Designation: F 2300 – 04a

Standard Test Method for Measuring the Performance of Personal Cooling Systems Using Physiological Testing[1]

This standard is issued under the fixed designation F 2300; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ϵ) indicates an editorial change since the last revision or reapproval.

INTRODUCTION

Individuals in various occupations are exposed to high heat stress resulting from increased metabolism, or the environment, or both. Environmental heat stress can be especially severe when individuals are required to wear Personal Protective Equipment (PPE), which impairs or prevents evaporation of sweat from the skin, and thus nullifies the body's principal means of removing metabolic heat. Failure to dissipate this heat can dramatically limit work capacity and heat tolerance, thereby increasing the risk of heat-related illness. To reduce this risk, workers are wearing Personal Cooling Systems (PCS) to extend their exposure time to thermal stress. These systems are intended to limit the effects of external environmental heat and the internally generated metabolic heat on the body. For this purpose, standards that objectively quantify the effectiveness of PCS are essential. Therefore, tests that measure important physiological variables, such as core temperature, are essential in evaluating PCS applications and increasing worker's health and safety.

1. Scope

1.1 This test method covers the physiological measurement of internal body core temperature, skin temperature, thermal exposure time, heart rate response, oxygen consumption, and whole body sweat rate, to assess the effectiveness of Personal Cooling Systems in reducing the effects of thermal stress.

1.1.1 To increase safety during physiological testing, this dynamic test requires the use of human participants who exhibit specific health and physical fitness requirements.

1.2 This test incorporates the use of protective clothing ensembles (outer garments) used in conjunction with or worn over top of the PCS. This scope is therefore oriented to industrial rather than athletic applications.

1.2.1 The effectiveness of different PCS will be quantified with the same protective clothing ensemble. Therefore, the physiological values obtained apply only to the cooling systems, the particular protective outer garment, and the specific test conditions.

1.2.2 When a protective outer garment is not provided, this test method requires that PCS shall be tested with the standard outer garment defined within this test method.

1.2.3 The present standard does not attempt to determine important clothing characteristics, such as thermal insulation and evaporative resistance, of the PCS or of the garments worn with the PCS. Test Method F 1291 can be referenced for clothing measurements.

1.3 The values stated in this test method shall be SI units.

1.4 It is the responsibility of the test laboratory to obtain the necessary and appropriate approval(s) required by their institution for conducting tests using human participants.

1.5 *This test method does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this test method to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:* [2]

F 1291 Test Method for Measuring the Thermal Insulation of Clothing Using a Heated Manikin

[1] This test method is under the jurisdiction of ASTM Committee F23 on Protective Clothing and is the direct responsibility of Subcommittee F23.60 on Human Factors.
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[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

F 1494 Terminology Relating to Protective Clothing

2.2 *Other Standards:*

ISO 8996 Ergonomics—Determination of Metabolic Heat Production[3]

ISO 9886 Ergonomics—Evaluation of Thermal Strain by Physiological Measurements[3]

The Commission for Thermal Physiology of the International Union of Physiological Sciences (IUPS Thermal Commission-) Glossary of Terms for Thermal Physiology

3. Terminology

3.1 *Definitions:*

3.1.1 *acclimation, n*—physiological adaptations occurring within an organism, which reduces the strain or enhances endurance of strain, caused by artificially or experimentally induced stressful changes in particular environmental conditions.

3.1.1.1 *Discussion*—Acclimation describes the adaptive changes that occur within an organism in response to artificially induced changes in particular climatic factors such as ambient temperature and humidity in a controlled environment.

3.1.2 *acclimatization, n*—physiological adaptations occurring within an organism, which reduces the strain or enhances endurance of strain, caused by stressful changes in the natural environment.

3.1.3 *clo, n*—unit of thermal resistance defined as the insulation required to keep a resting man (producing heat at the rate of 58 W/m^2) comfortable in an environment at 21°C, air velocity 0.1 m/s, or roughly the insulation value of typical indoor clothing.

3.1.3.1 *Discussion*—Numerically the clo is equal to 0.155 $K \cdot m^2/W$, which is equal to 0.18°C·m^2·h/kcal.

3.1.4 *clothing ensemble, n*—a group of garments worn together on the body at the same time.

3.1.5 *thermal core, n*—the deep tissues of the brain, neck and torso whose temperatures are not changed in their relationship to each other by circulatory adjustments

3.1.5.1 *Discussion*—These deep tissues comprise the most thermally protected tissues of the body and are most critical to temperature regulation. The thermal core is distinct from changes in heat transfer to the environment that affects the appendages and other tissues of the body.

3.1.6 *core temperature, n*—the mean temperature of the thermal core.

3.1.6.1 *Discussion*—Core temperature is commonly represented by rectal temperature, or by the more rapidly responding esophageal temperature. Core temperature is also measured by ingested telemetric thermometers in the form of a capsule.

3.1.7 *garment, n*—a single item of clothing (for example, shirt).

3.1.8 *maximum oxygen consumption (VO_{2max}), n*—the highest rate at which an organism can take up oxygen during aerobic metabolism.

3.1.8.1 *Discussion*—Determination of VO_{2max} requires very high motivation of the individual and is expressed in mL per min or as a term relative to body mass in mL per kg per min. Maximum oxygen consumption is often referred to as maximal aerobic power (MAP).

3.1.9 *metabolic rate, n*—the rate of transformation of chemical energy into heat and mechanical work by aerobic and anaerobic activities within an organism.

3.1.9.1 *Discussion*—Metabolic rate, as with VO_{2max}, is commonly measured by indirect calorimetry, during long-term steady-state work. Metabolic rate, also referred to as energy expenditure, is usually expressed in terms of unit area of the total body surface (W/m^2) or ~~surface~~ of total body mass (W/kg).

3.1.10 *thermal insulation, n*—the resistance to dry heat transfer by way of conduction, convection, and radiation.

3.1.11 *thermal strain, n*—any deviation of body temperature induced by sustained thermal stress that cannot be fully compensated by temperature regulation.

3.1.11.1 *Discussion*—Thermal strain results in the activation of thermoeffector activities that causes sustained changes in the state of non-thermal regulatory systems. Thermal strain is measurable by an increased heart rate and whole body sweat rate, as determined by pre and post nude mass loss.

3.1.12 *thermal stress, n*—any thermal change between a temperature regulator and its environment, which if uncompensated by temperature regulation, would result in hyperthermia.

3.1.12.1 *Discussion*—Thermal stress is often referred to as heat stress.

3.2 IUPS Thermal Commission document[4] was referenced for the modified definitions related to thermal physiology listed above, and for terms related to protective clothing used in this test method, refer to Terminology F 1494.

4. Significance and Use

4.1 This test method can be used to quantify and compare the cooling provided by different Personal Cooling Systems (PCS) worn with a standard outer garment or with a specified protective outer garment.

4.1.1 This test method will assess the performance of PCS based on the physiological measurement of core temperature, mean skin temperature, heart rate, exposure time, oxygen consumption, and whole body sweat rate.

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[3] Available from American National Standards Institute (ANSI), 25 W. 43rd St., 4th Floor, New York, NY 10036.

[4] *The Japanese Journal of Physiology*, Vol 51, No. 2, 2001.

4.2 Evaluating the effectiveness of PCS is an extremely complicated endeavor that involves many factors related to thermal exchange between the PCS, the environment, and the participant. It would not be practical in a test method of this scope to establish details sufficient to cover all contingencies. Therefore, a valid physiological method of measuring core temperature, along with other variables of thermal strain, provides an acceptable means of classifying the performance of PCS. This test method will also measure the amount of time the PCS maintains core temperature within safe limits during a specified condition of thermal stress.

4.3 Departures from the instructions in this test method may lead to significantly different test results. Technical knowledge concerning thermoregulatory responses, the theory of heat transfer, physiological and environmental temperature measurement, and testing practices is needed to evaluate which departures from the instructions given in this test method are significant. All departures must be reported with the results.

5. Materials

5.1 *Controlled Environmental Chamber*— Testing will take place within a chamber that is large enough to accommodate a treadmill, the test participant, and at least two people at the same time. Also, the chamber must provide uniform conditions, both spatially and temporally.

5.1.1 *Spatial Variations*—Spatial variations shall not exceed the following: air temperature ±1.0°C, relative humidity ±5 %, and air velocity ±50 % of the mean value. In addition the mean radiant temperature shall not be more than 1.0°C different from the mean air temperature. The spatial uniformity shall be verified at least annually or after any significant modifications are made to the chamber. Spatial uniformity shall be verified by recording values for the conditions stated above at heights of 0.6, 1.0, 1.4, and 1.8 m above the floor at the location occupied by the participant.

5.1.2 *Temporal Variations*—Temporal variations shall not exceed the following: air temperature ±0.5°C, mean radiant temperature ±0.5°C, relative humidity ±5 %, air velocity ±20 % of the mean value for data averaged over 5 min.

5.1.3 *Relative Humidity Measurement*— Any humidity-sensing device must have an accuracy of ±5 % relative humidity and a repeatability of ±3 % is acceptable (for example, wet bulb/dry bulb, dew point hygrometer). Only one location needs to be monitored during a test to ensure that the temporal uniformity requirements are met.

5.1.4 *Air Temperature Sensors*—Shielded air temperature sensors shall be used. Any sensor with an overall accuracy of ±0.15°C is acceptable (for example, RTD, thermocouple, thermistor). The sensor shall have a time constant not exceeding 1 min. The sensor(s) shall be 0.5 to 1.0 m in front of the subject. If a single sensor is used it shall be 1.0 m above the floor. If multiple sensors are used, they shall be spaced at equal height intervals and their readings averaged.

5.1.5 *Air Velocity Indicator*—An omni-directional anemometer with ±0.05 m/s accuracy shall be used. Measurements shall be averaged for at least 1 min at each location. If it is demonstrated that velocity does not vary temporally by more than ±0.05 m/s, then it is not necessary to monitor air velocity during the test. The value of the mean air velocity must be reported, however. If air velocity is monitored, then measurement location requirements are the same as for air temperature.

5.2 *Treadmill*—An adequately sized treadmill shall be used with a physical structure that must be able to accommodate the smallest and the largest participant safely and comfortably.

5.2.1 *Treadmill Characteristics*—The treadmill running surface shall be not less than 1.8 m by 0.6 m. The treadmill must have a calibrated analog scale or digital indicator of speed and angle of inclination (degrees or % grade). Elevation shall be variable over a range of at least 0 to 25 % grade. The speed shall be variable from 2 to 20 km/h in increments of 0.2 km/h. Calibrate treadmills for speed and grade. The control mechanism must provide for error of less than 1.0 % of the testing load both during the test and between tests (that is, 0.15 % grade at 15 % treadmill grade).

5.3 *Equipment for Measuring Body Temperature*—The core and skin temperatures shall be measured with temperature transducers (that is, point sensors) that must be calibrated prior to testing.

5.3.1 *Temperature Transducers*—The temperature measurements may be carried out with liquid thermometers, thermocouples, resistance temperature devices (RTD), or thermistors. The transducers shall provide an accuracy of ±0.1°C between the range of 30 to 42°C for core temperature and 25 to 40°C for skin temperature. The transducers shall be of low thermal capacity. Their response time to 90 % of the value must be the lowest possible and less than 30 s. Skin temperature measurements can be taken at 4, 8, or 14 different locations. Refer to ISO 9886 for the location of the various measurement sites, and the weighting coefficients to determine overall skin temperature.

5.3.2 *Core Temperature Transducer Cleaning*—Special requirements are to be made concerning the hygiene of the core temperature transducer. Laboratories must follow specific biohazard control procedures as stipulated by their institution. Generally, this includes thoroughly cleaning and removing all organic matter prior to disinfection with an agent such as hydrogen peroxide, isopropanol, or ethanol. Following cleaning, the transducer must be rinsed thoroughly with water to remove all traces of the disinfectant which might provoke irritation or allergy in the next user. Refer to ISO 9886 for more information.

5.3.2.1 *Disposable Transducers*—Disposable transducers are also recommended for core temperature measurements. These transducers can be cleaned and disinfected between trials for the same participant and then discarded once the participant has completed all test conditions, thus eliminating the risk of contamination from inter-participant use.

5.4 *Measuring Heart Rate*—Heart rate can be measured with either a portable heart rate monitor or by using an electrocardiogram (ECG).

5.5 *Measuring Urine Specific Gravity*— Urine specific gravity (USG) is used to determine the hydration level of the participants prior to starting the required test conditions. USG is a simple measurement of the density or solute concentration of urine as

compared to pure water. A level of 1.028 g/mL or lower must be obtained prior to participation.

5.5.1 *USG Refractometer*—A refractometer is used to determine the specific gravity of urine. It must be calibrated prior to each use and can be either digital or analogue. The required scale is 0.001 g/mL with a minimum measurement range of 1.000 to 1.080 g/mL.

5.6 *Data Acquisition Systems*—All thermophysiology laboratories will be equipped with their own valid data acquisition hardware and software. A maximum sampling rate of 5 s can be used; however, rates of 15, 30 or 60 s are also adequate. This will depend on the data acquisition system and the physiological variable being sampled. It is important that sampling rates from different physiological variables (for example, heart rate and core temperature) are all the same or at least divisible to allow for easy interpretation. Also, the data acquisition system must be capable of storing a sufficient amount of data (for example, approximately 2.5 h).

5.7 *Participant Clothing Ensembles*— To standardize the testing, subjects will be required to wear a standard under garment during all tests and a standard outer garment when no other protective outer garments are provided for testing.

5.7.1 *Under Garments*—Participant under garments will be worn underneath the PCS during all test conditions. The clothing ensemble will include a T-Shirt, shorts, sport socks, underwear, and athletic shoes. If female participants are used, an athletic bra that is 100 % cotton will be required.

5.7.1.1 *Shirt*—65 % polyester, 35 % cotton T-shirt.

5.7.1.2 *Shorts*—65 % polyester, 35 % cotton shorts.

5.7.1.3 *Sport Socks*—80 % cotton, 20 % nylon; covers only area distal to the malleolii; jersey and rib knit.

5.7.1.4 *Underwear*—100 % cotton underwear; jockey or boxer style.

5.7.1.5 *Athletic Shoes*—Unless protective outer garments include specific or required footwear, athletic shoes with a soft rubber sole must be worn during testing. Other footwear (for example, hard sole shoes) can become problematic, not only because of possible foot soreness, but they can cause a change in gait due to discomfort and can affect mechanical efficiency, and therefore heat production at a fixed workload.

5.7.2 *Outer Garments*—This test method is applicable to testing the performance of PCS when worn underneath protective outer garments (for example, HAZMAT protective ensemble). If a particular outer garment is not provided, then a standard outer garment as described below must be used during testing.

5.7.2.1 *Standard Outer Garment*—A two-piece coverall, including trousers, 65 % polyester and 35 % cotton durable press and 2 by 1 twill weave with two front and hip pockets, and a long sleeve jacket, 65 % polyester and 35 % cotton single layer plain or twill weave will be used. If unavailable, then an outer garment of similar fabrics with a combined intrinsic thermal resistance representing 1 clo (0.155 K $\times$ m^2/W) shaould be used.

5.7.3 No outer garment is necessary if the PCS evaluated do not require the use of such protective ensembles. This circumstance, however, will increase the heat exchange between the environment and the PCS and will likely decrease the available heat exchange between the PCS and the human body.

5.7.4 PCS and protective outer garments shall be cleaned in accordance with the manufacturer's instructions, and report the specific care method and number of times repeated.

6. Sampling, Participants, and Familiarization Period

6.1 *Sampling*—A minimum of five different participants shall be tested for evaluating the performance of each PCS.

6.2 *Test Participants*—Individuals who participate in this test method will do so strictly on a volunteer basis. To undertake this testing, all test laboratories must adhere to and obtain the proper approval for human testing that their respective institution requires. As part of the approval process, participants will be informed of all the details of this test method and the associated risks and discomforts before providing their informed written consent. As well, complete anonymity and confidentiality will be given to each participant.

6.2.1 *Medical Evaluation*—Screen participants for medical problems. This would involve answering a questionnaire assessing their past and current personal health (for example, Canadian Par-Q). Participants may be required to undergo a medical examination depending upon each respective institutional review committee's rules and regulations for physiological thermoregulation research.

6.2.2 *Participant Fitness Level*—A strong aerobic level of fitness is required for individuals to participate in this test method. Screen out participants who do not partake in regular aerobic activities at least ½ h three to five times a week. An evaluation determining the participant's maximum oxygen consumption (VO_{2max}), or maximal aerobic power, will be used as an objective measure to screen for successful participants and allow some comparison of findings between research results.

6.2.2.1 *Maximum Oxygen Consumption*—Only individuals with a VO_{2max} between the range of 4 35 and 65 mL/kg/min will be used as participants in this standard test method. Refer to ISO 8996 for the proper method for measuring oxygen consumption. Otherwise, physiological testing laboratories shall follow their own specific procedures for testing VO_{2max}. The only requirements are that the test is continuous, the exercise is walking, and it is performed using a treadmill. Continuous tests generally start at relatively low intensities and progress by increasing the work rate (treadmill velocity, or % grade, or both) at preset time intervals until the participant is unable to continue. This form of test causes the participant to progressively increase power output over time. If it is continued long enough to allow the body to adapt and is short enough so that factors such as lactate accumulation, thermal

load, or muscular soreness do not force termination of the exercise, the participant will eventually achieve their aerobic energy maximum.

6.2.3 *Participant Gender*—Participants being tested must either be all male or all female in gender. Since conditions will be tested at a maximum frequency of two per week, with the probability of multiple test conditions, the effects of physiological heat production variability associated with the menstrual cycle of female participants needs to be controlled. If females are used, it is recommended that participants be tested within nine days after start of menstruation (follicular phase) to control for hormonal effects. For safety concerns, pregnant women will not be used as participants in this test method in order to avoid unnecessary heat exposure.

6.2.4 *Participant Stature*—Participants are required to be of similar stature. Adults between the ages of 21 and 40 years shall be selected. If testing males, mass of the participants should be between 65 and 100 kg and body height between 1.70 and 1.95 m. If testing females, mass of the participants should be between 55 and 90 kg and body height between 1.60 and 1.85 m.

6.2.5 *Test Preparation*—Pre-test standardization regarding exercise and food consumption must be followed. Individuals must avoid moderate to high-level exercise 24 h prior to the test, no stimulants or diuretics (for example, cigarettes and caffeine) 12 h prior to testing, and no large meals 2 to 3 h prior to testing. Testing is ideal between morning and mid-afternoon hours. A large meal must be avoided less than 3 h prior to testing, with food consumption stopped 2 h prior to testing. All food consumption 12 h prior to testing should be recorded. In addition, all individuals must be normally hydrated prior to testing (for example, 500 mL approximately 2 h before bed the night prior, then approximately 1 to 1.5 L, 1 to 2 h before the trial). Euhydration will be determined by measuring USG 1 h prior to testing. If a level of 1.028 g/mL or lower is not obtained, the participant will be required to consume water until this level is reached. A small amount of water (250 to 500 mL) will be ingested ½ h prior to testing to assist with proper esophageal thermistor placement, if used for core temperature measurement.

6.2.6 *Test Sessions*—Participants must be willing to commit to multiple test conditions at a rate of one, maximum twice, per week. Test sessions shall occur at the same time and day of each week over sequential weeks to minimize the effects of fatigue, acclimation and confounding between the test sessions. The number of test conditions will depend on the number of PCS being evaluated, plus the control condition (no cooling). The control and PCS conditions will be tested in a random order.

6.2.6.1 *Acclimation Period*—More than two tests per week can be performed only if the participants are acclimatized or have gone through a proper acclimation period prior to testing. Research institutions are required to follow ~~a~~ their proper laboratory protocol throughout the testing period in order to maintain acclimation ~~for a.~~ All participants should then be acclimatized, or acclimated, or both. Control and PCS conditions will still be tested as indicated in Section 7.

6.3 *Familiarization Period*—A familiarization session shall be provided prior to the actual testing which would introduce individuals to the test protocol and allow them to get 'comfortable' with core temperature measurement, protective outer garments, and the environmental chamber. ~~Perf~~ More importantly, theis familiarization period ~~for all subjects before undertaking the actual testing to~~ would confirm that the intended rate of energy expenditure (250 W) elicits the appropriate thermal strain, or if a higher metabolic rate ~~of energy expenditure~~ is required.

6.3.1 *Familiarization Protocol*—Participants will be required to wear the mandatory under garments and outer garments. A transducer will be used to measure core temperature in the esophagus or rectum (refer to the following section). It is important that individuals have this done during the familiarization period because in regards to esophageal temperature measurement, the 'gag' reflex is usually stimulated during the first experience leading to the risk of vomiting. Participants will then walk on the treadmill at the required oxygen consumption and environmental conditions for approximately 15 to 30 min. The familiarization period will provide the opportunity to determine the approximate speed and percent grade of the treadmill for each individual. Treadmill speed will be first adjusted to obtain the required work rate. In the event that walking speed becomes so fast as to be uncomfortable, percent grade of the treadmill will then be adjusted to achieve the required energy expenditure. The initial starting grade must be 1 %. In addition, this period will provide enough time to show that the individual is competent to perform the actual test protocol.

7. Procedure

7.1 *Environmental Test Conditions*— The environmental chamber conditions provided below shall be standard for all tests. It should be cautioned that test conditions dependent on ambient air temperature (dry bulb) and relative humidity (wet bulb temperature) might underestimate actual heat stress encountered in natural environmental conditions, where radiant temperature (black globe) may be much higher and can impact meaningfully on individuals wearing protective outer garments.

7.1.1 *Air Velocity*—~~A low~~—An air velocity less than or equal to 0.15 m/s (that is, ~~natural convection) shall be selected, as~~ still air conditions) is required prior to ~~produce the best interlaboratory agreement.~~ participant testing.

7.1.2 *Relative Humidity*—Maintain the relative humidity at a level of 50 % with an acceptable variability range of ±5 %.

7.1.3 *Air Temperature*—The air and wall temperature for the chamber shall be 35°C.

7.2 *Physiological Measurements*—Evaluating the effectiveness of PCS, worn with protective outer garments, will be based on the measurement of core temperature and exposure time. Other physiological variables, such as heart rate, mean skin temperature, oxygen consumption and whole body sweat rate, will be examined for additional performance assessment and safety in order to indicate participant fatigue and heat stress. Hardware and software filtering can be used to smooth out the data to eliminate erroneous artifacts in any of the physiological measured variables.

7.2.1 *Core Temperature Measurement*—Core temperature is the most appropriate measurement available to determine the level

of thermal strain of the participant. It represents the internal tissues of the torso, head and neck regions. Two different sites represent the most efficacious measurement: esophageal and rectal. Both are commonly used and considered acceptable. The proper measurement and placement of esophageal and rectal temperature is outlined in the ISO 9886.

7.2.1.1 *Esophageal Temperature*—The esophageal temperature is more sensitive to changes in the temperature of central venous and arterial blood than rectal measurements. This improved sensitivity is due to the low heat capacity of the esophagus and the proximity to the heart and pulmonary circulation. The temperature at the level of the heart is presumably also the temperature of the blood supplying the hypothalamus (temperature regulation center) in the brain.

7.2.1.2 *Esophageal Thermistor Location*— Introduce the thermistor (or thermocouple) through the nasal cavity into the lower part of the esophagus to the level of the left atrium. The length of the catheter at this point to the origin of insertion at the nose is approximately 25% of the subject's height. If it is placed too low it could read gastric temperature. Too high and it might be affected by breathing. Artifacts in the signal are produced when swallowing (saliva) and drinking fluids. Therefore, indicate the times when the participant swallows or the participant should be told to avoid swallowing during a specific time period (for example, 1 min out of 5, or the last 15 s of every min).

7.2.1.3 *Rectal Temperature*—The rectal temperature tends to be influenced by local muscle contractions and is higher when work is performed with the legs than when it is carried out exclusively with the arms. Rectal temperature measurement is also susceptible to a slower frequency response and lags behind as compared to esophageal during some activities. Therefore, it is generally recommended that rectal temperature be measured only when work is performed using the whole body.

7.2.1.4 *Rectal Thermistor Location*—Insert the thermistor into the rectum no less than 10 cm and no greater than 15 cm in depth past the edge of the anal sphincter. Slight temperature differences can be registered depending on the depth of insertion of the temperature transducer. Therefore, the depth must remain the same throughout the measurement period.

7.2.2 *Skin Temperature Measurement*—Skin temperature measurements can be taken at 4, 8, or 14 positions, located on the forehead, neck, scapula, upper chest, arm, hand, abdomen, lower back, thigh, shin, calf, and foot. Refer to ISO 9886 for the location of the different measurement sites, and the weighting coefficients to determine mean skin temperature. This test method recommends eight skin site locations, on the forehead, right scapula, left upper chest, upper right arm, lower left arm, left hand, right anterior thigh, and left calf.

7.2.2.1 *Skin Thermistor Placement*—It is important that the thermistors are in flat contact with the prepared skin surface. To avoid local effects, attach the transducer to the skin with heat-conducting adhesive tape. Other tapes capable of modifying heat transfer by convection, radiation and evaporation must be avoided or used only when necessary. Although skin temperature is expected to be lower under the PCS, therefore the position of individual thermistors can be altered slightly to avoid direct contact with the cooling source (for example, ice). The top of the thermistors located underneath the PCS should also be insulated to minimize biased mean skin temperature estimations within or across PCS. Standard laboratory procedures for preparing the skin sites and proper attachment are to be followed.

7.2.3 *Heart Rate Measurement*—As a safety and performance measure, always monitor heart rate. Follow respective laboratory procedures for the measurement of heart rate.

7.2.4 *Whole Body Sweat Rate*—Whole body sweat rate is used to assess the performance of the PCS and the level of dehydration caused by the thermal stress of the test conditions. Sweat rate is determined by subtracting the measured post-dry nude body mass from pre-dry nude body mass. If urination occurs during the testing, the mass of the urine must be added to the post body mass. If fluid consumption occurs during testing, the mass of the fluid must be subtracted from the post body mass.

7.3 *Standard Work Rate*—Work rate, determined by energy expenditure, is an important component of this test ~~method.~~ standard. The work rate ~~cannot~~ must be ~~too high~~ sufficient to ~~induce uncompensable heat stress, or too low to~~ elicit ~~no~~ a thermoregulatory response. The interaction of the environmental conditions, clothing ensemble and metabolic heat production, has to be severe enough for the PCS to demonstrate an effect on core temperature. The work or exercise will involve walking on a treadmill. Treadmill walking will not interfere with the cooling system, outer garment and data collection instrumentation. Oxygen consumption or a metabolic energy expenditure of 250 W (±2.5 %) will be used during all conditions in this test method. The proper speed and percent grade of the treadmill will be determined during the familiarization period using the control condition. Adjustments will be made during the first 5 min of each PCS condition to attain the required energy expenditure of 250 W. After this time period, the treadmill will not be adjusted since oxygen consumption is expected to increase as fatigue occurs. Therefore, oxygen consumption will be monitored throughout this test procedure. Treadmill speed and percent grade of each participant will also be used to determine the appropriate external work.

7.3.1 *Moderate Work Rate*—An energy expenditure range of 250 to 400 W represents a moderate level of work. If due to the PCS, or the protective outer garment, or both, a reasonable level of heat stress is not produced with ~~a metabolic rate of 250 W,~~ 250 W, as evident in the familiarization period, ~~the~~ work rate can be increased up to ~~a level of~~ 400 W. ~~Apply this change in work rate~~ This must apply to all participants and conditions ~~involved~~ in the standard testing.

7.4 *Test Procedures*:

7.4.1 Upon arriving at the test laboratory, the participant is required to change into the required under garments and perform lower body stretching exercises to eliminate the risk of muscular injury during the actual testing. Collect anthropometric measurements of age, mass and height. The mass of the PCS, fully charged, and clothing ensembles must also be obtained for analysis.

7.4.2 Attach the temperature thermistors (core and skin) and the heart rate monitor to the participant. The participant shall then remain seated for 5 to 10 min in order to obtain baseline data and verify that all signals are being received and within normal physiological ranges.

7.4.3 Prior to entering the environmental chamber, the selected PCS with the required outer garment are placed on the participant so as not to interfere with any of the data collection equipment. Since oxygen consumption is measured throughout the test, facemasks and other headgear might have to be altered to provide space for the equipment used to measure this metabolic rate.

7.4.3.1 Test the PCS and control conditions in a randomized process, with each participant tested in all conditions. The standard outer garment, if used, is required to be worn during the control (no cooling) and PCS conditions.

7.4.3.2 Each PCS must be used in accordance with the manufacturer's operational instructions. All cooling materials (for example, ice packs) and batteries must be fully charged prior to testing to manufacturer's instructions.

7.4.4 Immediately after entering the environmental chamber, the PCS is turned on, if appropriate, at the exact instance the participant begins the required treadmill walking at the predetermined speed and grade. Minor adjustments to obtain the specified metabolic rate of 250 W for each PCS shall be allowed during the first 5 min of testing. This will give the participant enough time to equilibrate at 250 W and not too much time for an increase in metabolic cost to occur due to the exercise-induced heat stress. Treadmill controls will not be adjusted following this period. All physiological variables will be collected from this point to test termination.

7.4.5 At no time must the participant be left unattended during the test.

7.4.6 Fluid consumption (water) will be allowed during the testing. No more than 250 mL every ½ h shall be provided for the participants if requested. If measuring esophageal temperature, it is important to record the periods of fluid consumption throughout the test since core temperature will be slightly lowered during these events.

7.4.7 Test termination will result either by voluntary withdrawal, signs of impending heat injury (for example, disorientation, chills, or nausea), heart rate reaches 90 % of age predicted maximum, core temperature exceeds 39.0°C, skin temperature sites exceed 38.0°C, or the participant has exceeded the total time required for the test, or a combination thereof.

7.4.7.1 A number of institutions have produced material that outlines specific precautions regarding work in hot environments based on core temperature measurements. The World Health Organization recognizes a maximum core temperature of 39.0°C for intermittent exposures in the heat, but recommends 38.0°C for continuous exposures to heat stress. The National Institute for Occupational Safety and Health recommends a safe limit of 38.0°C for all exposures.

7.4.7.2 Participants must attempt to last as long as possible to allow the core temperature response to become sufficiently evident. A maximum time of 2 h will be allotted for this test method.

7.4.7.3 Certain PCS have limited cooling capacities (for example, ice vest). These cooling sources can be replenished during this test method as long as the individual keeps exercising and the protective or standard outer garment remains on.

~~7.4.8 Provide a~~

7.4.8 A recovery period must be provided for the participants upon completion of each test condition. Recovery requirements can be based on the respective institutional laboratory protocol that has been accepted by the institutional review board. Otherwise, ~~monitor~~ core temperature should be monitored until it decreases to a level below 38.0°C, and ~~monitor~~ heart rate decreases to less than 100 beats per minute. Until these values are reached, participants must be monitored at all times. Furthermore, fluids (for example, water or ergonomic sports drink) must be provided during this period.

8. Calculations

8.1 Percent Grade (% grade) of a treadmill is defined as the units of rise per 100 horizontal units of run and is calculated using Eq 1:

$$\%Grade = \tan \alpha \cdot 100 \tag{1}$$

where:

%Grade = represents the angle of inclination of the treadmill, %, and
α = treadmill angle of inclination, degrees.

8.2 Estimate the average external work rate (EWR) performed on the treadmill for each participant using Eq 2:

$$WR = \frac{m \cdot g \cdot \left(\sin\left[\tan^{-1}\left(\frac{\%Grade}{100} \right) \right] \cdot D \right)}{T} \tag{2}$$

$$EWR = \frac{m \cdot g \cdot \left(\sin\left[\tan^{-1}\left(\frac{\%Grade}{100} \right) \right] \cdot D \right)}{T} \tag{2}$$

where:

EWR = average external work rate calculated for the treadmill, W,
m = participant mass, kg,

g = the acceleration due to gravity, 9.81 m/s^2,
$\%Grade$ = inclination of treadmill, %,
D = total ~~vertical~~ distance traveled, m, and
T = total exposure time, s.

8.3 Record the duration of cooling as the time required for the core temperature to reach 39.0°C, the participant to voluntarily withdraw due to extreme fatigue or nausea, the heart rate to reach~~ed~~ 90 % of age predicted maximum, the skin temperature to exce~~ed~~ed 38.0°C, or the test to reach~~ed~~ the maximum time allotted of 2 h, or a combination thereof. If the situation was to occur that the participant exceeded the maximum testing period, the duration is defined as "more than 2 h."

8.4 Calculate mean skin temperature from the combination of the different measurement sites. Mean skin temperature can be calculated for each 5-min interval during the test. Refer to ISO 9886. Eq 3 determines the mean skin temperature based on 8 measurement sites.

$$t_{sk} = 0.07a + 0.175b + 0.175c + 0.07d + 0.07e + 0.05f + 0.19g + 0.2h \quad (3)$$

where:
t_{sk} = mean skin temperature using 8 different sites, °C,
a = forehead temperature, °C,
b = right scapula, °C,
c = left upper chest, °C,
d = upper right arm, °C,
e = lower left arm, °C,
f = left hand, °C,
g = right anterior thigh, °C, and
h = left calf, °C.

8.5 Perform a statistical analysis of the different PCS using the physiological variables measured and the duration of cooling. It is recommended that a repeated measures analysis of variance (ANOVA) be used with a moderate post-hoc test when suitable. The repeated measures ANOVA factors out the inter-individual differences of the participants. The repeated measure ANOVA shall be used to separately compare exposure time, final core temperature, change in core temperature, final mean skin temperature, final oxygen consumption, whole body sweat rate, and final heart rate, of the different PCS.

9. Report

9.1 Report the following information:

9.1.1 State that the specimens were tested as directed in this test method.

9.1.2 Report the test location and the institution.

9.1.3 Indicate that all participants used in this test method were selected as directed in the test method, and that all individuals met the medical health requirements and signed the ethics form.

9.1.4 Report the average age, mass, and height of the participants. Also provide the participants average maximum oxygen consumption.

9.1.5 Report the environmental chamber conditions and the external work rate used, as well as the average treadmill speed and % grade for all the participants during each condition.

9.1.6 ~~Des~~If acclimated parti~~b~~cipants were used, report the procedures used to develop, or maintain, or both, acclimation prior to and during testing.

9.1.7 Describe the Personal Cooling Systems and outer garments used, if applicable. Also indicate the mass of each PCS, fully charged, and of all other clothing ensembles.

9.1.~~7~~8 Report the average cooling (exposure) times for each PCS and for the control condition. Also report the average final core temperature, change in core temperature, final mean skin temperature, change in mean skin temperature, whole body sweat rate, oxygen consumption, and final heart rate, and if filtering was used during data processing. Indicate the results of the statistical analysis.

9.1.~~8~~9 Provide a summary of physiological results for data collected from at least every 5-min period during testing. Also describe the reason for test termination with each PCS.

9.1.~~9~~10 Report and explain any modifications or departures from the specified test procedure.

10. Precision and Bias

10.1 *Precision*—Due to the inherent variability of human subject testing, precision will vary with different physiological variables. In comparing three independent observations of a physiological variable from a single participant, the variation should not exceed ±5 % of the average of the three measurements when the measurements are taken by the same well-trained operator using the same testing equipment. Otherwise, additional replications must be conducted until this criterion is met.

10.2 *Bias*—The procedure in this test method has no bias because the value can be defined only in terms of a test method, or because there is no accepted reference material suitable for determining the bias for the procedure in this test method for measuring PCS performance with human subjects.

11. Keywords

11.1 acclimation; core temperature; maximum oxygen consumption; personal cooling systems; thermal strain; thermal stress; whole body sweat rate