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REFINEMENT OF PROBABILITY OF SURVIVAL DECISION AID (PSDA)

United States Army
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USARIEM TECHNICAL NOTE TN14-02

REFINEMENT OF PROBABILITY OF SURVIVAL DECISION AID (PSDA)

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14. ABSTRACT
PSDA predicts the impact of hypothermia and dehydration on survival time during exposure for a wide range of conditions in marine environments. The United States Coast Guard (USCG) has mandated PSDA use in their search and rescue (SAR) operations since June 2010. USCG and USARIEM have collaborated to make refinements to PSDA. The enhancements described here (PSDA v1.2 beta) include 1) creating an option to read environmental parameters directly from the server; 2) deriving and implementing algorithms for the descriptive categories in the pull-down menus for height, weight and body fat%; 3) implementing the Monte Carlo method to simulate the inherent uncertainties of inputs and the dynamic nature of environmental conditions. In addition, five personal floatation devices (PFD, see Appendix A) were evaluated on manikins to determine the PFD's thermal and evaporative resistances in air, and thermal resistance in water. The measured results indicated the PFD resistances were minimal and thus will have a minimal impact on the heat loss from the body to the environment.

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EXECUTIVE SUMMARY

US Army Research Institute of Environmental Medicine (USARIEM), working in cooperation with the United State Coast Guard (USCG), developed the Probability of Survival Decision Aid (PSDA v1.0). PSDA predicts the impact of hypothermia and dehydration on survival time during exposure for a wide range of conditions in marine environments. The United States Coast Guard (USCG) has mandated PSDA use in their search and rescue (SAR) operations since June 2010.

USCG and USARIEM have been collaborating in an on-going effort to refine PSDA. The enhancements described here (PSDA v1.2 beta) include 1) creating an option to read environmental parameters directly from the server; 2) deriving and implementing algorithms for the descriptive categories in the pull-down menus for height, weight and body fat%; 3) implementing the Monte Carlo method to simulate the inherent uncertainties of inputs and the dynamic nature of environmental conditions. In addition, five personal floatation devices (PFD, see Appendix A) were evaluated on manikins to determine the PFD's thermal and evaporative resistances in air, and thermal resistance in water. The measured results indicated the PFD resistances were minimal and thus will have a minimal impact on the heat loss from the body to the environment. Therefore, it was not necessary to add a PFD option to PSDA.

INTRODUCTION

Search and Rescue is a primary mission of the United States Coast Guard (USCG). The suspension of active searching for maritime victims is always a difficult and delicate decision. An accurate estimate of survival times is one of the key factors in the decision to continue or suspend active searching. US Army Research Institute of Environmental Medicine (USARIEM) and USCG's Research and Development Center have been working together to develop a Probability of Survival Decision Aid (PSDA) (1;2). The decision aid predicts survival times based on the impact of hypothermia and dehydration during prolonged exposure in marine environments for a wide range of conditions. After a peer review sponsored by the USCG (3), the use of PSDA became mandatory in USCG search and rescue operations beginning in June 2010 (4;5).

PSDA version 1.0 consists of the Six-Cylinder Thermoregulatory Model (SCTM) and a Graphic User Interface (GUI) (1;2). The interface was designed and the event-driven code was written in Microsoft Visual Basic 2005. The SCTM computational portion of the code was written in FORTRAN and was imported for use with the GUI via a Dynamic Link Library (DLL). PSDA v1.0 is now operational as a stand-alone model within the Coast Guard's Search and Rescue Optimal Planning System (SAROPS).

The GUI is a critical element of PSDA which enables users to easily access the model and enter or select inputs for ten basic parameters: air temperature, water temperature, relative humidity, wind speed, gender, height, weight, percent body fat, immersion state and clothing type. Conversions between metric and English units are available for all parameters. When victim traits are unknown, and thus specific values cannot be entered, the pull-down menus allow users to select different descriptive categories such as medium, tall, light, lean, etc. Based on this information, the GUI program runs SCTM, then posts or updates the display predictions for cold functional time (i.e., the point in time when core temperature reaches 34 °C), cold survival time (i.e., when the core temperature reaches 28 °C) and dehydration survival time (i.e., when water loss reaches 20% of body weight).

The USCG's Office of Search and Rescue and USARIEM have collaborated to develop a refined version of PSDA (PSDA version 1.2 beta). This technical note is a summary of the implemented changes which include 1) an option for PSDA to read environmental parameters directly from the SAROPS server; 2) new algorithms for the menu of descriptive categories of height, weight and body fat%, which take into account age-related differences; 3) adaptation of the Monte Carlo (MC) method to address the inherent uncertainty of inputs and the dynamic nature of operational environments.

METHODS

UPGRADED PROBABILITY OF SURVIVAL DECISION AID

The refined version of PSDA (PSDA v1.2 beta) is shown in Figure 1. The places where three improvements were incorporated are highlighted on the display by red boxes, and are described in the following sections.

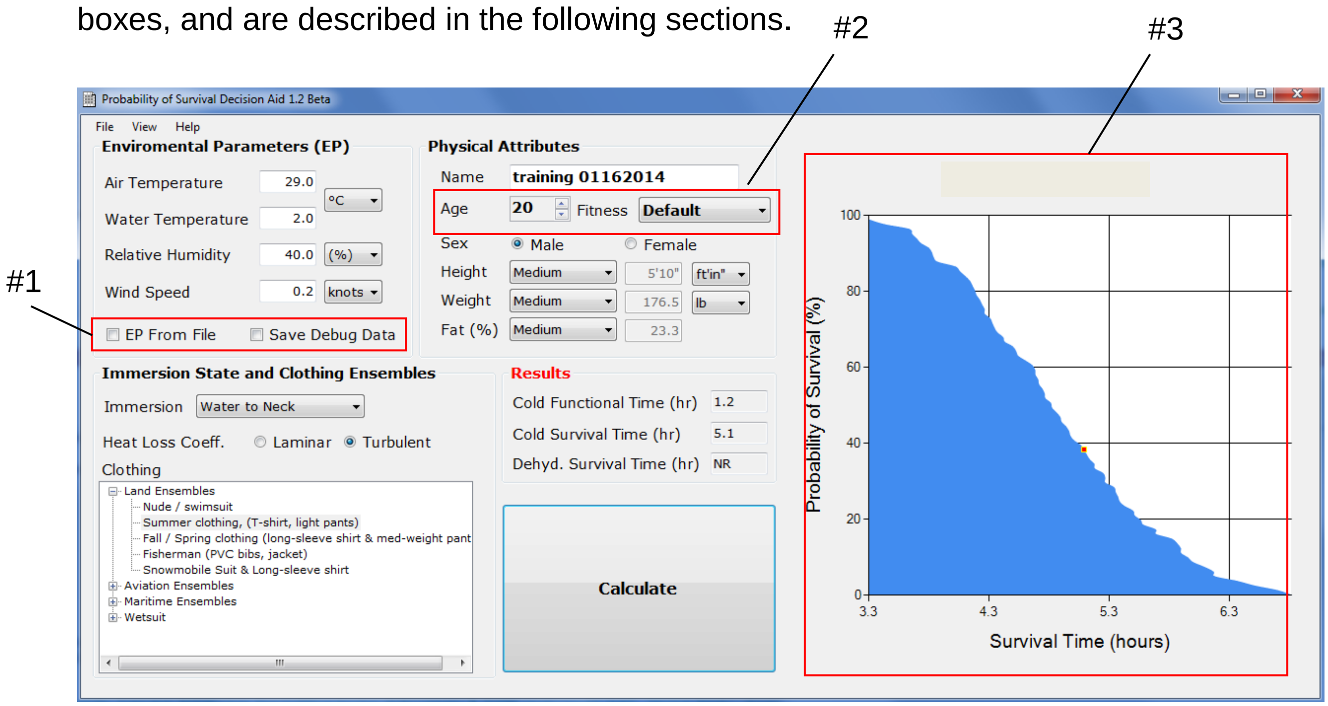

Figure 1. Probability of Survival Decision Aid (PSDA v1.2 beta) interface showing improvement #1, #2 and #3

ENVIRONMENTAL PARAMETERS

PSDA requires the following environmental parameters: air and/or water temperature, humidity, and wind speed. PSDA v1.2 beta provides options to use these environmental values directly from the SAROPS server. When the “EP From File” is checked PSDA will read data from a file named environmental.txt. The format of this file is shown in Figure 2. The first row is the air temperature in °C, the second row is the water temperature in °C, the third row is the relative humidity in %, and the last row is the wind speed in m/s.

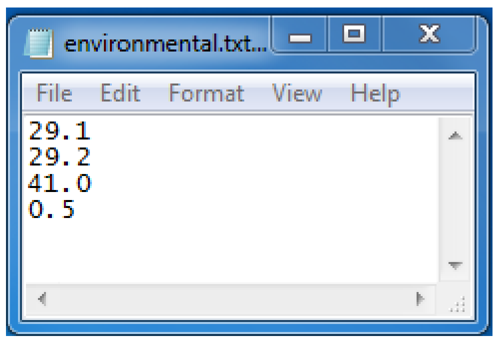

Figure 2 File for environmental data

PHYSICAL ATTRIBUTES

PSDA provides the user the option of entering values for the victim’s anthropometric parameters; i.e. height, weight and body fat percentage as actual values, or an alternative option of selecting descriptive categories from a pull-down menu with descriptions such as very short to very tall for height and very light to very heavy for body weight. In the enhanced PSDA v1.2 beta, these descriptive categories are age dependent (they were constant in PSDA 1.0) and are based on the survey data for U.S. population in the National Health and Nutrition Examination Surveys (NHANES) [Centers for Disease Control and Prevention (CDC). National Center for Health Statistics (NCHS). National Health and Nutrition Examination Survey Data. Hyattsville, MD: U.S. Department of Health and Human Services, Centers for Disease Control and Prevention, http://www.cdc.gov/nchs/nhanes.htm, accessed on August 12 2012].

The NHANES interviews and examines approximately 5000 persons each year from representative samples. Three two-year data sets were obtained from NHANES from 1999-2004. From this six-year period, data was collected for 12,729 males and 13,430 females and classified relative to their portion of the US population. The NHANES data and corresponding documentation can be downloaded directly from the NHANES web site. Demographics (weighting of each sample by its proportion of the US population), anthropometric measurements, cardiovascular fitness, and percentage body fat (fat%) measured by Dual-Energy X-ray Absorptiometry (DXA) for the two-year data sets were downloaded and then imported into MATLAB® (MathWorks, Natick, MA) for analysis. First, the three two-year data sets were combined into the six-year set. Then, individuals with incomplete data were eliminated from the combined data set. Finally, the compiled data set was sorted by gender and age (8.0 - 16.7 years and 16.7 to 85.0 years).

Equations (non-linear weighted regressions) were derived from NHANES database to determine the descriptive height and weight categories according to the age and gender. The derived equation can be used to calculate an age adjusted height or weight by using different constants for height and weight. Equation 1 determines the mean, upper 97.5% and lower 2.5% limits of the height and weight for male and female populations between 20 and 85 years of age:

$$\mathrm{Y} = \mathrm{A} + \mathrm{B} \cdot \mathrm{X} + \mathrm{C} \cdot X^2 \quad \text{(Eq. 1)}$$

where the input value Y is either height (cm) or weight (kg), A, B and C are the respective constants for height or weight respectively, and X is age in months. The constants for the height and weight calculations are listed in Table 1 and Table 2, respectively.

Table 1 Height constants for calculating the mean, upper and lower limits

Gender	Limits	A (cm)	B (cm·month^{-1})	C (cm·month^{-2} ·10^{-5})
M	Upper	188.85	0.014	-1.72
M	Mean	174.08	0.014	-1.72
M	Lower	159.31	0.014	-1.72
F	Upper	172.82	0.017	-1.98
F	Mean	159.87	0.017	-1.98
F	Lower	146.92	0.017	-1.98

Table 2 Weight constants for calculating the mean, upper and lower limits

Gender	Limits	A (kg)	B (kg·month^{-1})	C (kg·month^{-2} ·10^{-5})
M	Upper	147.00	0.010	-5.20
M	Mean	63.05	0.088	-7.31
M	Lower	31.33	0.088	-7.31
F	Upper	121.00	0.021	-3.50
F	Mean	50.63	0.089	-7.43
F	Lower	34.40	0.070	-7.45

The descriptive body fat percentage (fat%) categories were also derived (using a non-linear regression of mean and 95% confidence limit surfaces to the weighted samples) from NHANES database and related to the age and gender. Equation 2 was used to determine the mean of fat% for male and female populations above 20 years of age:

$$\text{fat\%} = \text{D} + \text{E} \cdot \text{X} + \text{F} \cdot (1.0 - e^{-\frac{BMI}{G}}) \quad \text{(Eq. 2)}$$

where BMI is body mass index in kg·m^{-2}, and D, E, F, and G are constants listed in Table 3. The upper and lower limits for fat% were calculated from the mean ± 6.97% for male and the mean ± 6.72% for female.

Table 3 Constant for fat % mean

Gender	Values	D	E (month^{-1})	F	G (kg·m^{-2})
M	Mean	-27.05	0.0080	72.36	22.88
F	Mean	-37.38	0.0057	87.56	14.44

The descriptive categories for height, weight and fat% are determined from the lower, mean and upper limits according to the Table 4.

Table 4 Descriptive categories for height, weight, and body fat percentage

Height	Very Short	Short	Medium	Tall	Very Tall
Weight	Very Light	Light	Medium	Heavy	Very Heavy
Fat	Very Lean	Lean	Medium	Fat	Very Fat
Values	Lower	0.5·(Mean + Lower)	Mean	0.5·(Mean + Upper)	Upper

According to the survey guidance for the 1999-2004 NHANES, the maximum oxygen uptake ($\dot{V}O_{2max}$ in ml/kg/min) was estimated from the self-reported fitness level shown in Table 5 (P, 0 – 7) and age (12 – 49 years) by the following empirical Equation, which incorporates gender as Female = 0, Male = 1):

$$\dot{V}O_{2max} = 56.363 + 1.921 \cdot \mathrm{P} - 0.381 \cdot \frac{age}{12} - 0.754 \cdot \mathrm{BMI} + 10.987 \cdot (\mathrm{F} = 0, \mathrm{M} = 1) \qquad \text{(Eq. 3)}$$

When the fitness level is unknown, the input “Default” should be selected, see #2 in Figure 1.

Table 5 NHANES Physical Activity Readiness Code

Fitness Level	Physical Activity Description
0	Little or no regular recreation, sport or physical activity and avoids walking or exertion
1	Little or no regular recreation, sport or physical activity, but walks for pleasure and occasionally exercises
2	Participating regularly in recreation or work requiring modest physical activity for 10 to 60 minutes per week
3	Participating regularly in recreation or work requiring modest physical activity for more than 60 minutes per week
4	Participating regularly in heavy physical activity for less than 30 minutes per week
5	Participating regularly in heavy physical activity for 30 to 60 minutes per week
6	Participating regularly in heavy physical activity for 1 to 3 hours per week
7	Participating regularly in heavy physical activity for more than 3 hours per week

MONTE CARLO (MC) SIMULATION

When PSDA is used in an operation setting, one challenge is the selection of model inputs that are accurate for the victims and reflect the dynamic nature of operational environments. Sometime these data are hard to obtain. Therefore all input parameters likely include a degree of uncertainty. To enhance PSDA applications, the MC approach was adapted to address the inherent uncertainty of input parameters.

PSDA calculation is a deterministic simulation and has ten input parameters. It is assumed that each required input (N) contains a potential error of $\pm\Delta$. If N has a uniform distribution, the actual value would be a random number between $N-\Delta$ and $N+\Delta$. Thus the PSDA inputs are a large set of random numbers from correspondent ranges specified for each input (i.e., input probability distribution). To keep the MC process simple and reduce the number of iterations, it is assumed that each input would be represented by $N-\Delta$, N, and $N+\Delta$. Each combination of the representative points is a set of inputs into the model which will generate an outcome point. Therefore, the total of all individual predicted outcomes, each corresponding to a specific combination of input variables, will define the probability distributions of possible outcomes.

The height, weight, fat%, and air/water temperature (air and water temperatures are considered one input parameter) are selected as input parameters for inclusion in MC simulation. The height (H) and weight (W) values are assumed to have 5% error; therefore, their range would be H ± 0.05H and W ± 0.05W respectively. The fat% is assumed to have 10% error; therefore, its range will be fat% ± 0.1fat%. Error for the air temperature will be ±0.5°C and error for the water temperature will be ±1.0 °C. In total, there will be 81 combinations (3x3x3x3) of the inputs, and the simulation will generate 81 predicted outcomes. The survival time probability plot shown on the GUI display (Figure 1) is an example of the 81 predicted outcomes.

An expansion of the clothing menu to incorporate the additional effect of Personal Floatation Devices (PDF) on the thermal and evaporative resistance properties was considered as an additional refinement of PSDA. However, as described in Appendix A, testing determined that wearing a PFD had little effect on the thermal and evaporative resistance properties of the clothing.

GUI CALL TO DYNAMIC LIBRARY LINK (DLL) OF SCTM

When data entry is completed and the compute button is clicked, all input variables are checked for errors, stored, and converted to the proper units used by the computational model. The input variables are then passed to the Dynamic Library Link (DLL), which calculates the predicted results and returns them to the GUI. Then the GUI displays the results and gives the user the option to save and print the input and output variables. The GUI flowchart is shown in Figure 3.

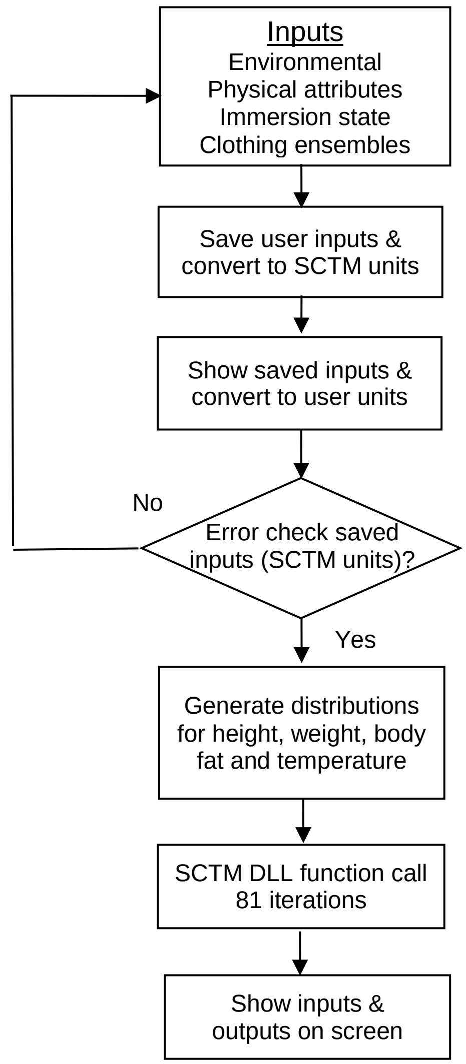

Figure 3. Graphic User Interface (GUI) Flowchart

The GUI only accepts anthropometric parameters within a previously defined acceptable range. If the input values are out of range, the GUI marks the out-of-range value with a warning label and SCTM will not run. The GUI input check process consists of the following steps: (a) check to ensure the entered height and weight are within the upper and lower limits (1.3-2.1 m for height and 38.0-185.0 kg for weight, for both male and female); (b) check to ensure that the BMI value calculated from height and weight is within the allowable range, 17-45 kg/m^2 for male and 16-47 kg/m^2 for female; (c) when fat% is entered as a descriptive category, the GUI will use the equations presented earlier in the paper to calculate body fat percentage; (d) when %fat is known and inputted, the GUI, i.e., PSDA v1.2 beta program, will check to ensure that fat% value is within upper and lower limits; (e) ensure that the body fat percentage is above 5% for males and 12% for females; (f) generate distributions (i.e., upper, medium and lower values) for height, weight, body fat and temperature; (g) after the completion of the above checks, the GUI will run SCTM 81 times and generate the outcome distribution.

DISCUSSION

Several new features have been added to PSDA. With PSDA v1.2 beta, users may choose to enter environmental data manually or take data from the files in the server of Search and Rescue Optimal Planning System (SAROPS). When PSDA is integrated into SAROPS, PSDA will exchange environmental data directly with SAROPS. Two additional parameters, fitness level and age, were added to provide users with more flexibility to define the characteristics of a victim. However, it may also add additional burden for users to determine these two parameters, especially the fitness level. Therefore, user feedback will be required to determine the benefits and challenges of incorporating these two extra input parameters.

The Monte Carlo (MC) simulation takes into account inherent uncertainty of the input parameters. The predicted results likely represent the true scenario more accurately and provide a more comprehensive view of what may happen. At this point, only four input parameters are included in MC simulation, and more input parameters could be included. However, PSDA appears to run slower when the environmental conditions are moderate, as the predicted survival times are longer than in severe conditions: underlying SCTM calculation times are longer, reflecting the 81SCTM runs. It is expected that the PSDA would run slower if more input parameters are included in A MC simulation and the number of required iterations increases. The inclusion of additional inputs into the MC simulation must be balanced again the increased number of SCTM calculation to optimize the efficiency of the PSDA.

SUMMARY

A refined version PSDA (v1.2 beta) has been developed. An option to read environmental parameters directly from the server was added. New algorithms for the descriptive categories of height, weight and fat% were developed and implemented. The impact of personal floatation devices on heat loss from the body to the environment is minimal, thus an extra clothing option for PFD was not added. Monte Carlo simulation was implemented into PSDA to address the inherent uncertainty of input parameters and the dynamic nature of operational environments.

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APPENDIX A

PERSONAL FLOATATION DEVICE EVALUATION

INTRODUCTION

A Personal Floatation Device (PFD) is designed to keep victims afloat during immersion. The PFD floatation is made of thick, bulky material that captures dead air space that is often impermeable to air and water. Those are characeteristics of insulating materials, and a reasonable question is whether or not, wearing a PFD increases thermal or evaporative resistance. A PFD may alter the heat exchange between the skin and the environment, and may thus provide additional protection from hypothermia during water immersion or by trapping more heat. It may increase sweating loss and dehydration during air exposure to warm or hot environments. However, as there was no available data of PFD thermal and evaporative resistance, it was necessary to test PFDs to determine their thermal and evaporative resistances in air, and thermal resistance in water.

METHODS

Five PFDs were evaluated on Nemo, the Navy Clothing and Textile Research Facility's (NCTRF) immersible thermal manikin. The pictures of these five PFDs were shown in Figures A2-A6, and they are:

1. Etransport Type III PFD (Extrasport Inc., Old Town, Maine)
2. Stearns Work Vest PFD (Coleman Company Inc, Wichita, KS)
3. Stearns Type I PFD Model No.429-06, Catalog No.1600 (Coleman Company Inc, Wichita, KS)
4. Stearns Catalog No. 5311PFD (Coleman Company Inc, Wichita, KS)
5. Kent Sporting, Near Shore Buoyant Vest, Type II PFD (Kent Sporting Goods Co, Inc, New London, OH)

The sweating thermal manikin Nemo at NCTRF has 20 independently heated and sweating thermal zones. The manikin is covered with a fabric skin layer to distribute water over its surface. The set points for water flow in each zone are adjusted to keep the manikin skin saturated. A computer program controls, records data, and displays real time numerical data and graphical plots of section temperatures. The software also calculates thermal resistances, evaporative resistances and power input into the manikin.

Thermal and evaporative resistances for each PFD were measured on the sweating thermal manikin according to the procedures of ASTM F1291 and ASTM F2370 respectively. For thermal resistance tests, the manikin surface temperature was set to 35ºC and climatic chamber conditions were controlled at 25ºC, 50% relative humidity with a 0.4 m/sec air velocity. For evaporative resistance tests, the manikin skin temperature was set to 35ºC and the manikin skin was fully saturated. The environmental chamber conditions were 35ºC, 40% relative humidity with a 0.4 m/sec air velocity. After the manikin reached steady state, all skin temperatures, power inputs and environmental conditions were recorded for 30 minutes. Manikin tests were repeated three times with each PFD. The data was used to calculate thermal and evaporative resistances in air.

Immersion tests were conducted in the hydro-environmental climatic chamber at NCTRF. The manikin was immersed in the water, as shown in Figure A1. The manikin skin temperature was set to 30ºC and water temperature was set to 28.5 ºC. After the manikin reached steady state, all skin temperatures, power inputs and water temperatures were recorded for 30 minutes. Manikin immersion tests were also repeated three times. The immersion manikin data was used for calculation of thermal resistances during immersion.

Figure A1 Nemo in climatic chamber (left), and water tank (right) with Stearns Type I PFD

RESULTS

Table A1 lists thermal insulation (Clo), and evaporative resistance (m^2Pa/W) of the PFDs in air. The nude manikin value is 0.56 clo for thermal resistance and 14.42 m^2Pa/W for evaporative resistance. Table A2 lists the immersion (water) thermal insulation of PFDs. The nude manikin value during immersion is 0.01 clo.

Table A1: Thermal Insulation and Evaporative Resistance for air exposure

	Thermal Resistance (clo)		Evaporative Resistance (m^2Pa/W)	
Personal Floatation Devices (PFD)	**Whole Body**	**Torso**	**Whole Body**	**Torso**
Etransport PFD	0.57	0.82	19.56	41.95
Stearns Work Vest PFD	0.57	0.77	18.78	36.79
Stearns Type I PFD Model No.429-06, Catalog No.1600	0.58	0.84	19.53	46.85
Stearns Catalog No. 5311 PFD	0.59	0.93	20.65	54.18
Kent Sporting, Near Shore Buoyant Vest, Type IIPD	0.55	0.67	18.07	28.97

Table A2: Thermal Insulation during Water Immersion

	Thermal Resistance (clo)	
Personal Floatation Devices (PFD)	**Whole Body**	**Torso**
Etransport PFD	0.015	0.020
Stearns Work Vest PFD	0.015	0.019
Stearns Type I PFD Model No.429-06, Catalog No.1600	0.016	0.020
Stearns Catalog No. 5311 PFD	0.016	0.026
Kent Sporting, Near Shore Buoyant Vest, Type IIPD	0.012	0.012

DISCUSSION

Thermal Manikin testing shows that the total (all zones) thermal insulation value (clo) of all PFDs are similar. Since the PFDs cover only the torso region, thermal insulation values, evaporative resistance and immersed clo values of the torso region are also provided in Table A1 and A2. Etransport PDF, Stearns Work Vest PDF, and Stearns Type I PFD Model No.429-06 were very similar in terms of thermal insulation, evaporative resistance and immersed clo. Stearns Catalog No. 5311 PDF covers more of the torso than the other tested PFDs and hence has the highest clo and immersed clo values and the highest evaporative resistance. In contrast, the Kent Sporting, Near Shore Buoyant Vest covers less of the torso relative to the other PFDs and hence has a lowest clo evaporative resistance values.

CONCLUSION

As the insulation provided by PFD were all very low and similar to the nude manikin values, it is not necessary to add their values to the current ensemble list in PSDA.

Figure A2 Etransport

Figure A3 Stearns work vest

Figure A4 Stearns Type I PFD Model No.429-06, Catalog No.1600

Figure A5 Stearns Catalog No. 5311

Figure A6 Kent Sporting, Near Shore Buoyant Vest, Type II PFD