor for successful operations in the north. These departments and agencies regularly operate in the Arctic and are faced with the challenge of ensuring their personnel are adequately protected from harsh conditions. Frostbite, hypothermia, and challenges with basic usability of equipment with bulky outwear are all examples of documented challenges faced by Canadian Forces personnel (Sullivan-Kwanes et al., 2020), for example. Improved methods for protecting all personnel from these harsh conditions would help to increase their safety, and improve their operational performance as well.

1.1. Background

Aside from dated, passing mentions in non-scientific literature (e.g. a reference to use reindeer hide for aviator clothing in the 1930s, in Sweeting, 2015), there has been extremely little research on the thermal protection offered by Indigenous clothing (Post, 2020). Two previous Canadian studies (Oakes et al., 1995; Hill, 2020) did investigate the protection offered by traditional garments. Oakes et al (1995) found no significant differences between caribou skin clothing, and military or expedition ensembles, when worn by their test subjects. Hill (2020) as well found there were no difference between caribou skin clothing and western clothing using thermal imaging. While it is promoted that natural materials such as seal skin, eider duck down or qiviut (muskox wool fibers) have superior thermal performance compared to synthetic materials, there exists very few published studies evaluating this, with the exception of how such fibres protect the original animal (Post, 2020). This study uses the Oakes et al. (1995) research as a stepping stone, to expand to a wider range of Indigenous clothing types, including those that have the potential to be developed to be available for operational (e.g. government, expedition) use.

1.2. Project Objectives

The overarching objective of this project is to investigate the ability of Indigenous clothing to protect the wearer according to its construction and purpose, and how guidance can be provided for the use of harsh weather personal protective equipment(PPE), leading to increased personal safety and security in Arctic environments.

This project's sub-objectives are:

- to evaluate the thermal insulation of various Indigenous-made cold weather garments for use in Arctic conditions;
- to evaluate the thermal insulation of various clothing garments and ensembles used by Canadian Government staff with operational requirements in the North;
- to investigate whether Indigenous clothing ensembles and components could provide a means to meet Canadian Federal fleet (e.g. Canadian Coast Guard, Fisheries and Oceans and Parks Canada) and military operational challenges;
- to investigate how the thermal properties of Indigenous clothing and its ability to protect the wearer according to its construction and purpose can provide guidance for design and construction of harsh weather clothing.

The project seeks to bring together IK and western science in order to help contribute to the understanding of how traditional clothing ensembles worn by Canada's northern residents may help to improve operational activities in harsh environments. A separate document will describe the fourth sub-objective, the Indigenous Knowledge and federal operational needs assessment. For that task, working with the partners, a northern researcher was selected, and was provided with funding to compile, with permission from the clothing partners, craft councils and Hunter and Trapper Committees, IK on relevant clothing ensembles. This could include material thermal properties, garment care and traditional use, including comfort and dexterity. An ethics review (NRC Research Ethics Board) and the appropriate research licensing (Nunatsiavut, Nunavut and Northwest Territories) was completed for this aspect of the project. This researcher will also document northern clothing use by a variety of operational organizations, such as the Coast Guard Auxiliary, the Canadian Rangers,and Parks Canada, Fisheries and Oceans, Coast Guard and Department of National Defense staff.

This report presents the measurements of the thermal insulation of a variety of Indigenous-made cold weather garments, along with garments used by Canadian Government organizations with operational responsibilities in the north, as described in the first three sub-objectives of the overarching project.

Outcomes of the research will include:

- Foundational knowledge about the thermal performance of a variety of Indigenous clothing components;
- Development of preliminary knowledge base to provide alternative PPE to organizations with operational responsibilities in cold regions.

The research will lead to impacts of:

- Removing barriers to economic diversification to communities by improving the opportunities for individuals' small enterprises, through supporting procurement options for Indigenous clothing;
- Ensuring that staff in cold regions, by using personal protective equipment that is best-suited to the operational environment, are supported by promoting safe practices in the field for personal security.

2. Methodology

2.1. Craft Organization Support and Input

At the outset of the project, the research team had a series of meetings with its crafting partners: the Nunavut Arts and Crafts Association, the Northwest Territories Arts Program, the Nunatsiavut Arts Program and the Craft Council of Newfoundland and Labrador. Early meetings:

- determined the types of garments to be evaluated, based partly upon previous input from Canadian Special Operations Forces Command (CANSOFCOM) as well as discussion with representatives from the Government of Canada partners with operational responsibilities in the north;
- and identified the crafters, chosen from across Inuit Nunangat and northern First Nations communities.

Once the clothing was chosen, the Craft Council of Newfoundland and Labrador acted as the lead organization for procuring garments for testing at full market rate. In addition, small contracts with the chosen crafters were put in place, to support a few days of their time to provide input into the project, including information about the material they use, their chosen construction methods, and so on. Once procured, the clothing was sent to the Craft Council of Newfoundland and Labrador, who in turn delivered it to the National Research Council of Canada's (NRC) St. John's laboratory.

2.2. Clothing Ensembles

In addition to the garments procured by Indigenous crafters, reference garments used for northern operations by Parks Canada, the Canadian Coast Guard and the Department of National Defence[3] were supplied. A complete list of the different garments used are given in Tables 1, 2 and 3. All garments were size "Medium", and two sets of each were provided or procured. Table 1 lists the garments comprising the NRC standard base layer ensemble which is based on that prescribed in ASTM F2732-16 (ASTM, 2016b).The descriptions for each ensemble are given in Appendix B.

[3] The Department of National Defence garments were tested at a later date, and are reported upon in a separate document.

Table 1: NRC Base layer ensemble.

Base Layer Garments	Description
Underwear briefs	100% cotton
Underwear jersey	100% cotton
T-shirt	100% cotton
Long sleeved shirt	100% cotton
Pants	60% polyester; 30% cotton; 10%
Socks	unknown, possibly cotton
Toque	Shell: 50% ragwool; 50% acrylic. Lining: 100% polyester
Mittens	Gore-Tex® mittens
Boots	90% neoprene; 10% nylon boots

Table 2: Government of Canada cold weather garments.

Garment	Description
Canadian Coast Guard (CCG) Parka	CCG standard issue parka with heavyweight insert
CCG Jacket	off-the-shelf/commercial option
CCG Pants	off-the-shelf/commercial option
CCG Jacket	off-the-shelf/commercial option
Parks Canada Shirt	98% nylon, 2% spandex
Parks Canada Socks	Merino wool /Nylon socks
Parks Canada Long underwear	100% Merino wool
Parks Canada undershirt	100% Merino wool vest
Parks Canada tuque	100% Merino wool chef style hat
Parks Canada Mittens	Leather mittens
Parks Canada liner for pants (with Bib)	100% nylon with Powderfill, 100g/m^2
Parks Canada Leather Dress Gloves	Leather gloves with 100% fleece insulation
Parks Canada Parka	100% polyamide (Primaloft®) 100% insulation, coyote fur trim on removable insulated hood
Parks Canada Neck Warmer	Fleece back brushed, anti-pilling, wicking 92% Polyester, 8% Lycra
Parks Canada Pants	Cargo pants, silicone polymer encapsulation, plain weave, DWR, 99% Nylon, 1% Spandex, 161 g/m^2 cargo pants

Table 3: Indigenous crafters garments

Garment	Description
Trapper Hat	Trapper style hat made with beaver fur
Beaver Neck Warmer	Neck warmer made with sheared beaver fur
Qivuit Neck Warmer	Neck warmer made with knitted qivuit
Fur Warmer Bundle	Glove and boot warmer inserts made with sheared beaver fur
Bison Mittens	Mittens made with bison hide and sheared beaver fur
Parka	Commander and fur pull over hunting style parka
Wind Pants	
Beaver Mittens	Mittens made with beaver fur
Seal Mittens	Mittens made with seal skin
Beaver Gauntlets	Gauntlet style mittens made with beaver fur
Booties	Booties made with qivuit fur
Melton parka	Parka lined with melton (wool)
Socks	Socks made from homespun wool
Shin boots	Boots made with sealskin
Siliapik Parka	
Sealskin Mittens	Sealskin and fur-long hunting mittens
Trapper Hat	
Long Mittens	Mittens lined with sheep skin

2.3. Thermal Manikin (NEMO)

All tests were conducted using a 23-zone submersible thermal manikin, NEMO (Figure 1). Each of the 23 independently heated zones contain a heater, and two precision thermistors for measuring skin temperature. While NEMO is capable of being submerged, all tests for this project were conducted in the air. NEMO was dressed in different garments to create various ensembles that would be representative of what a person may wear in harsh environments, and to allow for comparisons between garments.

2.4. Thermal Measurements Lab (TML)

All tests were conducted in the Thermal Measurements Lab (TML), located in the NRC's St. John's facility. The TML is a temperature controlled facility that is capable of maintain an air temperature (T_A) over a range of 4 to 30°C, which is monitored by a pair of thermistors located on the North side of the room. For all tests, NEMO was suspended from an overhead crane located in the TML (Figure 1).

Figure 1: Thermal manikin, NEMO, in NRC TML.

2.5. Procedure

All clothing garments and ensembles were tested according to ASTM F1291-16 (ASTM, 2016) and ASTM F2732-16 (ASTM, 2016b) with the following deviations that were agreed upon at the outset of testing:

1. NEMO was not calibrated using a calibration ensemble as described in ASTM F1291-16 (ASTM, 2016). NRC-OCRE uses a custom procedure (Mak et al., 2010) that verifies NEMO's power output by immersing it in a known volume of water. Additionally, NEMO was calibrated through a procedure compliant with ISO/IEC 17025 (2017) and ANSI/NCSL Z540.1 (2002).
2. NEMO was programmed to maintain a mean skin temperature (T_{SK}) of 40°C instead of 35°C. This was done to increase the thermal gradient between NEMO and the ambient air temperature of the TML, which was set to 4°C, which is the lowest stable temperature it can maintain. Previous work by NRC-OCRE with high insulation clothing found that a T_{SK} of 35°C resulted in a thermal gradient that only required the heaters in NEMO to operate with minimal, if any, power. Having the heaters in NEMO operate with little to no power can make it difficult to get an accurate measurement of the thermal insulation provided by an ensemble. By increasing T_{SK} to 40°C, the thermal gradient is increased, requiring more power from the heaters in NEMO, allowing for more accurate measurements of thermal insulation of clothing ensembles with high insulation.
3. Only two tests of each ensemble were performed, instead of the three specified by ASTM F1291-16 (ASTM, 2016).

As these deviations to ASTM standards were chosen, the tests cannot be said to have strictly followed ASTM procedures. The tests did, however, follow a very robust methodology and can be said to have produced outputs that can be interpreted with a high degree of confidence.

NEMO was suspended off the ground for each test by two hooks underneath its axilla (armpits) (Figure 1).

T_A was set to 4°C in the TML for all tests.

A stationary Honeywell Advanced QuietSet fan (model #: HSP600SC) generated wind at approximately 0.4 $m \cdot s^{-1}$ at the chest of NEMO (Figure 1). The wind velocity was measured using an anemometer integrated into NEMO's data acquisition system.

All garments were hung on a coat rack in the TML for at least 12 hours prior to testing to allow them to acclimatize with the atmosphere in the facility.

Once NEMO was dressed in the various garments to create the specified ensemble, it was programmed to raise its T_{sk} to 40°C and maintain for the duration of the test. Once NEMO reached a thermal steady state, a minimum of 30 minutes of data was collected. ASTM F1291-16 (ASTM, 2016) defines steady state as less than 3% variation in T_{sk} and power output of the thermal manikin. The last 30 minutes of steady state data were averaged to calculate thermal resistance.

After the test was completed, NEMO was undressed and allowed to cool down to the point where its skin temperature was near equal to room temperature. NEMO was then redressed in the same ensemble and the test repeated.

In addition to the ensembles, nude tests were performed where NEMO was suspended by the hooks while wearing no clothing garments. These tests were performed to measure the thermal insulation of the air layer around NEMO.

Discussions with the partners over likely scenarios for simulation eliminated testing a condition that would represent submergence in water, and rain was also an unlikely scenario for the conditions in which the types of clothing provided would be worn. As a result, the wet-tests were designed to represent activities in milder, potentially slushy conditions. To do so, additional wet-tests were performed on ensembles 3 and 18 where 500 mL of water was sprayed on the outer garments. To do so, 250 mL of water was measured out equally into two separate spay bottles via weighing, and then one bottle was used to wet the front the ensemble; the other was used to wet the back.

2.6. Thermal Insulation Calculations

The equations for calculating thermal insulation are given in Appendix A.

All thermal insulation values are reported in clo, a unit of measurement of thermal insulation for clothing garments. One clo is equal to the amount of insulation needed to keep a seated person comfortable in air at a temperature of 21°C, 50% or less relative humidity, with an air velocity of 0.1 $m \cdot s^{-1}$ (Golden and Tipton, 2002). For the smaller garments, the clo value reported is for the zone (or zones) on NEMO where the garment was used.

Where specified, the thermal insulation values for large garments (e.g. parkas), or ensembles that contain multiple large garments (e.g. parka and pants) have their clo values reported as standardized total thermal resistance (insulation). The standardized total insulation values (STIV) account for the thermal insulation provided by both clothing and surface air layer around the manikin, and allow for temperature ratings to be calculated (ASTM, 2016b).

Two different temperature ratings were calculated for select large garments and ensembles according to ASTM (2016b): TR_2 and TR_4. These temperature ratings provide an estimate of the air temperature (°C) a person could wear the garment or ensemble and remain in a thermoneutral condition (heat loss is equivalent to heat gain).

A TR_2 temperature rating is for a low level of physical activity, which is equal to a metabolic equivalent[4] of 2 (2 MET). A low level of physical activity is equivalent to a person walking very slowly (ASTM, 2016b).

A TR_4 temperature rating is for a moderate level of physical activity, which is equal to a metabolic equivalent of 4 (4 MET). A moderate level of physical activity is equivalent to a person walking very fast (ASTM, 2016b).

[4] One metabolic equivalent (1 MET) level of activity is equal to the amount of energy consumed, and heat produced, by a person who is lying down motionless.

3. Results

3.1. Ensembles

Twenty one different clothing ensembles (including the base layer) were tested. Some of these ensembles were comprised of many of the same garments as others, with only small articles of clothing changed (like hand garments) to allow individual comparisons to be made. Therefore, no comparisons were made between overall STVI clo values of each ensemble against the others as that would not provide an accurate assessment of the thermal insulation of the different, smaller garments. Instead, comparisons are made between ensembles that contain large garments that cover a large portion of the body, and smaller garments such as gloves. Table 4 provides the mean STIV (clo) for select ensembles, as well as the estimated TR_2 (°C) and TR_4 (°C) values. Figure 5 plots the estimated TR_2 (°C) and TR_4 (°C) values for the same ensembles.

Table 4: STIV (clo), estimated TR_2 (°C), and TR_4 (°C), values for select ensembles.

Ensemble #	Description	STIV (clo)	TR_2 (°C)	TR_4 (°C)
BL	NRC Base layer ensemble	1.251	15.6	-3.4
1	Parks Canada parka	2.206	3.0	-29.2
2	Parks Canada parka and pants	2.539	-1.4	-38.2
3	Parks Canada parka, pants, and bib lining	2.851	-5.5	-46.6
4	Parks Canada parka, pants, bib lining, neck warmer, long socks, chef hat, and leather mittens	2.905	-6.2	-48.1
5	Commander and fur pull over parka	2.118	4.1	-26.8
6	Commander and fur pull over parka and wind pants	3.162	-9.6	-55.0
7	Parka lined with duffle	1.811	8.2	-18.5
15	Siliapik parka	1.976	6.0	-23.0
18	Commander and fur pull over parka, wind pants, beaver neck warmer, beaver trapper hat	3.353	-12.2	-60.2
19	CCG Parka with Base layer ensemble	1.994	5.8	-23.5
20	CCG Custom Clothing – Commercial outer jacket, commercial insulated pants, commercial mid layer jacket.	3.142	-9.4	-54.5
3 - Wet	Parks Canada parka, pants, and bib lining – 500 mL of water	2.936	-6.7	-48.9
18 - Wet	Commander and fur pull over parka, wind pants, beaver neck warmer, beaver trapper hat – 500 mL of water	3.258	-10.9	-57.6

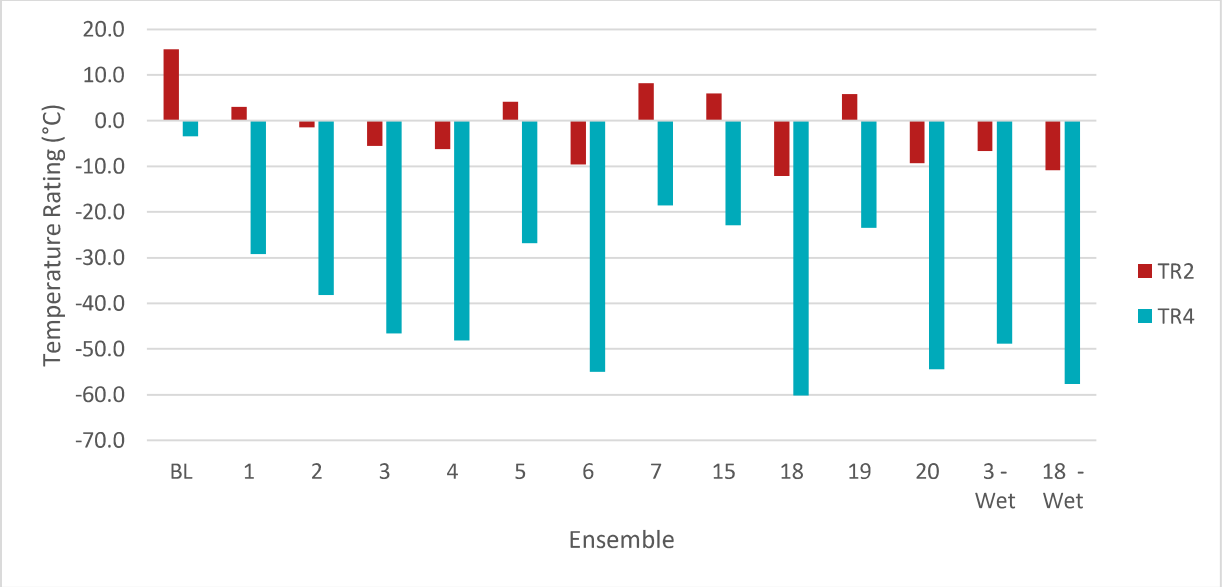

Figure 2: Estimated temperature ratings (°C) for the various ensembles at TR_2 and TR_4 of physical activity.

3.2. Hand Garments

Table 5 and Figure 3 provide the clo values (clo) for the various hand garments tested.

Table 5: Right and left hand clo values (clo) for the various hand garments tested.

Hand Garments	Zone Mean Clo Value (clo)		
	Right Hand	Left Hand	Mean
Base layer mittens	1.503	1.523	1.513
Leather mittens	1.252	1.308	1.280
Leather mittens with fur warmers	1.202	1.430	1.316
Bison hide mittens	1.710	1.756	1.733
Beaver mittens	2.695	2.848	2.772
Seal mittens	2.168	2.199	2.183
Beaver gauntlet mittens	2.102	2.194	2.148
Sealskin and fur long hunting mittens	1.961	1.985	1.973
Sheepskin long mittens	2.716	2.936	2.826

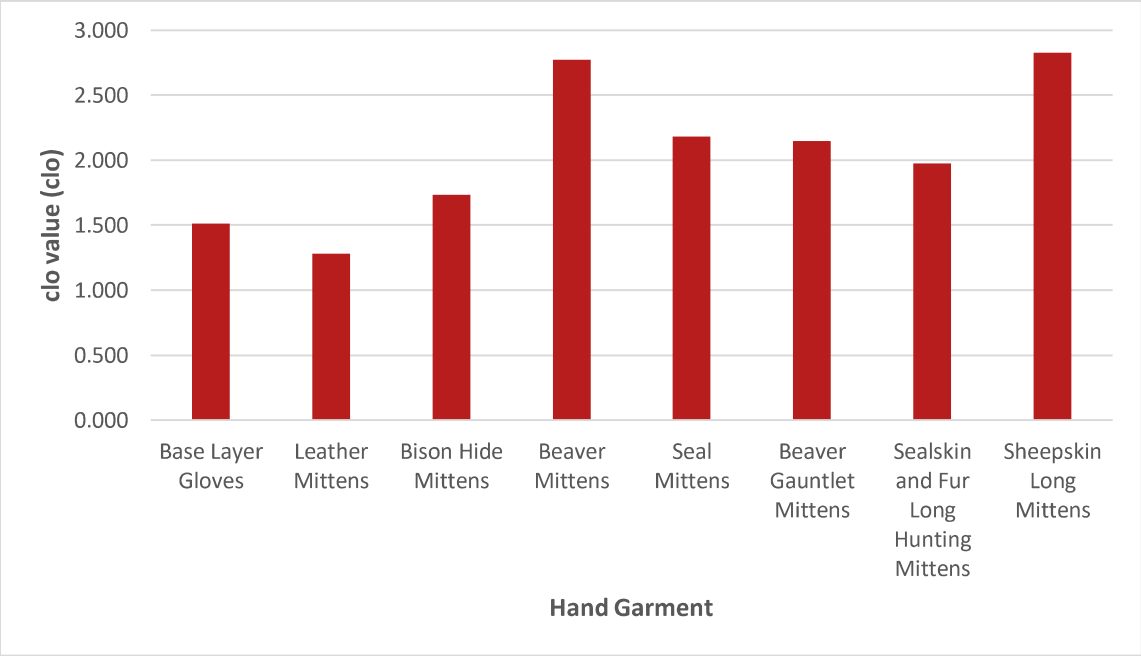

Figure 3: Mean clo value (clo) for the various hand garments tested.

3.3. Foot Garments

Table 6 and Figure 4 provide the clo values for the different foot garments tested.

Table 6: Right and left foot clo values (clo) for the different foot garments tested.

Foot Garments	Zone Mean Clo Value (clo)		
	Right Foot	Left Foot	Mean
Base layer boots and socks	1.214	1.249	1.232
Base layer boots and Parks Canada socks	1.175	1.224	1.199
Base layer boots and Homespun wool socks	1.369	1.407	1.388
NEOS Overshoe® Navigator 5 and Parks Canada socks	1.835	1.902	1.869
Booties (underneath NEOS Overshoe® Navigator 5)	2.305	2.292	2.298
Shinboots and Base layer socks	1.657	1.617	1.637

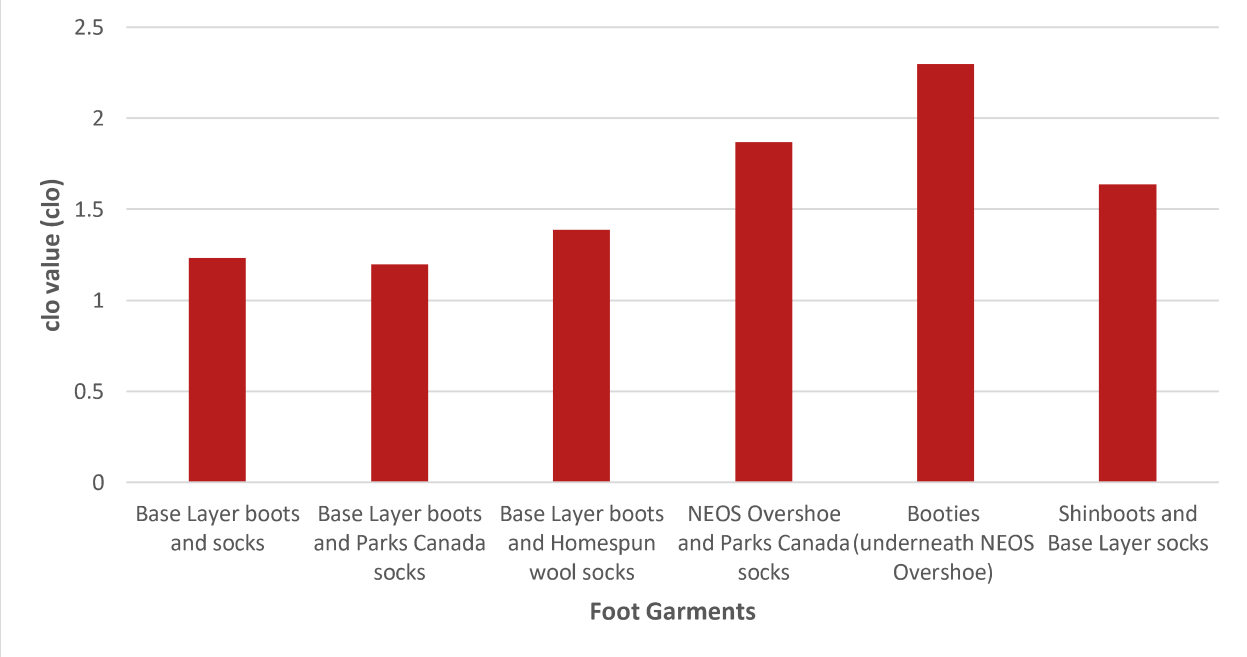

Figure 4: Mean clo value (clo) for the various foot garments tested.

3.4. Head and Neck Garments

Table 7 and Figure 5 provide the clo values of the face, head, chest, and shoulders zones of NEMO for the various head and neck warmer garments tested with the Parks Canada Parka hood up, and tightened around the face.

Table 7: Face, head, chest, and shoulders clo values (clo) for the various head and neck warmer garments tested. All garments were tested with the Parks Canada parka hood pulled tight around the face of NEMO.

Garments	Zone Mean Clo Value (clo)			
	Face	Head	Chest	Shoulders
Base Layer hat and no warmer	0.912	3.734	4.170	4.727
Parks Canada hat and neck warmer	1.118	3.871	4.702	5.121
Beaver neck warmer and beaver, trapper style hat	1.529	3.391	4.469	5.045
Beaver neck warmer with trapper hat	1.226	3.923	4.284	4.813
Qivuit neck warmer and beaver, trapper style hat	1.263	3.106	4.321	4.977

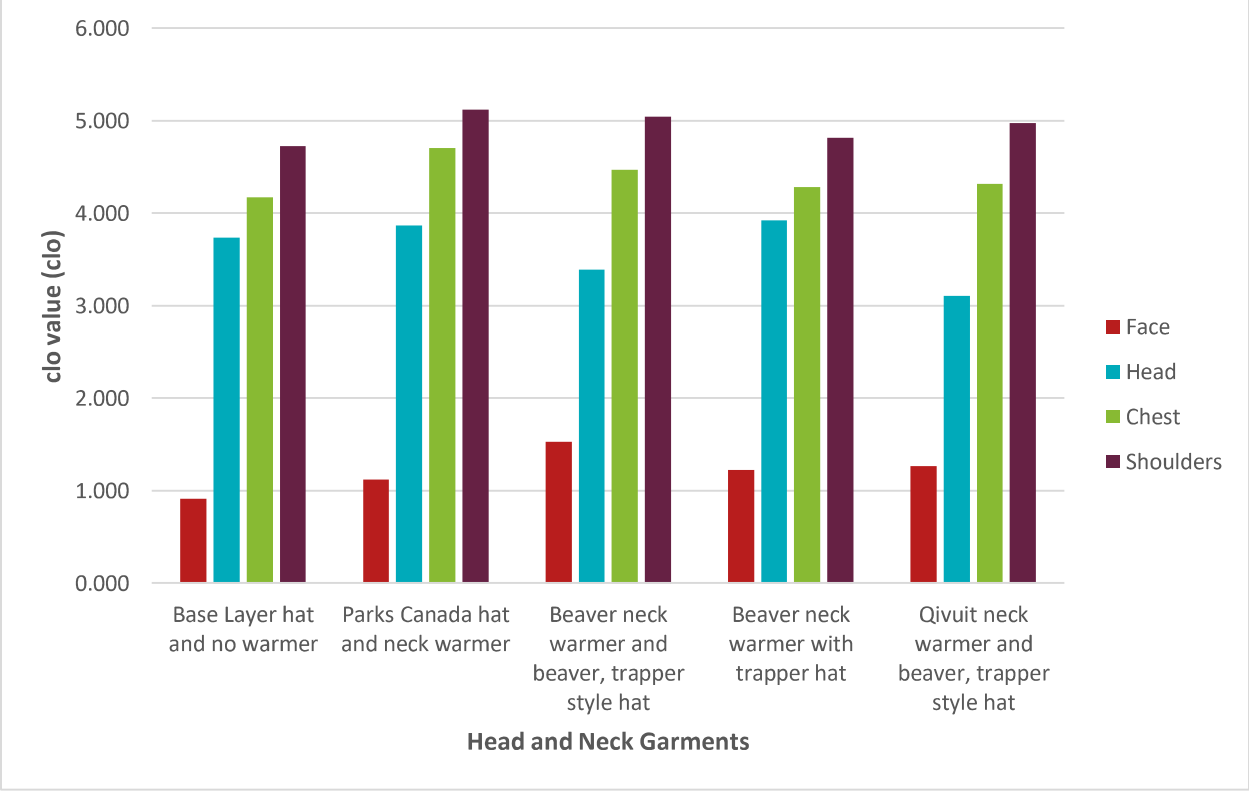

Figure 5: Mean clo value (clo) for the various head and neck garments tested for the zones that they covered on NEMO.

As the head and neck warmer garments cover more than one zone on NEMO, and are affected by other garments on NEMO at the time, such as a coat, information is also provided on the individual and total heat output (W) for the four different zones of NEMO covered by these garments. This gives the actual amount of heat required by each zone to maintain the set skin temperature, allowing the different zones

covered by the garments to be summed. A lower amount of heat output (W) to maintain the set skin temperature indicates the garments covering these zones have a higher level of insulation. Table 8 provides the heat output from each of the four zones of NEMO for the various headwear and neck warmers.

Table 8: Face, head, chest, and shoulders heat output (W) for the various head and neck warmer garments tested. All garments were tested with the Parks Canada parka hood pulled tight around the face of NEMO.

Garments	Zone Heat Output (W)				
	Face	Head	Chest	Shoulders	Total
Base layer hat and no neck warmer	8.99	6.69	5.46	4.97	26.11
Parks Canada hat and neck warmer	7.32	6.37	4.80	4.56	23.05
Beaver neck warmer and beaver, trapper style hat	5.39	7.40	5.14	4.70	22.64
Beaver neck warmer with trapper hat	6.72	6.38	5.34	4.92	23.37
Qivuit neck warmer and beaver, trapper style hat	6.66	8.17	5.34	4.76	24.93

4. Discussion

4.1. Thermal Insulation – Large Garments

Ensembles that consisted of only a parka over the base layer clothing (1, 5, 7, 15, and 19) had lower STIV compared to others that included garments that covered the legs of NEMO (Table 4), which was to be expected. Regardless of how warm a parka/jacket may be, wearing a garment that covers the legs will always increase the overall STIV, allowing for lower temperature ratings. The effects of adding outer pants to an ensemble can be seen by comparing Ensemble 1 and Ensemble 2 (Table 4), where the only difference is the addition of the Parks Canada pants.

When looking at the ensembles that consisted of large garments covering both the torso and the legs, those that were composed mainly of Parks Canada items (ensembles 2, 3,) had lower STIV values compared to those that included garments from Indigenous Crafters (Table 4). Generally, ensembles that contained items from Indigenous crafters had higher STIV compared to those that did not contain them. The one exception to this is Ensemble 20 which had one of the highest STIV of 3.142 clo.

Ensembles 4 and 18 were comprised not just of large garments from Parks Canada and Indigenous Crafters, respectively but also smaller items such as neck warmers gloves, and socks. This was done to compare the overall STIV for ensembles that were comprised entirely of one set of garments (with the exception of a few items from the NRC base layer) against the other. Ensemble 4 had a STIV of 2.905 clo, while Ensemble 18 had a STIV of 3.353 clo which was a 15% increase (Table 4).

Ensembles 3 and 18 were sprayed with 500 mL of water to simulate wearing them while they were wetted. Two different results were observed with wetting the ensembles: the STIV of Ensemble 3 increased to 2.936 clo when wetted; a slight increase from the dry value of 2.851 clo. When Ensemble 18 was wetted, the STIV decreased slightly to 3.258 clo from the dry value of 3.353 clo. The insulation of clothing will become reduced when water is able to penetrate into the fabric and displace trapped air (Light et al., 1987) since the former is capable of transferring heat 23 times faster than the latter. It was observed during the wetting tests of Ensemble 3 that the water did not penetrate into the parka, and remained on the surface until the end (Figure 6). This would explain why there was no observed decrease in STIV for ensemble 3 as the water was not able to penetrate into the clothing and displace trapped air. The slight increase in the STIV (~3%) for Ensemble 3 when it was wetted compared to being dry may have been due to dressing variations between the two conditions.

Figure 6: Wet test of Ensemble 3.

The decrease in STIV for Ensemble 18 when it was wetted may have been caused by some of the garments absorbing water. During the first wetting test of Ensemble 18, it was observed that near the end of the test there was no water visible on the outer surface of the garments (Figure 7). To confirm that the garments in Ensemble 18 may have been absorbing water, all articles of clothing that would be wetted were weighed before and after the next wetting test. The mass of the different garments of Ensemble 18 before and after the second wetting test are given in Table 9.

Figure 7: Ensemble 18 at the end of a wet test.

Table 9: Mass of garments (g) in Ensemble 18 that were wetted before and after the second wetting tests.

Garment	Pre Test Mass (g)	Post Test Mass (g)	Difference (Post Test – Pre Test) (g)
Commander and fur pull over parka	1,647.7	1,740.0	92.3
Wind pants	1,133.2	1,141.2	8
Sealskin and fur long gloves	406.2	427.0	20.8
Sealskin with hide shin boots	673.0	670.0	-3

Based on the changes in mass for the commander and fur pull over parka, and sealskin and fur long gloves, these garments absorbed water throughout the duration of the wetting test, which would explain the small decrease in the STIV.

4.2. Thermal Insulation – Hand Garments

Similar to the results from the large garments, hand garments made by Indigenous crafters had a higher clo value compared to the Base Layer mittens, and the Parks Canada leather mittens (Table 5). These differences in clo values compared to the Base Layer mittens (1.513 clo) ranged from small (Bison hide mittens: 1.733 clo; ~14% increase) to significant (Sheepskin long mittens: 2.826 clo; ~87% increase).

Previous work by Fallahi et al. (2017b) provided estimates for the safe hand garment clo value to prevent frostbite of human fingers for different lengths of time across a range of temperatures (Figure 8). These estimations were derived from a 3D model of the human finger that assumed the individual was stationary, and not physically active (Fallahi et al., 2017).

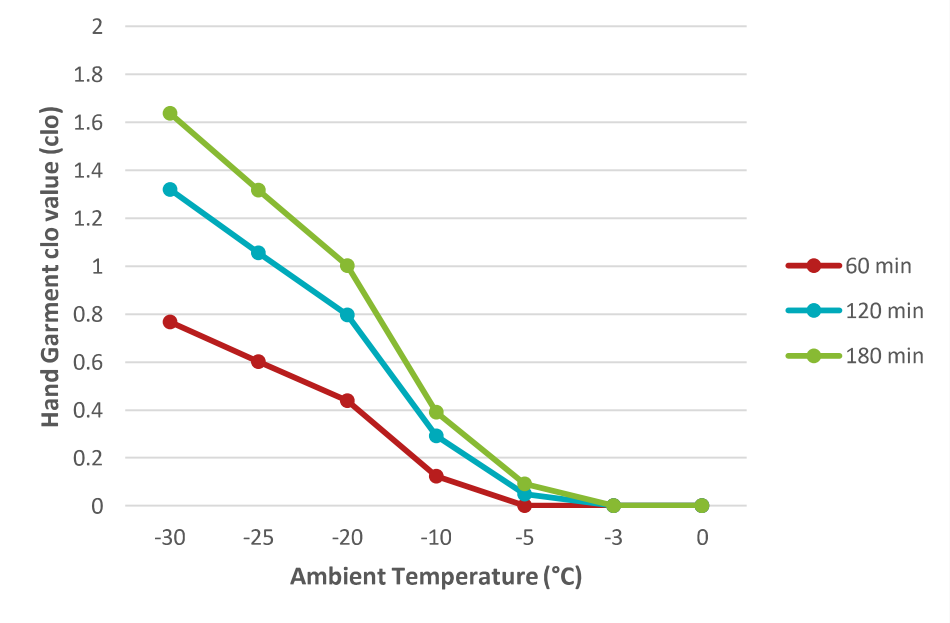

Figure 8: Estimated hand garment clo value (clo) to prevent frostbite in human fingers in 3 $m \cdot s^{-1}$ wind, for various durations (min) across a range of ambient air temperatures (°C) (adapted from Fallahi et al. (2017b)).

For example, if an individual was stationary for 60 minutes outside at a temperature of -20°C with a wind of 3 $m \cdot s^{-1}$, the clo value of a hand garment to prevent frostbite should be about 0.45 or higher. For that same person to be outside at the same temperature for 180 minutes, the clo value of the hand garment would need to be 1 or higher.

Based on the estimations from Fallahi et al. (2017b), all of the hand garments tested have a sufficient amount of thermal insulation to prevent frostbite in -30°C air (with 3 $m \cdot s^{-1}$ wind) for a 60 minute exposure (Table 5; Figure 8). If the exposure time was increased to 120 minutes, all hand garments would again have a sufficient amount of insulation to prevent frostbite, but the Base Layer and Parks Canada leather mittens would be very close to the minimum amount required at -30°C. The addition of the fur warmer bundles to the Parks Canada leather mittens provided a slight increase in thermal insulation (1.280 clo to 1.316 clo; Table 5), which would allow them to nearly meet the 120 minute exposure duration at -30°C. If the exposure time was 180 minutes, then only the hand garments made by the Indigenous crafters would have a sufficient amount of thermal insulation to prevent frostbite at -30°C ambient air temperature.

4.3. Thermal Insulation – Footwear

When worn with the Base Layer boots, the Base Layer and Parks Canada socks provided similar levels of thermal insulation (1.232 and 1.199 clo respectively) (Table 6). Replacing those socks with the Homespun wool socks increased the clo value to 1.388 clo; a 12.6% increase in insulation. When wearing the Shinboots with the Base Layer socks, the thermal insulation was 1.637 clo. When worn with the Parks Canada socks, the heavier NEOS Overshoe® Navigator 5 boots had a thermal insulation value of 1.869 clo. The booties made by the Indigenous Crafters caused the largest increase of thermal insulation when added to any of the footwear combinations. When worn with the NEOS Overshoe® Navigator 5 boots and Parks Canada socks, the thermal insulation was 2.298 clo; an increase of 22.9% due to the addition of the booties.

4.4. Thermal Insulation – Head and Neck Protection

The mean zone clo values reported in Table 7 and Figure 5 would initially suggest that the base layer hat with no neck warmer may have provided more insulation in certain zones compared to other configurations. For example, the head zone clo value for the base layer hat and no neck warmer was 3.734 clo, but was only 3.391 clo for the beaver neck warmer with the beaver, trapper style hat (Table 7). The qivuit neck warmer with beaver, trapper style hat had the lowest clo value for the head zone of 3.106 clo. However, the chest and shoulder zone clo values were higher for both the beaver neck warmer with beaver, trapper style hat configuration (Chest: 4.469 clo; Shoulders: 5.045 clo), and the qivuit neck warmer with beaver trapper style hat configuration (Chest: 4.321 clo; Shoulders: 4.977 clo), compared to the base layer hat with no neck warmer (Chest: 4.170 clo; Shoulders: 4.727 clo) (Table 7; Figure 5).

Examining only the mean clo values of the zones that are covered by the head and neck warmer garments can make it challenging to draw any conclusions on how the different configurations perform relative to one another. This may be attributed to variations in dressing the manikin between the different tests. The neck warmers in particular were easily compressed when dressing the manikin, resulting in them not being worn exactly the same between repeat testing of the same ensemble, and when compared to other ensembles.

An alternative method to compare the performance of the head and neck warmer garments is to determine the total amount of power required by the manikin to maintain a T_{sk} of 40°C for all segments covered by the clothing (Table 8). As observed in Table 8, the manikin required the most power to maintain

a T_{sk} of 40°C for all four zones when wearing the base layer hat with no neck warmer (26.11 W total) compared to all other configurations. The configuration that required the least amount of power to maintain a T_{sk} of 40°C across all four zones was the beaver neck warmer, and beaver, trapper style hat (22.64 W total), which required ~13.3% less power than the base layer and no neck warmer configuration. Compared to the base layer hat and no neck warmer configuration, the Parks Canada hat and neck warmer configuration (23.05 W total) required ~11.7% less power; the beaver neck warmer with trapper hat configuration (23.37 W total) required ~10.5% less power; and the qivuit neck warmer and beaver, trapper style hat configuration (24.93 W total) required ~4.52% less power.

While these differences are small, they do indicate that there is an increase in insulation when using a configuration with a hat different from the one in the base layer, and neck warmer. This would be expected, as additional clothing (i.e. a neck warmer) would increase the overall insulation provided by the clothing ensemble. Even though they may only provide a small increase, a neck warmer can be a simple addition to any clothing ensemble to help improve its overall thermal insulation.

5. Considerations Regarding Government of Canada Procurement

Each federal department and agency has their own operational considerations and realities with respect to the procurement of clothing for staff uniforms. These are meant to provide high level considerations surrounding procurement of uniform items and specifically, Indigenous northern items. Procurement need not be a significant barrier, however the approach to procuring such items may require adaptation from standard or established methods. The following notes are from the perspective of Parks Canada, provided by Stephanie Sirois.

5.1. Central Uniform Supplier

Typically, the vast majority of uniform items are purchased through one central supplier. This supplier is responsible for developing, improving, sourcing or producing and shipping these items. As these are high value, specialised contracts, Public Services and Procurement Canada (PSPC) is often (if not always) the lead on procurement. Requests For Proposals (RFP) are put out with very specific specifications for each uniform item required. Throughout the contract period, new items can be developed and added to the contract through a contract amendment. This supplier will at times produce the item “from scratch” and sometimes source a ready-made item, which may or may not require adjustments for the uniform needs. Such adjustments could be done by the third party supplier or the uniform supplier (e.g.: fabric colour could be adjusted by the third party and adding government identifiers could be done by the uniform supplier).

It would thus be possible for this central supplier of uniforms to include Indigenous northern clothing to any department or agency’s uniform catalogue. The benefits of doing so would be to have a “one-stop-shop” for uniform needs, ensure inventory is on-hand for quick delivery and allowing for these to be standard issue items. Doing so however introduces sometimes significant added costs (mark-up for services rendered by the uniform supplier).

5.2. Specialty Uniform Suppliers

An alternative procurement process which is made available for PPE or specialty items, at least at Parks Canada, is to procure items locally. In some instances, specifications must still be met (e.g.: identifiers must follow Federal Identity Program requirements as outlined below, regulations on % high visibility material on a vest, etc). This option is most often adopted where there is a very small and/or localized number of team members who require the item (e.g.: Parks Canada has a few lifeguards at PEI National Park beach and Fundy National Park pool but no others; Canadian Special Operations Forces Command within the Department of National Defence has a small number of staff with specialized responsibilities and therefore clothing needs). It is also used where the item is broadly available commercially (e.g.: high visibility vests).

In the case of Indigenous northern clothing, it could easily be argued that the items are both PPE and for a somewhat small number of employees. Because it would be for a larger group than Parks Canada would typically consider as small, one could propose advancing a “hybrid” model whereby a central standing offer would be established outside of the main uniform supplier. It would be made available across the Agency at the discretion of cost centre managers. The procurement mechanism could be much simplified because the total dollar value would be low enough to keep authority within the Agency (no need to go through PSPC) and one could leverage flexibilities which exist for Indigenous procurement and meet established targets. See the following links for examples of these:

Modernization of Indigenous participation in procurement: discussion paper (sac-isc.gc.ca)

(https://www.sac-isc.gc.ca/eng/1554219055004/1612130030035)

Government of Canada announces federal-wide measures to increase opportunities for Indigenous businesses - Canada.ca

(https://www.canada.ca/en/public-services-procurement/news/2021/08/government-of-canada-announces-federal-wide-measures-to-increase-opportunities-for-indigenous-businesses.html)

When Indigenous businesses are listed in the directory, it is much easier for the Federal Government to undertake sole source procurement actions. There is also very specific guidance which helps support procurement processes involving Indigenous businesses. These are very new (August 2021) and so are rolling out gradually. However, there is a general understanding that such procurement is not simply to meet targets but also points to best practices in ongoing efforts for economic benefits for Indigenous communities while creating added value to government. It truly is win-win.

Indigenous business and federal procurement (sac-isc.gc.ca)

(https://sac-isc.gc.ca/eng/1100100032802/1610723869356)

Indigenous business procurement information for federal procurement officers (sac-isc.gc.ca)

(https://www.sac-isc.gc.ca/eng/1617817287014/1617817368226)

In the context of a potential collective, made up of many crafters, this could be viable approach, if the collective became a registered business within the directory.

5.3. Considerations for Indigenous Northern Ensembles Testing Team

The research lead by NRC on Indigenous northern ensembles provides important data to inform future decisions with regards to garments that will help ensure comfort and safety of employees. It also is key in developing relationships which may help inform “with whom” future standing offers may be established. Purchasing directly through individual crafters can be easier as it is very low dollar value however it may not provide the necessary level of certainty that the garments are fabricated in such a way as to ensure a certain clo value or other item attributes found in items tested. Procurement through a collective would both allow for greater volume of items to be procured through one procurement vehicle while also providing greater confidence that items meet certain standards, that is, if the collective were to be willing to vouch for their crafters.

5.4. Branding Considerations

The Federal government, through the Federal Identity Program (FIP) is required to meet specific branding requirements for uniforms. FIP is managed through Treasury Board and, as such, the vast majority of departments and agencies must abide by the same standards. There are specific requirements for headwear and tops (shirts, coats, etc). There are no requirements for brand identifiers as it pertains to footwear (in fact some organizations such as Parks Canada does not have uniform footwear), neckwear and gloves or mittens. See “Department Issued Clothing” at the following link.

Personnel identification: Design Standard for the Federal Identity Program - Canada.ca

(https://www.canada.ca/en/treasury-board-secretariat/services/government-communications/design-standard/personnel-identification-design-standard-fip.html)

5.5. Public Services and Procurement Canada Centralized Procurement Examples

Procurement requirements that were posted relatively recently on the Government of Canada's Buy and Sell pages (https://buyandsell.gc.ca/) were pulled to examine the types of requirements that may typically be requested by Government of Canada Departments and Agencies when seeking garments for operational use.

Buyers required timelines for delivery, cost estimates, information about properties of the clothing, availability and sizing information from bidders. Where samples were being sought, rather than an outright procurement, no payment would be provided for samples sent from a supplier, in one case. The examples had a variety of needs for initial supply volumes; in one case, it was as many as 900 to 1200 mittens for use in extreme cold, with an additional 90 to 500 per year, for example.

Of particular relevance to this study, in terms of design specifications, the procurement examples contain descriptions of the garment's construction – in two cases, for example, for a handwear "system", with an outer mitten and an inner removable mitten or glove, with the ability to wear them together, or either independently. Waterproofness, dexterity, bulkiness, length of cuffs, retention systems to secure the outer mitten to a coat, colour, ability to provide sizing for women, and material composition (e.g. a leather palm and thumb) are also examples of the types of specifications that may be put into a requirement. A further consideration is whether the materials are part of the Government of Canada's regulated Controlled Goods, which can lead to a request for material data sheets for each material used in the clothing.

Submission packages may also request items such as a clo value. For this, which is in part the genesis of this research project, departments may use wording such as the provision of a "summary of the complete test results that confirms that the material meets the standards specified. Testing must be performed by an independent accredited laboratory. Test report(s) must be dated within six (6) months of the solicitation posting date." We expect that the relatively limited availability of such testing methodologies, the time requirements, and the associated costs are unlikely to be attainable for most small, northern enterprises, although it could be financially feasible for a community of crafters coming together as an enterprise.

By way of example, a previous Royal Canadian Mounted Police solicitation on https://buyandsell.gc.ca/ for Arctic mitten samples (Solicitation No. - N° de l'invitation M7594-210967/A), had the following technical requirement. It is noted that the requirement was for a mitten system, with an outer and an inner mitten, that could be worn together or either independently. "Combined insulation should be appropriate for use in cold weather temperatures between approximately -25°C to -40°C. The clo value for the outer mitten insulation material should be approximately 1.8 when tested to ASTM D 1518-14. The clo value for the inner mitten insulation material should be approximately 1.2 when tested to ASTM D 1518-14. The total minimum combined mitten, inner and outer, should be approximately 3.0 clo."

The testing standard ASTM D 1518-14 (2014) prescribes that a hot plate be used to measure the thermal insulation of the gloves, while a thermal manikin was used in this project. While previous work has shown that there exists variation between the results of thermal manikins and hot plates under certain conditions (Satsumoto et al., 1997), the clo values for certain Indigenous-made hand garments vastly exceed the 1.8 clo required for the outer mitten (Table 5), and some, in fact, approach 3.0 clo with no inner

mitten at all. The high clo values on these Indigenous-made garments should overcome any variations between hot plates and thermal manikins. One can hypothesize that the larger Indigenous-made gloves (e.g. the beaver gauntlet mittens) can easily accommodate a smaller, inner mitten that when combined, would exceed the 3.0 clo requirement.

In addition, there are certification requirements for procurement. These can be worded similarly to the following (Solicitation No – No de l'invitation W6399-21-LF57/A): "Where a third party certification is required, the certification must be from the component or fabric manufacturer that certifies that the component or fabric fully meets or exceeds the stated requirement. This document must be on official company stationery; it must be dated after the Request for Proposal posting date; it must make reference to the applicable specification and have the original signature of the Company's designated representative. Canada reserves the right to verify the statements made in the third party certification." Or, as the following excerpt requests:

Rules of Origin - Textiles
With reference to the Canadian Content Certification clause, item(s) on this solicitation are considered to be Canadian goods if they meet the following definition: MODIFIED RULE OF ORIGIN FOR TEXTILES: "Textiles and textile articles classified in Chapters 50 to 60 inclusive of the Harmonized System that are woven, knitted or otherwise manufactured from yarns or fibers in Canada, and further processed in Canada by dyeing, finishing, coating or other processes as applicable, will be considered Canadian textiles. Woven fabrics of 100% cotton or of polyester and cotton blends that are dyed and finished in Canada will be considered Canadian."
Rules of Origin – Apparel
With reference to the Canadian Content Certification clause, apparel goods are considered to be Canadian goods according to the North American Free Trade Agreement Rules of Origin as follows: Apparel goods classified in Chapters 61 and 62 of the Harmonized System that are both cut (or knit to shape) and sewn in Canada will be considered Canadian goods.
Canadian Content Certification
This procurement is conditionally limited to Canadian goods. Subject to the evaluation procedures contained in the bid solicitation, bidders acknowledge that only bids with a certification that the good(s) offered are Canadian goods, as defined in clause A3050T, may be considered. Failure to provide this certification completed with the bid will result in the good(s) offered being treated as non-Canadian goods. The Bidder certifies that: ( ) the good(s) offered are Canadian goods as defined in paragraph 1 of clause A3050T.

While the certification of clothing is beyond the scope of the current study, it is an important consideration in order to examine how Indigenous garments could be procured federally, and whether or not such certification systems are overly burdensome for small enterprises, especially for procurement of goods that will remain within Canada. There are more difficult, political-level considerations for products that might be used outside of Canada; for example, the procurement of seal products for purchase and use by cruise ship passengers' PPE kit, in jurisdictions where these products have been either banned or where onerous certifications of origin exist and are not realistically attainable for small enterprises.

6. Conclusions and Next Steps

This foundational study may be viewed as a first step for a number of opportunities. It has been a preliminary opportunity for some Indigenous crafters to have access and the means to laboratory performance evaluations of their harsh environment clothing. It has similarly been an opportunity to examine how those garments compare to commercially available products currently in use by Canadian Government Departments and Agencies with operational requirements in the north, and how they could augment the performance of those issued kit items. Finally, it is an opportunity for those same Federal Departments and Agencies to examine first-hand how Indigenous clothing may be able to play a role in increasing occupational safety for their staff when carrying out their duties in the North.

Women have been the driving force behind the fabrication of northern harsh weather garments. While the development of clothing is sometimes solely viewed as a craft, there is also a large STEM component to their creation; Indigenous garments have been developed with natural items, through observations that the component materials have properties that promote water resistance, wicking, and heat retention; all properties required for northern survival. The next document produced for this project will examine the intertwining of this Indigenous Knowledge with western science, through the surveys conducted with the crafters about their knowledge about their garments, as well as with users of such garments and Federal employees who wear the uniforms tested here.

The possibility of additional studies is very strong. We suggest that such studies should include:

1. Additional laboratory studies at NRC for a particular type of garment (for example, mittens) to evaluate the thermal performance across different construction methods and materials (perhaps up to five different types);
2. Additional laboratory studies at NRC to examine the same garment (material and construction) as made by a number of individuals (10, for example) to investigate the consistency of thermal performance as influenced (or not) by individuals' methodologies. This would be of benefit in order to examine how the procurement of many tens or hundreds of items of the same type could potentially be achieved through a network of crafters, rather than a solitary enterprise. One condition for this possibility of such a test programme would be the availability of similar material (from the same kind of animal) in quantities sufficient for multiple crafters to use.
3. A suite of preliminary field studies should be completed collaboratively across Federal departments with operational responsibilities in cold regions. These studies would examine the thermal performance of select garments in the field and also add dexterity, GBA+ considerations (such as fit, etc.) and social science studies into operational preferences to that study, sharing the results across those departments and back to crafters and crafting organizations. We propose that this could be co-ordinated and led by an organization such as Defence Research and Development Canada, during their annual participation in northern operations programs.
4. Examining the potential of "maker-space" types of opportunities for crafting, such as Aurora Research Institute's Innovate Centre for Arts, Crafts and Technology https://www.innovatetac.ca/ Working with Aurora Research Institute, governmental organizations and development corporations, this study would examine how they could play a role in both crafting access as well as higher volumes of production if warranted. We propose that such a study could be led by Aurora Research Institute, in collaboration with an early career researcher and support from organizations such as ACOA and CanNor if possible.
5. Further analysis by a student into Government of Canada clothing procurement requirements and procurement of authentic Indigenous goods. We propose that this study could be led by an organization

such as Parks Canada, working in conjunction with a student, such as a senior undergraduate, graduate student or an early career researcher.

While such studies could run in series as individual projects, we recommend that they be considered as a package, with different tasks ongoing at the same time. For example, if additional studies regarding mittens were chosen, the sequencing could be such that after having been used for the laboratory analysis, all of the samples used in the laboratory could be provided to staff for use in subsequent field studies. With potentially 30 pairs of mittens (noting that there are GBA+ considerations to the cut of mittens, potentially, that could be considered), that would be sufficient for small-scale field trials, with 10 pairs of mittens distributed across three different departments (or all to one department, providing results to the others). Combined with a "control" group, that would provide concrete field performance results. In parallel, working in partnership with development corporations such as CanNor and ACOA if possible, a study into maker space access and feasibility could be initiated. Also in parallel, a study of procurement requirements from the Government of Canada would be helpful, working with other Government departments such as Public Service and Procurement Canada, Indigenous Services Canada, Heritage Canada's Knowledge Centre for Indigenous Inclusion, and Innovation, Science and Economic Development Canada, as well as small departments and agencies that may have more flexibility with respect to smaller contracts.

We propose that such a package could be initiated in the autumn of 2022, with laboratory studies completed by in spring 2023, in time for clothing to be distributed for use in field trials.

Regardless of the timing of the next steps, are pleased to present the outputs of this report, providing valuable insights into how Indigenous garments can provide protection for individuals in harsh weather.

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Appendix A – Calculations

Parallel Thermal Resistance

NEMO's onboard software (ThermDac) automatically calculates total thermal resistance using the parallel method (parallel thermal resistance) for each zone during the tests using the following equations specified in its operator's manual (Thermetrics, 2007):

$$R_{ct} = \frac{T_{skin} - T_{amb}}{\left(Q/A\right)}$$ *Equation 1*

Where:

R_{ct} = Zone thermal resistance ($m^2 \cdot °C \cdot W^{-1}$)

T_{skin} = Zone average temperature (°C)

T_{amb} = Ambient temperature (°C)

Q/A = Area weighted heat flux ($W \cdot m^{-2}$)

After the zone thermal resistance was calculated, parallel thermal resistance was calculated using the following equation:

$$R_{wtd}(parallel) = \frac{1}{\sum \frac{A_i}{(A_{tot} \cdot R_{ct})}}$$ *Equation 2*

Where:

R_{wtd} (parallel) = parallel thermal resistance ($m^2 \cdot °C \cdot W^{-1}$)

A_i = Zone surface area (m^2)

A_{tot} = Total surface area (m^2)

Parallel clo value

Parallel thermal resistance values were converted to clo[5] units using the following equation (Thermetrics, 2007):

$$R_{clo} = R_{wtd}(parallel) \cdot 6.45$$ *Equation 3*

Where:

R_{clo} = Parallel clo value

[5] One clo is equal to the amount of insulation needed to keep a seated person comfortable in air at a temperature of 21°C, 50% or less relative humidity, with an air velocity of 0.1 $m \cdot s^{-1}$ (Golden and Tipton, 2002).

The parallel clo value from each of the three tests were averaged to get the mean value for each clothing ensemble.

Intrinsic Thermal Resistance

As per ASTM F2732-16 (ASTM, 2016b), the intrinsic thermal resistance of each clothing ensemble was calculated using the following equation:

$$I_{cl} = I_t - \left({}^{I_a}/_{f_{cl}}\right) \qquad \textit{Equation 4}$$

Where:

I_{cl} = intrinsic thermal resistance (insulation) of the clothing (clo)

I_t = total thermal resistance (insulation) of the clothing and surface air layer around the manikin (clo), which is equal to R_{clo} calculated using Equation 3.

I_a= thermal resistance (insulation) of the air layer on the surface of the nude manikin (clo)

f_{cl} = clothing area factor (dimensionless). A value of 1.35 was used for all the clothing ensembles as per ASTM F2732-16 (ASTM, 2016b).

Standardized Total Thermal Resistance

Standardized total thermal resistance (insulation) was calculated using the following equation as defined by ASTM F2732-16 (ASTM, 2016b):

$$I_{t.s} = I_{cl} - \left({}^{I_{a.s}}/_{f_{cl}}\right) \qquad \textit{Equation 5}$$

Where:

I_{cl} = intrinsic thermal resistance (insulation) of the clothing (clo)

$I_{t,s}$ = standardized total thermal resistance (insulation) of the clothing and surface air layer around the manikin (clo)

$I_{a,s}$ = standardized thermal resistance (insulation) of the air layer on the surface area of the nude manikin which has a value of 0.5 clo.[6]

f_{cl} = clothing area factor (dimensionless). A value of 1.35 was used for all the clothing ensembles as per ASTM F2732-16 (ASTM, 2016b).

[6] The thermal resistance of the air layer measured with a nude manikin (I_a) will vary from lab to lab due to air velocity and flow patterns throughout the room. As a result, each lab will need to use their own I_a value to determine I_{cl} and use the standard $I_{a,s}$ of 0.5 clo to calculate a standardized total thermal resistance (insulation) value $I_{t,s}$ for each clothing ensemble (ASTM, 2016b).

Temperature Rating Calculations

The following equations, as specified[7] by ASTM F2732-16, were used to calculate temperature ratings for ensembles that cover a substantial amount of body surface area such as jackets, coats, and insulated pants (ASTM, 2016b). As there were deviations from the test standards specified in ASTM F2732-16, and some ensembles had a different base layer than was is prescribed in the standard, the temperature ratings reported are not "ASTM Temperature Ratings" but are estimated values that would allow a person to remain in a thermoneutral condition for a given metabolic rate and T_{amb}. The temperature ratings of head wear, footwear, and hand wear cannot be determined using the methods described in ASTM F2732-16.

$$TR_2 = \left((-23.78 \cdot It,s + 89.93) - 32\right) \cdot \frac{5}{9} \qquad \textit{Equation 6}$$

$$TR_4 = \left((-48.61 \cdot It,s + 86.70) - 32\right) \cdot \frac{5}{9} \qquad \textit{Equation 7}$$

Where:

TR_2 = temperature rating (°C) for a low level of physical activity, which is equal to a metabolic equivalent[8] of 2 (2 MET). A low level of physical activity is equivalent to a person walking very slowly (ASTM, 2016b).

TR_4 = temperature rating (°C) for a moderate level of physical activity, which is equal to a metabolic equivalent of 4 (4 MET). A moderate level of physical activity is equivalent to a person walking very fast (ASTM, 2016b).

Manikin Segment Heat Output Calculation

The heat output (W) for the four different zones of NEMO covered by the different head and neck warmer garments were calculated by multiplying the area weighted heat flux ($W \cdot m^{-2}$) by the surface area (SA; m^2) of each zone. The four zones and their specific surface area values (Thermetrics, 2007) are:

- Face: 0.03601 m^2
- Head: 0.10965 m^2
- Chest: 0.10033 m^2
- Shoulders: 0.10369 m^2

$$Q = {}^{Q}/_{A} \cdot SA \qquad \textit{Equation 8}$$

Where:

Q = Zone heat output (W)

[7] The equations in ASTM 2732-16 provide the values in °F. The conversion from °F to °C have been included in Equations 6 and 7.
[8] One metabolic equivalent (1 MET) level of activity is equal to the amount of energy consumed, and heat produced, by a person who is lying down motionless.

Q/A = Zone area weighted heat flux ($W \cdot m^{-2}$)

SA = Manikin zone SA (m^2)

Appendix B - Individual Clothing Garment Descriptions – Canadian Government Departments

Base Layer Garments

Figure 9: Base layer underwear briefs (ID: BL1).

Figure 10: Base layer underwear jersey (ID: BL2).

Figure 11: Base layer T-shirt (ID: BL3).

Figure 12: Base layer long sleeved shirt (ID: BL4).

Figure 13: Base layer jogging pants (ID: BL5).

Figure 14: Base layer socks (ID: BL6).

Figure 16: Base layer toque (ID :BL7).

Figure 17: Base layer mittens (ID: BL8).

Figure 18: Base layer neoprene boots (ID: BL9).

Figure 19: NEOS Overshoe® Navigator 5 Style #: N5P3 (ID: BL10).

Parks Canada Garments

Figure 20: Merino/Nylon wool long socks (ID: 2).

Figure 21: Merino wool long underwear (ID: 3).

Figure 22: Merino wool undershirt (ID: 4).

Figure 23: Merino wool chef hat (ID: 5).

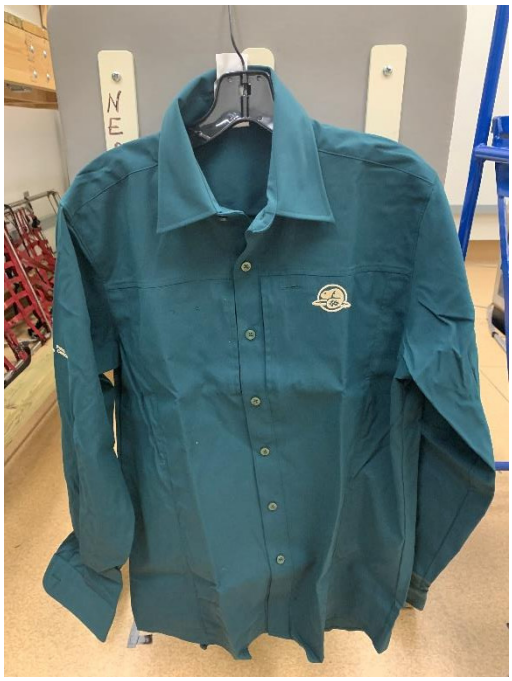

Figure 24: Long sleeved shirt (ID: 6).

Figure 25: Leather mittens (ID: 9).

Figure 26: Liner for pants (with Bib) (ID: 10).

Figure 27: Winter parka (ID: 12).

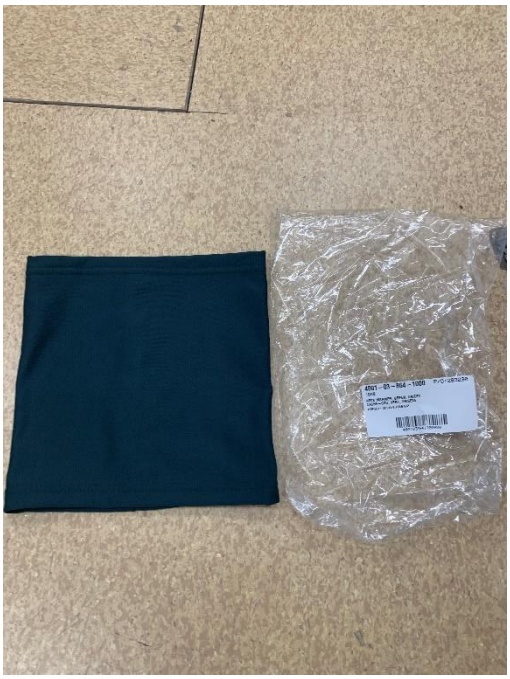

Figure 28: Neck warmer (ID: 14).

Figure 29: Cargo pants (ID: 19).

Canadian Coast Guard Garments

Figure 30: Parka with heavyweight zip in liner (ID: CG35).

Figure 31: CCG commercial outer jacket (ID: CG36).

Figure 32: CCG commercial insulated pants (ID: CG37).

Figure 33: CCG commercial mid layer jacket (ID: CG38).

Appendix C - Individual Clothing Garment Descriptions - Crafters

Item	Material		ID#:	Cost per unit	Region	Artist/Community	Artist/Community Link
Hat (Trappers)	Beaver		21	400	NWT	Cheryl Fennel/ Yellowknife	https://www.nwtarts.com/artist-profile/cheryl-fennell
Neck Warmer	Sheared Beaver		22	200	NWT	Dene Fur Clouds/ Fort Providence	https://www.denefurclouds.com/
Neck Warmer	Knitted qivuit		23	175	NWT	UAC/ Uluhaktok	https://ulukhaktok.com/
Fur warmer bundle	Sheared beaver		24	200	NWT	Aurora Heat/ Fort Smith	https://auroraheat.ca/
Mitts	Bison hide/sheared beaver		25	250	NWT	Gerri Sharpe/ Yellowknife	https://www.nwtarts.com/artist-profile/gerri-sharpe
Parka	Commander and Fur Pull over - Hunting Style		26	580	Nunavut	Kiluk/ Arviat	https://ndcorp.nu.ca/we-invest/subsidiaries/kiluk/
Wind Pants			27	230	Nunavut	Kiluk/ Arviat	https://ndcorp.nu.ca/we-invest/subsidiaries/kiluk/

Mittens	Beaver		28	345	Nunavut	Kiluk / Arviat	https://ndcorp.nu.ca/we-invest/subsidiaries/kiluk/
Mittens	Seal		29	255	Nunavut	Kiluk/ Arviat	https://ndcorp.nu.ca/we-invest/subsidiaries/kiluk/
Mitts (Gauntlet)	Beaver		30	400	NWT	Sarah Cleary/ Yellowknife	https://www.nwtarts.com/artist-profile/sarah-cleary
Booties	Qivuit		31	200	NWT	Gerri Sharpe/ Yellowknife	https://www.nwtarts.com/artist-profile/gerri-sharpe
Parka	Lined with duffle or melton		32	750	NFLD	Barry Buckle/ Forteau	
Socks	Socks White Homespun wool		33	40	NFLD	Flora House / Happy Valley-Goose Bay	
Shin Boots	Sealskin with Hide		34	750	NFLD	Barry Buckle/ Forteau	

Parka	Siliapik		35	875	Nunatsiavut	Ashley Andersen/ Goose Bay	Ashley Andersen Handmade https://www.facebook.com/groups/497970537866424/
Mitts	Sealskin and Fur- Long Hunting Mitts		36	400	Nunatsiavut	Elsie Broomfield/ Makkovik	N/a
Hat	Trappers Hat-		37	400	Nunatsiavut	Margaret Broomfield/ Makkovik	N/a
Long Mitts	Sheep Skin-Lined		38	400	Nunatsiavut	Peggy Anderson/ Nain	Ommatikut Designs https://www.facebook.com/Ommatikut-Designs-584906191936413
Hat	Knitted Hat Pang Style Lopi Wool		39	200	Nunavut	Uqqurimut Arts / Pangnirtung	http://www.uqqurmiut.ca/

Appendix D - Clothing Ensemble Descriptions

Table 10: Base layer clothing garments.

Garment ID	Description
BL1	Underwear briefs
BL2	Underwear jersey
BL3	Short sleeved shirt
BL4	Long sleeved shirt
BL5	Jogging Pants
BL6	Socks
BL7	Toque
BL8	Mittens
BL9	Neoprene Boots

Figure 34: NEMO dressed in the Base Layer ensemble.

Table 11: Ensemble 1 clothing garments.

Garment ID	Description
BL1	Underwear briefs
BL2	Underwear jersey
BL3	Short sleeved shirt
BL4	Long sleeved shirt
BL5	Jogging pants
BL6	Socks
BL7	Toque
BL8	Mittens
BL9	Neoprene boots
12	Parks Canada winter parka

Figure 35: NEMO dressed in Ensemble 1.

Table 12: Ensemble 2 clothing garments.

Garment ID	Description
BL1	Underwear briefs
BL2	Underwear jersey
BL3	Short sleeved shirt
BL4	Long sleeved shirt
BL5	Jogging pants
BL6	Socks
BL7	Toque
BL8	Mittens
BL9	Neoprene boots
12	Parks Canada parka
19	Parks Canada pants

Figure 36: NEMO dressed in Ensemble 2.

Table 13: Ensemble 3 clothing garments.

Garment ID	Description
BL1	Underwear briefs
BL2	Underwear jersey
BL3	Short sleeved shirt
BL4	Long sleeved shirt
BL5	Jogging pants
BL6	Socks
BL7	Toque
BL8	Mittens
BL9	Neoprene boots
12	Parks Canada parka
19	Parks Canada pants
10	Parks Canada liner for pants (with Bib)

Figure 37: NEMO dressed in Ensemble 3.

Table 14: Ensemble 4 clothing garments.

Garment ID	Description
BL1	Underwear briefs
BL2	Underwear jersey
BL3	Short sleeved shirt
BL4	Long sleeved shirt
BL5	Jogging pants
BL9	Neoprene boots
12	Parks Canada parka
19	Parks Canada pants
10	Parks Canada liner for pants (with Bib)
14	Parks Canada neck warmer
2	Parks Canada merino wool /nylon socks
5	Parks Canada toque
9	Parks Canada leather mittens

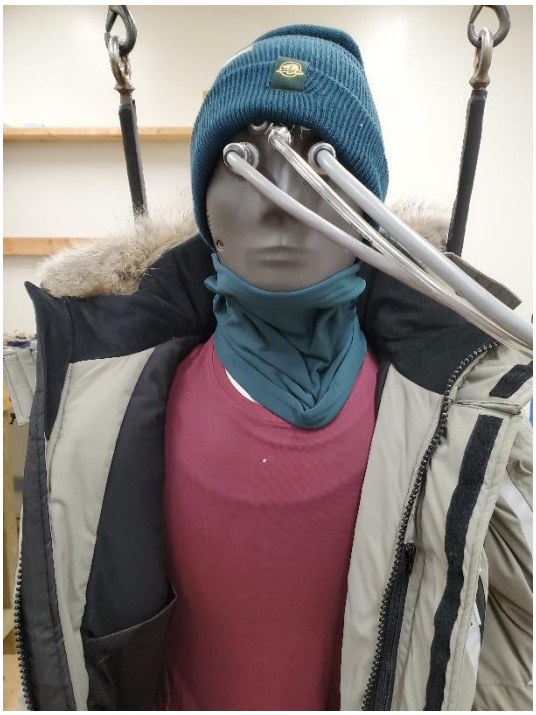

Figure 38: NEMO dressed in Ensemble 4.

Table 15: Ensemble 5 garments.

Garment ID	Description
BL1	Underwear briefs
BL2	Underwear jersey
BL3	Short sleeved shirt
BL4	Long sleeved shirt
BL5	Jogging pants
BL6	Socks
BL7	Toque
BL8	Mittens
BL9	Neoprene boots
26	Commander and Fur Pull Over Parka

Figure 39: NEMO dressed in Ensemble 5.

Table 16: Ensemble 6 garments.

Garment ID	Description
BL1	Underwear briefs
BL2	Underwear jersey
BL3	Short sleeved shirt
BL4	Long sleeved shirt
BL5	Jogging Pants
BL6	Socks
BL7	Toque
BL8	Mittens
BL9	Neoprene boots
26	Commander and fur pull over parka
27	Wind pants

Figure 40: NEMO dressed in Ensemble 6.

Table 17: Ensemble 7 garments.

Garment ID	Description
BL1	Underwear briefs
BL2	Underwear jersey
BL3	Short sleeved shirt
BL4	Long sleeved shirt
BL5	Jogging Pants
BL6	Socks
BL7	Toque
BL8	Mittens
BL9	Neoprene Boots
32	Parka lined with duffle

Figure 41: NEMO dressed in Ensemble 7.

Table 18: Ensemble 8 garments.

Garment ID	Description
BL1	Underwear briefs
BL2	Underwear jersey
BL3	Short sleeved shirt
BL4	Long sleeved shirt
BL5	Jogging pants
BL9	Neoprene boots
12	Parks Canada parka
19	Parks Canada pants
10	Parks Canada liner for pants (with Bib)
22	Sheared beaver neck warmer
33	Homespun wool socks
21	Trapper style hat made from beaver
25	Bison hide/sheared beaver mittens

Figure 42: NEMO dressed in Ensemble 8.

Table 19: Ensemble 9 garments.

Garment ID	Description
BL1	Underwear briefs
BL2	Underwear jersey
BL3	Short sleeved shirt
BL4	Long sleeved shirt
BL5	Jogging pants
BL9	Neoprene boots
12	Parks Canada parka
19	Parks Canada pants
10	Parks Canada liner for pants (with Bib)
23	Qivuit neck warmer
33	Homespun wool socks
21	Trapper style hat made from beaver
28	Beaver mittens

Figure 43: NEMO dressed in Ensemble 9.

Table 20: Ensemble 10 garments.

Garment ID	Description
BL1	Underwear briefs
BL2	Underwear jersey
BL3	Short sleeved shirt
BL4	Long sleeved shirt
BL5	Jogging pants
BL9	Neoprene boots
12	Parks Canada parka
19	Parks Canada pants
10	Parks Canada liner for pants (with Bib)
23	Qivuit neck warmer
33	Homespun wool socks
21	Trapper style hat made from beaver
28	Seal skin mittens

Figure 44: NEMO dressed in Ensemble 10.

Table 21: Ensemble 11 garments.

Garment ID	Description
BL1	Underwear briefs
BL2	Underwear jersey
BL3	Short sleeved shirt
BL4	Long sleeved shirt
BL5	Jogging pants
BL9	Neoprene boots
12	Parks Canada parka
19	Parks Canada pants
10	Parks Canada liner for pants (with Bib)
23	Qivuit neck warmer
33	Homespun wool socks
21	Trapper style hat made from beaver
30	Beaver gauntlet style mittens

Figure 45: NEMO dressed in Ensemble 11.

Table 22: Ensemble 12 garments.

Garment ID	Description
BL1	Underwear briefs
BL2	Underwear jersey
BL3	Short sleeved shirt
BL4	Long sleeved shirt
BL5	Jogging pants
BL6	Socks
BL9	Neoprene boots
12	Parks Canada parka
19	Parks Canada pants
10	Parks Canada liner for pants (with Bib)
23	Qivuit neck warmer
21	Trapper style hat made from beaver
30	Beaver gauntlet style mittens
34	Sealskin shin boots

Figure 46: NEMO dressed in Ensemble 12.

Table 23: Ensemble 13 garments.

Garment ID	Description
BL1	Underwear briefs
BL10	NEOS Overshoe® Navigator 5
3	Parks Canada long underwear
4	Parks Canada undershirt
6	Parks Canada shirt
19	Parks Canada pants
10	Parks Canada liner for pants (with Bib)
8	Parks Canada merino wool / nylon long socks
9	Parks Canada leather mittens
14	Parks Canada neck warmer
12	Parks Canada parka

Figure 47: NEMO dressed in Ensemble 13.

Table 24: Ensemble 14 garments.

Garment ID	Description
BL1	Underwear briefs
BL10	NEOS Overshoe® Navigator 5
3	Parks Canada long underwear
4	Parks Canada undershirt
6	Parks Canada shirt
19	Parks Canada pants
10	Parks Canada liner for pants (with Bib)
8	Parks Canada merino wool / nylon long socks
9	Parks Canada leather mittens
14	Parks Canada neck warmer
12	Parks Canada parka
24	Fur warmer bundle
31	Booties

Figure 48: NEMO dressed in Ensemble 14.

Table 25: Ensemble 15 garments.

Garment ID	Description
BL1	Underwear briefs
BL2	Underwear jersey
BL3	Short sleeved shirt
BL4	Long sleeved shirt
BL5	Jogging Pants
BL6	Socks
BL7	Toque
BL8	Mittens
BL9	Neoprene Boots
35	Siliapik Parka

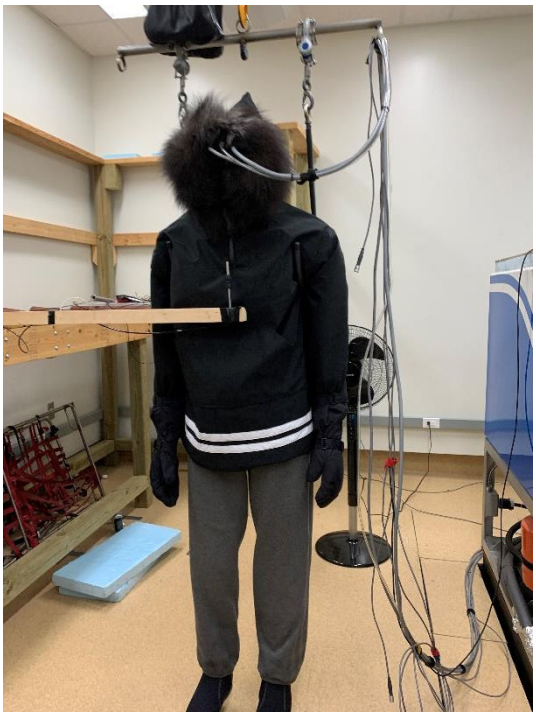

Figure 49: NEMO dressed in Ensemble 15.

Table 26: Ensemble 16 garments.

Garment ID	Description
BL1	Underwear briefs
BL2	Underwear jersey
BL3	Short sleeved shirt
BL4	Long sleeved shirt
BL5	Jogging pants
BL9	Neoprene boots
12	Parks Canada parka
19	Parks Canada pants
10	Parks Canada liner for pants (with Bib)
22	Sheared beaver neck warmer
33	Homespun wool socks
36	Sealskin and fun long hunting mittens
37	Trappers hat

Figure 50: NEMO dressed in Ensemble 16.

Table 27: Ensemble 17 garments.

Garment	Description
BL1	Underwear briefs
BL2	Underwear jersey
BL3	Short sleeved shirt
BL4	Long sleeved shirt
BL5	Jogging pants
BL9	Neoprene boots
12	Parks Canada parka
19	Parks Canada pants
10	Parks Canada liner for pants (with Bib)
22	Sheared beaver neck warmer
33	Homespun wool socks
38	Sheep skin lined long mittens
37	Trappers hat

Figure 51: NEMO dressed in Ensemble 17.

Table 28: Ensemble 18 garments.

Garment ID	Description
BL1	Underwear briefs
BL2	Underwear jersey
BL3	Short sleeved shirt
BL4	Long sleeved shirt
BL5	Jogging pants
33	Homespun wool socks
34	Sealskin shin boots
36	Sealskin and fur long hunting mittens
26	Commander and fur pull over parka
27	Wind pants
22	Sheared beaver neck warmer
21	Beaver trapper style hat

Figure 52: NEMO dressed in Ensemble 18.

Table 29: Ensemble 19 garments.

Garment ID	Description
BL1	Underwear briefs
BL2	Underwear jersey
BL3	Short sleeved shirt
BL4	Long sleeved shirt
BL5	Jogging Pants
BL6	Socks
BL7	Toque
BL8	Mittens
BL9	Neoprene Boots
CG35	CCG parka with heavyweight insert

Figure 53: NEMO dressed in Ensemble 19.

Table 30: Ensemble 20 garments.

Garment ID	Description
BL1	Underwear briefs
BL2	Underwear jersey
BL3	Short sleeved shirt
BL4	Long sleeved shirt
BL5	Jogging Pants
BL6	Socks
BL7	Toque
BL8	Mittens
BL9	Neoprene Boots
CG36	CCG commercial outer jacket
CG37	CCG commercial insulated pants
CG38	CCG commercial mid layer jacket

Figure 54: NEMO dressed in Ensemble 20.

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13. ABSTRACT/RÉSUMÉ (When available in the document, the French version of the abstract must be included here.)

Government departments with operational requirements in the Arctic have commented that the typical clothing ensembles worn by their personnel are a limiting factor for successful operations in the north. Frostbite, hypothermia, and challenges with basic usability of equipment with bulky outerwear, are all example of trials faced by personnel. Clearly, personnel conducting northern operations must be properly attired for their required tasks.

Indigenous Peoples provide leadership when it comes to protecting people from the elements in northern, often harsh, environments. Canada's northern residents have hundreds of years of successful development of clothing to protect themselves from the environment. This project brings together Indigenous Knowledge and western science in order to identify the components of traditional clothing ensembles that are most suitable for operational activities in cold climates.

Les ministères gouvernementaux ayant des besoins opérationnels dans l'Arctique ont fait remarquer que les ensembles vestimentaires typiques portés par leur personnel sont un facteur limitant pour le succès des opérations dans le Nord. Les engelures, l'hypothermie et les problèmes d'utilisation de base de l'équipement avec des vêtements d'extérieur volumineux sont tous des exemples d'épreuves auxquelles le personnel est confronté. De toute évidence, le personnel menant des opérations dans le Nord doit être convenablement vêtu pour les tâches requises.

Les peuples autochtones font preuve de leadership lorsqu'il s'agit de protéger les gens contre les éléments dans les environnements nordiques, souvent difficiles. Les résidents du Nord du Canada ont des centaines d'années de succès dans le développement de vêtements pour se protéger de l'environnement. Ce projet réunit le savoir autochtone et la science occidentale afin d'identifier les composantes des ensembles vestimentaires traditionnels qui conviennent le mieux aux activités opérationnelles dans les climats froids.