Lifeboat and life raft diminished occupancy capacity study

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Lifeboat and Life Raft Diminished Occupancy Capacity Study

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SUMMARY

This report describes a study aimed at determining the relative diminished occupant capacity of lifeboats and life rafts among individuals wearing personal protective equipment (PPE) while onboard cruise ships. The experiment was designed to establish the impact of PPE on occupancy by examining changes in anthropometric measures as participants donned various clothing ensembles (i.e. levels of PPE). The results of this study suggest that PPE can have an impact on the occupant capacity of lifeboats and life rafts. Donning various forms of PPE can increase anthropometric dimensions to the point that they no longer align with the IMO-SOLAS standards regarding the amount of space available per person onboard survival crafts.

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March 2012

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EXECUTIVE SUMMARY

This report describes a study aimed at determining the relative diminished occupant capacity of lifeboats and life rafts among individuals wearing personal protective equipment (PPE) while onboard cruise ships. The experiment was designed to establish the impact of PPE on occupancy by examining changes in anthropometric measures as participants donned various clothing ensembles (i.e. levels of PPE).

Trials were conducted in October 2011 at the National Research Council – Institute for Ocean Technology (NRC-IOT) in St. John's, Newfoundland and Labrador, Canada. Individual anthropometric measures were taken per participant (n = 20) at three sites (shoulder breadth, standing hip breadth, and sitting hip breadth). Measurements of randomly assigned groups of participants were also taken in standing and sitting positions. These group measurements were taken with participants aligned shoulder-to-shoulder and their backs flush against a long wall. Both the individual and group measurements were repeated with participants wearing three different clothing ensembles and levels of PPE (base clothing, thermal cruise wear, and certified marine abandonment suits). In addition, several special cases were investigated in which groups of the smallest and largest participants were measured, along with one trial in which the total complement of participants was examined.

Previous work (Kozey *et al*, 2009) has looked at the impact of human anthropometrics and PPE on space requirements among a group of offshore workers stationed on Atlantic Canadian installations. With the aim of expanding on this work, the objective of this study was to assess how different forms of PPE affect the occupant capacity of lifeboats and life rafts used on cruise ships operating in arctic waters with members of the general population onboard. After individual and group anthropometric means were calculated, these values were compared to existing anthropometric databases (CAESAR, 2003) and maritime occupancy regulations (International Maritime Organization Safety of Life at Sea Conference, 1974, as amended) to determine if the addition of PPE would decrease the rated occupant capacity of survival craft.

The results of this study suggest that PPE can have an impact on the occupant capacity of lifeboats and life rafts. Donning various forms of PPE can increase anthropometric dimensions to the point that they no longer align with the IMO-SOLAS standards regarding the amount of space available per person onboard survival crafts. Similar trends were seen among workers in the Newfoundland and Labrador offshore area (Kozey, 2009) and general North American populations (CAESAR, 2003). Therefore, if maritime regulations relating to survival craft occupant capacities are not made adaptable (i.e. fit-for-purpose) to the region in which they are implemented, cruise ships operating in northern waters may be ill-equipped to deal with large scale EER events that require the deployment of these vessels.

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GLOSSARY

cm	Centimeters (distance)
EER	Escape, evacuation, and rescue
IMO	International Maritime Organization
IOT	Institute for Ocean Technology
ISO	International Organization for Standardization
LSA	Lifesaving appliance
n	Sample size
NRC	National Research Council Canada
PPE	Personal protective equipment
REB	Research Ethics Board
SAE	Society of Automotive Engineers
SD	Standard deviation
SOLAS	Safety of Life at Sea
TC	Transport Canada
TEMPSC	Totally enclosed motor propelled survival craft
TR	Technical Report

1 INTRODUCTION

1.1 Background

In recent years, air and maritime traffic in the Arctic has increased, with arctic cruise ship tourism being a significant contributor (Wallace, 2012). Cruise ships have capacities ranging from hundreds to thousands of passengers and can remain at sea for weeks at a time. With this increase in traffic comes a higher likelihood that a major maritime disaster could occur in the Canadian Arctic, some of which may require mass rescue. Due to the remoteness of these marine operations, it is acknowledged that rescue could take up to five days (IMO, 2006). This highlights the importance for survivors to be able to rely on their group and personal survival equipment to sustain themselves for several days while they await rescue.

Previous work by Kozey *et al* (2009) looked at the impact of human anthropometrics and PPE on space requirements among a group of offshore workers in Atlantic Canada. Although this work offered important insight into some of the characteristics of a major component of the transient offshore population, its scope needs to be increased to include members of a broader population that are now making their way into northern waters via cruise ships. Therefore, with the aim of expanding on past work, this study was designed to provide an assessment of how different forms of personal protective equipment (PPE) affect the occupant capacity of survival craft used on cruise ships operating in arctic waters with members of the general population onboard.

1.2 Diminished Capacity Study

In this phase of the project quantitative data was used to determine if donning various ensembles of clothing and PPE would result in a diminished occupant capacity within lifeboats and life rafts, two commonly used lifesaving appliances (LSAs) used to evacuate cruise ships. In arctic environments, LSAs typically take the form of totally enclosed motor propelled survival crafts (TEMPSC) and approved marine abandonment suits. TEMPSC provide protection to their occupants during escape, evacuation, and rescue (EER) events that may take place in the harsh external environmental conditions that are common to northern waters. The PPE that are issued to cruise ship passengers can be bulky since they are intended to provide either flotation (lifejackets) or thermal insulation (winter outerwear). Although approved marine abandonment suits are widely regarded as providing the best chance for survival during EER scenarios in cold, wet arctic conditions, and are recommended for every passenger by the International Maritime Organization's (IMO) Guidelines for Ships Operating in Polar Waters (2010), they are not a mandatory requirement for operators. For this reason, the research team investigated the diminished occupant capacity of lifeboats and life rafts caused by standard cruise ship wear, as well as commercially available Transport Canada (TC) approved marine abandonment suits. Anthropometric data was collected from participants wearing different clothing ensembles that will help to establish the potential reduced occupant capacity of life rafts and lifeboats due to PPE.

1.3 Study Objective

This portion of the project has the following objective:

- To determine the relative diminished occupant capacity of lifeboats and life rafts given the increase in anthropometric values due to PPE among the general population.

2 METHODOLOGY

2.1 Ethics

The National Research Council (NRC) Research Ethics Board (REB) approved the study protocol (NRC REB # 2011-21). Upon receiving ethical approval, recruitment commenced in September of 2011 and the testing was carried out on October 19, 2011 (Appendix 1). Trials took place at the National Research Council of Canada Institute for Ocean Technology (NRC-IOT) in St. John's, Newfoundland and Labrador, Canada (+47°34'26"N, -52°44'13"W). All participants gave their written informed consent prior to testing (Appendix 2) and completed a medical history questionnaire (Appendix 3).

2.2 Recruitment

A sample size (*n*) of twenty healthy individuals (6 female, 14 male) between 19-48 years of age was included in the study. On the day of testing, all participants came wearing the requested base clothing ensemble (cotton socks, denim jeans and a long-sleeved cotton shirt). Several standard demographical and anthropometric measures were taken prior to testing (Table 2.1).

Table 2.1: Participant demographical and anthropometric information.

n = 20	Age (years)	Height (cm)	Weight (kg)	Body Fat (%)*
Mean	23.2	175.4	79.1	21.8
SD	6.6	9.20	18.93	8.37

*Body fat (%) as determined by the bioelectrical impedance scale ("non-athlete" setting).

2.3 Test Setup and Facilities

The study was conducted in a laboratory environment at the NRC-IOT facility. The trials took place in a long, wide hallway that was set-up to accommodate the measuring of subjects in standing (Figure 2.1) and sitting (Figure 2.2) positions. While in base clothing (Ensemble A), additional anthropometric measurements were taken from individuals at three anatomical sites: shoulder width (A), hip width while standing (B), and hip width while sitting (C) (Figure 2.3). The process was then repeated after the participants donned a soft pile fleece jacket and pants over top of the base clothing and a soft fabric lined nylon outer jacket and pants over top of both those layers (Ensemble B) (Figure 2.4). The process was repeated a final time with the outer layer of nylon clothing replaced with an insulated, TC approved marine abandonment suit (Whites Marine, Victoria, British Columbia, Canada) (Ensemble C) (Figure 2.5).

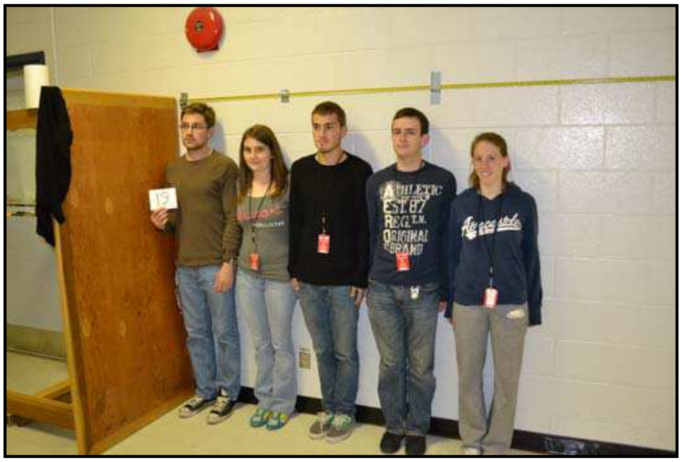

Figure 2.1: Standing measurement setup.

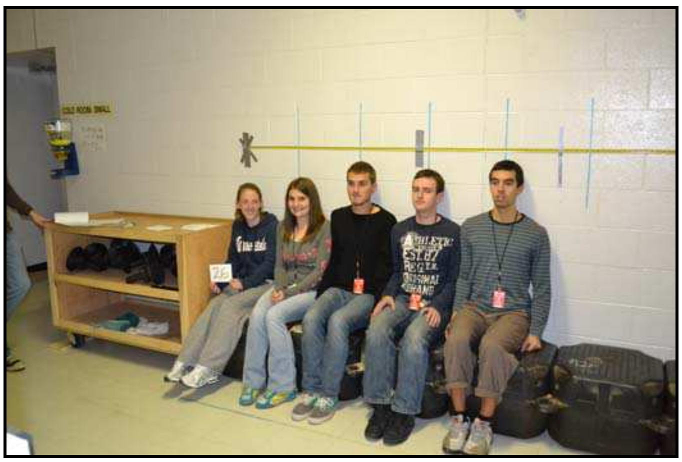

Figure 2.2: Sitting measurement setup.

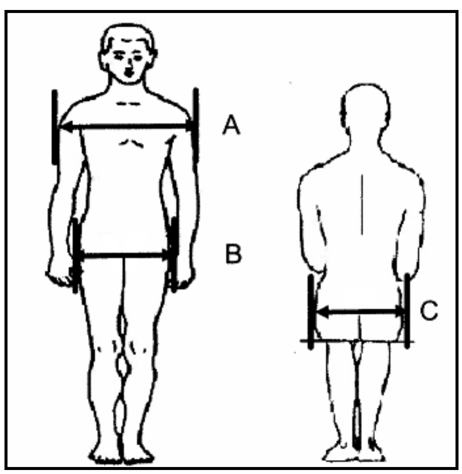

Figure 2.3: The three anthropometric measurement sites (Van Cott and Kinkade, 1972)

2.4 Equipment and Instrumentation

2.4.1 Clothing Ensembles

The three clothing ensembles (A, B, and C, as described below) were intended to represent varying levels of PPE and are comprised of several types of attire. First, Ensemble A (Cabin Wear) consisted of basic clothing that may be representative of the kind worn by passengers onboard an arctic vessel or cruise ship while in covered areas with heating and ventilation (e.g. dining halls, personal quarters). Second, Ensemble B (Deck Wear) consisted of fleece thermal-wear and windproof outerwear that would likely be worn while on deck and other exposed areas. Lastly, Ensemble C (Abandonment Wear) consisted of an insulated Transport Canada certified marine abandonment suit that may be part of the operator's EER protocols.

- Ensemble A – Cabin Wear: base layer (cotton socks, denim jeans and long-sleeved cotton shirt)
- Ensemble B – Deck Wear: base layer, second layer (soft pile fleece jacket and pants), third layer (wind proof winter jacket and pants) (Figure 4)

Figure 2.4: Soft pile fleece jacket and pants (left), and wind proof winter jacket and pants (right).

- Ensemble C – Abandonment Wear: base layer, second layer (soft pile fleece jacket and pants, third layer (insulated marine abandonment suit) (Figure 5)

Figure 2.5: Transport Canada Certified marine abandonment suit

2.4.2 Measurement Equipment

A bioelectrical impedance scale was used to measure body fat percentage. The subjects stood bare foot on the device as it passed a slight electric current through their body to estimate body fat percentage. The participants were not able to feel this current and it caused them no discomfort. This unit also contains a scale that gave the participant's weight (Figure 2.6).

Figure 2.6: Bioelectrical impedance scale.

Skin fold calipers were used to measure skin fold thickness at four anatomically landmarked sites (Figure 2.7). In order to ensure measurements were as accurate as possible, the subjects were escorted individually to a private room where they were asked to remove their t-shirts so that the calipers could be applied directly to the areas of interest. The measured values were then totaled and body fat percentage was calculated using the Durnin-Womersley method (1974).

Figure 2.7: Skin Fold Calipers

A modified anthropometer (Figure 2.8), wider than a traditional Harpenden anthropometer and similar to that used by Kozey et al (2009), was used to obtain shoulder and hip measurements (Figure 2.3). The extended reach of this device allowed for measurements to be taken on subjects while wearing each of the three clothing ensembles, including the relatively bulky marine abandonment suits.

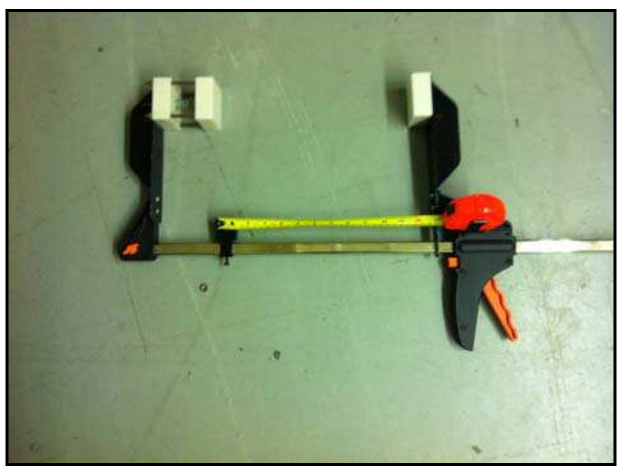

Figure 2.8: Modified Anthropometer.

A wooden carpenter’s square (Figure 2.9, left) was used to assist in the group measurements. It was placed vertically against the last subject’s shoulder perpendicular to the wall and aligned so that the upper arm of the board bisected the wall-mounted measuring tape that was affixed above the subjects (Figure 9, right). Since these measurements consisted of a single value taken flush with the shoulder of the last participant (i.e. there was no hip breadth measurement taken) they are referred to as “collective shoulder breadths”.

Figure 2.9: Wooden carpenter's square (left), and the square being used to obtain group anthropometric measurements (right).

2.5 Trial Matrix

During the test program a total of 44 tests took place (Table 2.2, Appendix 4). These tests included separate measurements of four randomly assigned groups of participants in sitting and standing positions while wearing different clothing ensembles. This same set of tests was repeated on a group consisting of the five largest participants followed by a group of the five smallest participants. Next, a set of tests was conducted measuring a random group of 12 participants in all three clothing ensembles in sitting and standing positions. Twelve individuals were involved because this was the maximum number of marine abandonment suits available to the research team at the time. Finally, two tests were carried out to measure all 20 participants in Ensemble A (base clothing) only, one sitting and one standing.

Table 2.2: Trial matrix.

Trial #	Group	# of Participants	Ensemble	Notes
1-6	A	5	*A_1 A_2 B_1 B_2 C_1 C_2	-
7-12	B	5	B_1 B_2 C_1 $C_2$$A_1$ A_2	-
13-18	C	5	C_1 C_2 A_1 A_2 B_1 B_2	-
19-24	D	5	A_1 A_2 C_1 $C_2$$B_1$ B_2	-
25-30	E	5	A_1 A_2 B_1 B_2 C_1 C_2	Smallest Individuals
31-36	F	5	C_1 C_2 A_1 A_2 B_1 B_2	Largest Individuals
37-38	All	20	A_1 A_2	All Participants
39-44	G	12	A_1 A_2 B_1 B_2 C_1 C_2	**Maximum Capacity

* 1 = Standing, 2 = Sitting, ** There were 12 marine abandonment suits available to the research team, and therefore the "maximum capacity" was limited to 12 individuals.

3 EXPERIMENTAL RESULTS

3.1 Overall Individual Measurements

The individual participant measurements obtained using the modified anthropometer are summarized in Table 3.1. The full individual measurement dataset is included in Appendix 5. Overall, there was an increase in minimum, maximum, and mean measured values across all variables (hips standing, hips sitting, and shoulders) when moving from Ensemble A to Ensemble B and from Ensemble B to Ensemble C. Also, there were considerable percent increases in the mean values when comparing the measured hip and shoulder breadths of Ensemble A to both Ensemble B and Ensemble C.

Table 3.1: Individual hip and shoulder breadth measurements by ensemble, including the percent increase relative to Ensemble A.

Ensemble	Site	Min (cm)	Max (cm)	Mean (cm)	*SD*	% Change
A	**Hips (Standing)**	34.5	48.4	38.7	3.10	-
	Hips (Sitting)	36.0	51.0	40.8	3.13	-
	Shoulders	41.5	54.3	48.1	3.93	-
B	**Hips (Standing)**	36.2	49	39.8	2.92	+ 2.8
	Hips (Sitting)	38.5	52.3	42.7	3.22	+ 4.5
	Shoulders	45.1	55.9	50.9	3.72	+ 5.4
C	**Hips (Standing)**	37.7	48	42.2	2.77	+ 8.2
	Hips (Sitting)	38.4	53.1	44.9	2.91	+ 9.3
	Shoulders	46.5	56.4	52.5	2.81	+ 8.4

3.2 Group Measurements

The group measurements obtained using the wall-mounted measuring tape and carpenter's square are summarized in Table 3.2. The full group measurement dataset is included in Appendix 6. As would be expected based on the individual measurements, the overall breadth measurements of randomly assigned subject groups (A-D) increased when moving from the base clothing (Ensemble A) to the other two ensembles (B and C). Similarly, separate groupings of the five smallest (E), five largest (F), and maximum number of subjects (G) yielded measurements with comparable percent increases.

Table 3.2: Collective shoulder breadth measurements by ensemble, including the percent increase relative to Ensemble A.

Group	Ensemble	Total Breadth (cm)	Average Breadth (cm)	*SD*	% Change
Standing					
A-D (Random Assignment)	A	-	225.3	17.57	-
	B	-	252.6	12.72	+ 10.9
	C	-	274.1	8.73	+ 17.8
E (Smallest Individuals)	A	195.1	-	-	-
	B	226.0	-	-	+ 13.7
	C	228.8	-	-	+ 14.7
F (Largest Individuals)	A	257.1	-	-	-
	B	275.3	-	-	+ 6.6
	C	294.5	-	-	+ 12.7
G (Maximum Capacity)	A	529.4	-	-	-
	B	598.0	-	-	+ 11.5
	C	635.0	-	-	+ 16.6
Sitting					
A-D (Random Assignment)	A	-	217.4	13.90	-
	B	-	236.8	12.13	+ 8.2
	C	-	250.5	15.05	+ 13.2
E (Smallest Individuals)	A	196.1	-	-	-
	B	217.5	-	-	+ 9.8
	C	223.5	-	-	+ 12.3
F (Largest Individuals)	A	242.1	-	-	-
	B	260.0	-	-	+ 6.9
	C	282.4	-	-	+ 14.3
G (Maximum Capacity)	A	518.5	-	-	-
	B	566.0	-	-	+ 8.4
	C	602.0	-	-	+ 13.9

3.3 Comparisons To Existing Datasets and Regulations

As a means of reinforcing the validity and reliability of this work, as well as highlighting the potential impact reduced occupancy due to PPE may have on general populations onboard cruise ships in arctic regions, the results have been compared and applied to the findings of similar studies. In 2009, Kozey *et al* investigated the effects of human anthropometrics and PPE on space requirements for offshore workers in Atlantic Canada. More broadly, the Society of Automotive Engineers (SAE, 2003) published their CAESAR anthropometric database that includes measurements taken from thousands of North Americans. Again, both of these datasets are used to establish whether or not the sample studied in this project is representative of a broader general population. They will also help determine how reduced occupancy might affect vessels operating in arctic waters by increasing the number of required survival craft onboard or by decreasing the number of workers and passengers that can accommodated safely.

The data from Kozey *et al* (2009) and the CAESAR database (2003) are included along with the Ensemble A values in Table 3.3. Although Kozey *et al* (2009) examined offshore workers across Atlantic Canada, only the data obtained from measurements of workers from Newfoundland and Labrador is presented. In most instances, both standing and sitting hip measurements were taken across the three datasets, and it was found that the seated values were consistently greater than those taken while standing. Since these values were greater, along with the fact that lifeboat occupants are restricted to their individual seats when the craft is loaded to its full complement, the seated hip measurements are seen as being the limiting factor when assessing survival craft seating capacity and will therefore be more thoroughly examined in this paper.

Table 3.3: Anthropometric measurements (cm) of individuals wearing similar clothing ensembles taken from various datasets.

Source	**TR-2012-01**		**Kozey *et al***		**CAESAR**	
	Ensemble A		**Work Clothes**		**Base Clothing**	
Site	**Mean**	***SD***	**Mean**	***SD***	**Mean**	***SD***
Shoulder	48.1	3.93	51.4	4.62	46.1	4.85
Hips (Standing)	38.7	3.10	36.8	3.12	-	-
Hips (Sitting)	40.8	3.13	38.6	3.15	39.6	4.40

As may be seen in Table 3.3, mean shoulder and seated hip breadths were found to be comparable across all studies, thereby suggesting that the sample examined in this study was representative of a general population that may be found on arctic vessels and cruise ships. Individual breadth measurements were then compared to the 430mm (minimum) space allotted per person onboard lifeboats and life rafts set by the IMO Safety of Life at Sea (SOLAS) Convention (1974, as amended) (Table 3.4). Although both sites showed measurements greater than 430mm, shoulder breadths most consistently showed greater values than the space provided by the IMO standard.

Table 3.4: The number and percentage of individuals whose breadth measurements were greater than the 430mm space allotted per person by IMO-SOLAS (1974).

Source	**Ensemble or Clothing**	**Site**	**Number of Subjects**	**Number Above IMO**	**% Above IMO**
TR-2012-01	A	Hips (Sitting)	20	3	15.0
		Shoulders		18	90.0
	B	Hips (Sitting)		6	30.0
		Shoulders		20	100.0
	C	Hips (Sitting)		17	85.0
		Shoulders		20	100.0
Kozey et al, 2009	Work Clothes	Hips (Sitting)	84	8	9.5
		Shoulders		83	98.8
CAESAR, 2003	Base Clothing	Hips (Sitting)	2388	422	17.7
		Shoulders	2391	1638	68.5

Next, to investigate the impact PPE may have on occupancy among this population, the mean percent increases when moving from Ensemble A to Ensemble B (+4.5%) and from Ensemble A to Ensemble C (+9.3%) were applied to the mean breadth measurements obtained from participants in base clothing (Table 3.5). With the additional bulk added by the respective forms of PPE, mean shoulder and seated hip breadths are now as much as 27.7% greater than the 430mm IMO space provision per occupant when wearing Ensemble B, and 33.4% greater in Ensemble C.

Table 3.5: The predicted percent increase across the populations included in the work by Kozey et al (2009) and the CAESAR database (2003) based on the relative percent increase found in TR-2012-01 when moving from base clothing (Ensemble A) to PPE (Ensemble B and Ensemble C).

Source	**Site**	**Mean (cm)**	**% Increase Due to PPE**		**% Increase Relative to IMO**
			Ensemble	**Adjusted Mean (cm)**	
TR-2012-01	Hips (Sitting)	40.8	B (+4.5)	42.6	- 0.9
			C (+9.3)	44.6	+ 3.7
	Shoulders	48.1	B (+4.5)	50.3	+ 17.0
			C (+9.3)	52.6	+ 22.3
Kozey et al, 2009	Hips (Sitting)	42.7	B (+4.5)	44.6	+ 3.7
			C (+9.3)	46.7	+ 8.6
	Shoulders	50.9	B (+4.5)	53.2	+ 23.7
			C (+9.3)	55.6	+ 29.3
CAESAR, 2003	Hips (Sitting)	44.9	B (+4.5)	46.9	+ 9.1
			C (+9.3)	49.1	+ 14.1
	Shoulders	52.5	B (+4.5)	54.9	+ 27.7
			C (+9.3)	57.4	+ 33.4

4 DISCUSSION

Currently, maritime regulations pertaining to occupant capacities of survival craft may be inadequate for cruise ships operating in arctic waters. In turn, this may restrict the ability of these survival crafts to ensure the safe evacuation of all passengers during an EER event. The results of the individual participant measurements show that donning thermal deck wear (Ensemble B) increased mean seated hip breadth measurements by 4.5% and mean shoulder breadth measurements by 5.4%. Participants wearing marine abandonment suits (Ensemble C) saw anthropometric increases of 9.3% and 8.4% in these two areas, respectively (Table 3.2). The randomly assigned group measurements also showed collective anthropometric increases that would impact occupant capacities (Ensemble B – 10.9% standing, 8.2% sitting; Ensemble C – 17.8% standing, 13.2% sitting) (Table 3.3). The applicability of these findings was validated by the fact that the mean anthropometric dimensions of the population studied (n = 20) were comparable to the larger datasets assessed by Kozey *et al* (2009) (n = 84) and the CAESAR database (2003) (n = 2391) (Table 3.4). Therefore, it may be suggested that the sample population included in this study is indeed representative of the general North American population. In isolation these percentages may seem like relatively insignificant values, but if one were to consider that certain models of IMO-SOLAS approved TEMPSC can carry hundreds of occupants, the implications of these increases become more apparent. These increases would compound, if in an emergency situation, thousands of cruise ship passengers boarded dozens of lifeboats and/or life rafts. Consequently, this type of scenario could lead to an underestimate of the number of vessels required to facilitate the evacuation and escape of all passengers.

An important factor that may influence regulations addressing anthropometric standards is the site of the limiting measurement. Although life rafts may theoretically provide slightly more room for adjustment, a lifeboat with a permanent and non-adjustable seating arrangement, such as a TEMPSC, forces occupants to sit in a specific orientation. Both free fall and davit launch lifeboats come equipped with seatbelts that restrain the occupants' shoulders flush with the perimeter walls or seatbacks (depending on the model) of the vessel. In light of this, and the fact that the data presented in this study has shown that shoulder breadth is typically wider than hip breath, shoulder breadth should be the limiting factor when determining the minimum amount of space available per person onboard survival craft. It is not obvious which measurement sites were used to derive the existing IMO-SOLAS standards (1974, as amended); however, it is clear that the 430mm of space provided per person is inadequate. Depending on the type of clothing or PPE worn, this study, the work by Kozey et al (2009), and the CAESAR database (2003), show that between 15% and 85% had seated hip breadths above 430mm, and between 68.5% and 100% had shoulder breadths above the same value (Table 6). Based on these findings, there may be a need to reassess the minimum standard prescribed by IMO and to ensure that future regulations are based on breadth measurements made at the shoulder.

Lastly, it is important to take into account the anthropometric variability that exists between populations from different regions of the world. For example, there are considerable differences in stature when comparing an average North American to an average European or Asian (Table 4.1). The specific numerical discrepancies are beyond the scope of this study; however, the fact that they exist highlights the need for fit-for-purpose (i.e. performance based) regulations. Since maritime governing bodies are charged with developing and implementing minimum operational and safety standards, there is sometimes a tendency to rely heavily on broad-scoped prescriptive regulations that apply to all areas of operation. While this approach may be suitable for some aspects of marine safety, it is not appropriate in the case of determining survival craft occupancies. The demographics of any given cruise ship population will likely be highly variable, and as such the only failsafe means of ensuring adequate occupancy would be to develop per person space regulations that would accommodate the high anthropometric extremes. In addition, complementary methodologies would need to be established to monitor and reassess the regulations as the anthropometric dimensions of populations change over time.

Table 4.1: Anthropometric dimensions of three international populations (ISO, 2010).

	Age (years)		Height (mm)		Shoulder Breadth (mm)		Seated Hip Breadth (mm)	
Country	**Male**	**Female**	**Male**	**Female**	**Male**	**Female**	**Male**	**Female**
Italy	38.0	36.0	1716.0	1592.0	460.0	409.0	350.0	359.0
Japan	41.6	40.5	1695.6	1570.3	458.8	407.4	358.8	360.5
USA	39.3	39.8	1766.6	1637.9	490.4	431.4	376.3	410.4

5 CONCLUSION AND RECOMMENDATIONS

Overall, the results of this study suggest that PPE can have a significant impact on the occupant capacity of lifeboats and life rafts. Donning various forms of PPE has been shown to increase anthropometric dimensions to the point that there is a considerable discrepancy between the current IMO-SOLAS standard and what would be required for arctic cruise ship passengers wearing this equipment. Similar trends were seen among workers in the Newfoundland and Labrador offshore area (Kozey, 2009) and general North American populations (CAESAR, 2003). If maritime regulations relating to survival craft occupant capacities are not made adaptable (i.e. fit-for-purpose) to the region in which they are implemented, cruise ships operating in northern waters may be ill-equipped to deal with large scale EER events that require the deployment of these vessels.

Based on the results of this study it is recommended that:

1) The amount of space allotted per person onboard lifeboats and life rafts is not appropriate given the increase in anthropometric dimensions due to the donning of PPE. As a result, the existing ratio of survival crafts to passengers onboard vessels needs to be adjusted. These adjustments could involve either increasing the number of lifeboats and life rafts (i.e. a retrofit to supply more survival crafts, meaning fewer people per craft), or decreasing the overall capacity of the main ship (i.e. having fewer people onboard would mean the existing survival crafts could accommodate all passengers during an EER event). This change could be applied to all vessels, regardless of their area of operation; however, it is most necessary for those operating in arctic waters because these regions require the bulkiest PPE (e.g. thermal and windproof outerwear, marine abandonment suits).

2) Breadth measurements used to determine the space provided per person onboard survival craft should be taken at the shoulders. This is because these measurements tend to be larger than those at the hip, and due to the seating orientations within some of these vessels (e.g. TEMPSC) shoulder breadth should be seen as the limiting factor.

3) Further research should be conducted to investigate the impact PPE may have on occupant populations in different regions of the world (i.e. outside of North America). This work could be based on the protocols developed and implemented by NRC-IOT throughout this study.

4) Protocols should be set in place to ensure that safety regulations specifically pertaining to occupant anthropometrics are reviewed and adjusted on a regular basis. Additional research may be necessary to determine the specific timeframe in which these standards should be reassessed.

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APPENDIX 1

Recruitment Poster

NRC·CNRC
Institute for
Ocean Technology

RECRUITMENT FOR SCIENTIFIC RESEARCH PROJECT

“Lifeboat and Life Raft Diminished Occupant Capacity Study”
NRC-REB: 2011-21
Contribute to the safety of ships travelling in polar waters.

Who can participate?

- Healthy individuals who are between 19-60 years old

Who cannot participate?

Anyone who has:

- any heart or respiratory illness
- latex allergies

What will be done: Individual and group measurements will be taken for the purposes of understanding human physical variations in 3 different clothing ensembles.

Duration for each scenario: You will be required to participate in several tests in different clothing during one day of testing for a total of approximately 4 hours.

Where: National Research Council Canada Institute for Ocean Technology, St. John’s, NL (on MUN campus next to the Engineering building, S.J. Carew)

Honorarium: You will be given $50 for participating.

Recruitment for the study will start on 6 October 2011. If you are interested in volunteering, please contact Lise Petrie at the NRC Institute for Ocean Technology:

772-7778 (M-F 8:00-4:00) or Lise.Petrie@nrc.gc.ca

772-3927 (M-F 8:00-4:00) or Stephanie.Power-Macdonald@nrc.gc.ca

APPENDIX 2

Consent Form

NRC·CNRC
From Discovery to Innovation...

Science at work for Canada

PART 3

Consent Form

Project Title
TR 2012-01: Lifeboat and Life Raft Diminished Occupant Capacity Study

Why are you being given this form?
You are being asked to participate in a study designed to investigate the effects of different clothing ensembles on the seating capacity of various rescue crafts used in the Arctic. The information in this form is intended to help you understand exactly what we are asking of you so that you can decide whether or not you want to participate in this study. Please read this consent form carefully and ask all the questions you might have before deciding whether or not to participate or in this study. Please take whatever time you need before reaching a decision, and consult with others as you wish. Your participation in this study is entirely voluntary, and a decision to not participate will not in any way be used against you.

Project team and sponsors
John Monk- Principal Investigator – National Research Council of Canada – Institute for Ocean Technology
Jonathan Power – National Research Council of Canada – Institute for Ocean Technology
Lise Petrie – National Research Council of Canada – Institute for Ocean Technology

Transport Canada (TC) and SAR-NIF are the sponsors for this project.

Why is the study being done?
In recent years, air and maritime traffic in the Arctic has increased, especially in cruise ship tourism. Cruise ships can carry hundreds to thousands of passengers. With increased traffic, there is a higher probability that a major air or maritime disaster could occur in the Canadian Arctic. Current international standards base the capacity of lifeboats and life rafts on occupants wearing clothing such as jeans, a t-shirt, and a lifejacket. There is currently a lack of knowledge to determine if various clothing ensembles or Personal Protective Equipment (PPE) could result in a reduced occupant capacity for lifeboats and life rafts; life saving appliances commonly used to evacuate cruise ships. The PPE that is issued to cruise ship passengers can be bulky, either to provide flotation (e.g. lifejackets) or thermal insulation (e.g. winter jackets). Although an immersion suit is recommended for every passenger in the International Maritime Organisation (IMO) Guideline for “Ships Operating in Polar Waters”, it is not a mandatory requirement for operators. For this reason we will investigate if there is a reduced occupant capacity of lifeboats and life rafts when occupants wear standard cruise ship wear or an approved commercially available immersion suit.

What will you be asked to do?

Before starting the test program, you will be asked to complete a medical history questionnaire to determine your eligibility for this study (The medical history questionnaire is a separate form from this document). Pre-existing medical conditions may result in some people not being eligible for this study.

For these tests, you will be asked to wear a specific set of clothing to NRC-IOT. This set of clothing will include socks, jeans, and a long sleeved shirt.

After arriving at NRC-IOT, your gender, weight, height, body fat and age will be recorded.

Bioelectrical Impedance Test: A bioelectrical impedance scale will be used to measure your body fat percentage. You will stand bare foot on a device that looks like a scale. The device will pass a slight electric current through your body to estimate your body fat percentage. You will not be able to feel this current and it will cause you no discomfort.

Scale: A scale will be used to measure your weight. The scale is built into the bio-electrical impedance scale (mentioned above).

Skin Fold Thickness: Skin fold calipers will be used to measure your skin thickness and calculate your body fat percentage.

You will then be asked to stand against a wall while your shoulder width (A) and waist width (B) are measured (Fig. 1). Once these individual measurements are taken, you will be asked to don either one of two different clothing ensembles (see below) and participate in group measurements, where a group of participants will line up against a wall to have measurements taken (Fig. 2). This process will be repeated for each of the 3 clothing ensembles.

The clothing ensembles are as follows:

Base Clothing
- The jeans, t-shirt, and socks you will wear to the test session.

Ensemble A
- Helly Hansen soft pile fleece jacket (F4592) and pant (F6017)
- Helly Hansen Compass jacket (AJ301) and pants (U310)
- SOLAS lifejacket

Ensemble B
- Helly Hansen soft pile fleece jacket (F4592) and pant (F6017)
- An insulated immersion suit (Whites Adult universal immersion suit)

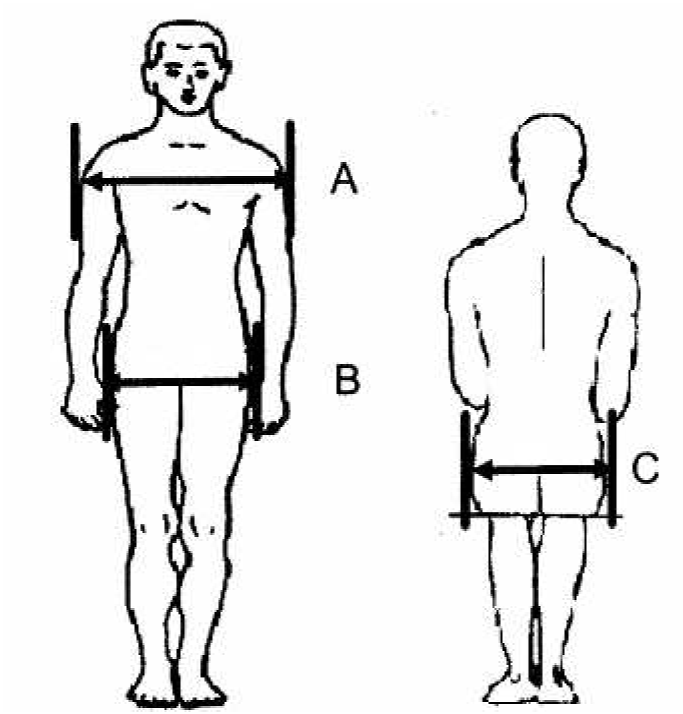

Figure 1. Measurement locations. Van Cott, H.P., and Kincaid, R.G. (eds) (1972) *Human engineering guide to equipment design*, U.S. Government Printing Office.

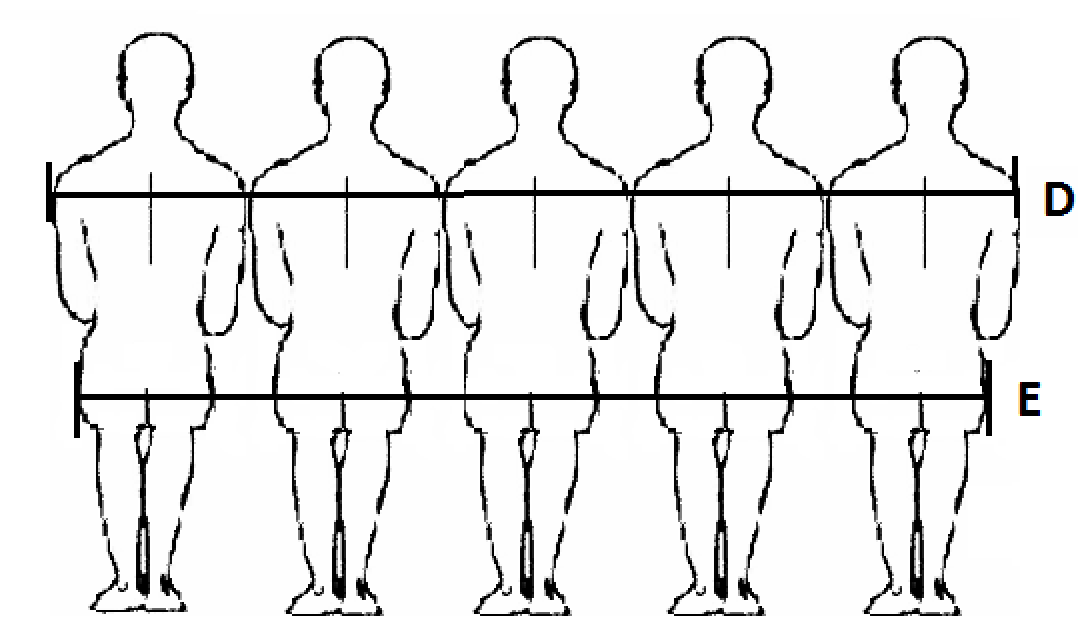

Figure 2. Locations of group measurements. Van Cott, H.P., and Kincaid, R.G. (eds) (1972) *Human engineering guide to equipment design*, U.S. Government Printing Office

Your entire time at NRC-IOT is expected to be about 4 hours.

Data and Information Collected From You During This Program:

- **Name and contact information**: To be taken on a separate form from all the others to generate a unique identifier number that will be used on all subsequent forms to allow only the research team to identify you. Also, you can provide the research team with contact information for another person in the event of injury or illness.
- **Medical questionnaire**: To be used to assess your eligibility for this study.
- **Physiological parameters**: Height, weight, body fat percentage, skin fold thickness. Height will be measured using a simple tape measure. Weight will be measured using a scale. Body fat percentage will be measured using a bioelectrical impedance scale. Skin fold thickness will be measured using skin fold calipers.
- **Photographs**: Non-identifiable photographs will be taken during the test program to capture the various groupings and clothing ensembles.

Potential harms / inconveniences / benefits

Discomforts:

It is possible that you may experience some discomfort due to the warmth of the clothing and/or immersion suit donned. This will be alleviated as soon as the clothing is removed.

Benefits:

Data collected from you in this experiment will be used to help refine current occupant capacity figures for life saving appliances such as lifeboats and life rafts.

Commercialization

At this time, there are no plans to produce a new product from this research project. If a product is indeed produced at a later date, you will not receive any financial benefit from it.

Privacy and confidentiality

All data, notes, and recordings are stored in a locked office at NRC-IOT and all information gathered from you will be confidential. Such data will be retained for at most 7 years.

Confidentiality will be respected. Unless required by law, no information that might directly or indirectly reveal your identity will be released or published without your specific consent to the disclosure.

NRC's Research Ethics Board will have access to the individual data, for monitoring purposes.

Compensation for injury, legal rights

By signing this consent form you are not waiving your legal rights.
Additionally, if you do suffer injuries while participating in this study, the medical care will be provided

to you at no cost to yourself.

Reimbursement of expenses/payments for participating

You will be given $50 CAD for your participation in this research project.

You have the right to change your mind

Your participation is entirely voluntary. You can to refuse to take part in this project at this point or withdraw from it at any time during the study, without incurring any penalty.

New information during the study

If any new information is discovered during the course of this research project that the research team feels may affect you, testing will be put on hold until you can be fully informed of it. Once the research team has briefed you with this new information, you may choose to remain in the study or withdraw freely.

Who to contact if you have any further concerns or questions?

Please contact either John Monk or Lise Petrie if you have any questions or concerns.

John Monk
Institute For Ocean Technology, National Research Council
Arctic Avenue
Office: (709) 772-7715
Email: John.Monk@nrc-cnrc.gc.ca

Lise Petrie
Institute For Ocean Technology, National Research Council
Arctic Avenue
Office: (709) 772-7775
Email: Lise.Petrie@nrc-cnrc.gc.ca

Ethics review

Since the National Research Council of Canada is supporting this study, which has been reviewed and approved by an NRC Research Ethics Board, any questions or concerns about the ethics of this study may be directed to Lea Maloney, OREB-CERO@nrc-cnrc.gc.ca , (613) 991-9920

Statement of consent – print and sign name

I, (printed name). . . . . ,

have read and understand the information given in this informed consent and all my questions have been answered to my satisfaction. I have had sufficient time to consider whether to participate in this study. I understand that my participation in this study is entirely voluntary and that I may withdraw from the study at any time without penalty.

I voluntarily consent to participate in this study.

Signature: . . . . Date:. . . . .

Team member who interacted with the subject

To the best of my knowledge, the information in this consent form, and the information that I, (printed name). . . . . have provided in the response to any questions, fairly represents the project. I am committed to conducting this study in compliance with all the ethical standards that apply to projects that involve human subjects. I will ensure that the subject receives a copy of this consent form.

Signature:. . . . . Date:. . . . .

APPENDIX 3

Medical History Questionnaire

Lifeboat and Life Raft Diminished Occupant Capacity Study (July 2011)
REB Ref no.: 2011-21
Medical History Questionnaire

Please complete the following medical history questionnaire to determine your eligibility for the study. For questions that ask if you have been diagnosed with a specific condition, answer yes if you have been diagnosed by a qualified health professional (e.g. your family doctor). All answers will be kept confidential.

1. Have you been diagnosed with heart disease? Y/N
2. Have you been diagnosed with high blood pressure? Y/N
3. Have you had a stroke? Y/N
4. Have you been diagnosed with a nerve and/or muscle disease? Y/N
5. Have you been diagnosed with a transmittable skin condition? Y/N
6. Do you have any respiratory (i.e. breathing) ailments or diseases? Y/N
   a.) If yes, what one(s)? ______________________________
7. Do you have any conditions that may be aggravated by increased anxiety that you could possibly experience during this research program? Y/N
8. Do you have any known food allergies? Y/N
9. Do you have any known latex allergies? Y/N
10. Do you have any condition that you think may exclude you from this study? Y/N
    a.) If yes, please list them

____
____
____
____
____
____

Research Team Member Signature: ____________________ Date:___________

APPENDIX 4

Trial Matrix

Appendix 4 – Trial Matrix

Trial	# of Participants	Type	Ensemble	Position
1	5	Random	A	Stand
2	5	Random	A	Sit
3	5	Random	B	Stand
4	5	Random	B	Sit
5	5	Random	C	Stand
6	5	Random	C	Sit
7	5	Random	B	Stand
8	5	Random	B	Sit
9	5	Random	C	Stand
10	5	Random	C	Sit
11	5	Random	A	Stand
12	5	Random	A	Sit
13	5	Random	C	Stand
14	5	Random	C	Sit
15	5	Random	A	Stand
16	5	Random	A	Sit
17	5	Random	B	Stand
18	5	Random	B	Sit
19	5	Random	A	Stand
20	5	Random	A	Sit
21	5	Random	C	Stand
22	5	Random	C	Sit
23	5	Random	B	Stand
24	5	Random	B	Sit
25	5	Smallest Individuals	A	Stand
26	5	Smallest Individuals	A	Sit
27	5	Smallest Individuals	B	Stand
28	5	Smallest Individuals	B	Sit
29	5	Smallest Individuals	C	Stand
30	5	Smallest Individuals	C	Sit
31	5	Largest Individuals	C	Stand
32	5	Largest Individuals	C	Sit
33	5	Largest Individuals	A	Stand
34	5	Largest Individuals	A	Sit
35	5	Largest Individuals	B	Stand
36	5	Largest Individuals	B	Sit
37	20	All Participants	A	Stand
38	20	All Participants	A	Sit
39	12	Max Capacity	B	Stand
40	12	Max Capacity	B	Sit
41	12	Max Capacity	C	Stand
42	12	Max Capacity	C	Sit
43	12	Max Capacity	A	Stand
44	12	Max Capacity	A	Sit

*There were 12 marine abandonment suits available to the research team, and therefore the "maximum capacity" was limited to 12 individuals.

APPENDIX 5

Individual Measurement Dataset

Appendix 5 – Individual Measurement Dataset

Participant Number	Ensemble A			Ensemble B			Ensemble C		
	Hips		Shoulders	Hips		Shoulders	Hips		Shoulders
	Stand (cm)	Sit (cm)	Stand (cm)	Stand (cm)	Sit (cm)	Stand (cm)	Stand (cm)	Sit (cm)	Standing (cm)
1	38.8	39.3	51.8	39.8	42.7	54.1	41.8	45	53.4
2	34.5	40.7	46	36.2	39.5	50.2	38.1	43.7	51.5
3	35.8	38.8	47.7	38.5	42.5	50.2	41	43.5	52.8
4	39.8	41.6	54.3	41.8	43.8	55.3	45	47.4	55.9
5	38.6	38.6	44.1	39.3	43.4	46	42.5	43.9	48.8
6	38.1	40.2	45.4	39.5	42.4	47.5	43.3	42.9	50.9
7	40.5	40.4	42.8	40.8	41.8	47	44.7	45	51
8	35.5	36.5	48	37.9	39.2	52	44.3	44.6	52.7
9	42.5	44.9	53	43.5	47.8	55.6	44.5	48	55.2
10	40	41.1	51.2	39.7	43	54.4	45	46.5	55.7
11	39	40.7	50.6	39.9	42.6	53.9	40.3	44.5	54.2
12	38.1	40.2	44.6	39.2	42.8	47.2	40.4	46.3	48
13	39.5	43.5	49.2	41.4	44.7	50.8	43.5	47	51.6
14	39.8	40.7	51.3	40.4	41	53.9	43.1	44.5	54
15	36.4	39.8	44.1	37.5	38.5	47	38.3	43.3	50.9
16	36.8	41	45.2	37	43	47.1	41.8	44.5	53.4
17	48.4	51	53.8	49	52.3	55.9	48	53.1	56.4
18	35.4	36	45.5	36.5	38.8	48.4	37.7	38.4	50
19	40.2	41.2	51.9	41.2	44.7	55.3	41.8	45.6	56.2
20	36.1	39.1	41.5	36.5	39.6	45.1	38.2	41.1	46.5
Mean	38.7	40.8	48.1	39.8	42.7	50.9	42.2	44.9	52.5
SD	3.10	3.13	3.93	2.92	3.22	3.72	2.77	2.91	2.81

APPENDIX 6

Group Measurement Dataset

Appendix 6 – Group Measurement Dataset

Trial Number	Total Measurement (cm)	Participants	Type	Ensemble	Status
1	236.0	1,3,4,6,12	Variable	A	Stand
2	221.9			A	Sit
3	256.2			B	Stand
4	243.8			B	Sit
5	264.5			C	Stand
6	251.6			C	Sit
7	255.9	7,8,9,14,19	Variable	B	Stand
8	246.0			B	Sit
9	279.0			C	Stand
10	267.0			C	Sit
11	234.6			A	Stand
12	229.8			A	Sit
13	231.5	10, 11, 13, 16, 17	Variable	A	Stand
14	220.5			A	Sit
15	264.0			B	Stand
16	238.0			B	Sit
17	283.5			C	Stand
18	253.0			C	Sit
19	199.1	2, 5, 15, 18, 20	Variable	A	Stand
20	197.5			A	Sit
21	234.4			B	Stand
22	219.3			B	Sit
23	269.2			C	Stand
24	230.5			C	Sit
25	195.1	5, 8, 15, 18, 20	Smallest Individuals	A	Stand
26	196.1			A	Sit
27	226.0			B	Stand
28	217.5			B	Sit
29	228.8			C	Stand
30	223.5			C	Sit
31	257.1	4, 9, 10, 13, 17	Largest Individuals	A	Stand
32	242.1			A	Sit
33	275.3			B	Stand
34	260.0			B	Sit
35	294.5			C	Stand
36	282.4			C	Sit
37	880.0	All	ALL	A	Sit
38	885.0			A	Stand
39	529.4	4, 5, 6, 7, 8, 9, 11, 13, 14, 15, 17, 20	Max Capacity	A	Stand
40	518.5			A	Sit
41	598.0			B	Stand
42	566.0			B	Sit
43	635.0			C	Stand
44	602.0			C	Sit