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Thermal resistance of inflatable and non-inflatable floors of one-man life rafts for the CF-188 escape system

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Thermal resistance of inflatable and non-inflatable floors of one-man life rafts for the CF-188 Escape System

M.B. Ducharme

Defence R&D Canada

Technical Report
DCIEM TR 2001-125
July 2001

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Canada

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Abstract

The purpose of this study was to define, using humans as heat source, the difference in thermal resistance of inflatable and non-inflatable floors of one-man life rafts for the CF188 Escape System of the Canadian Forces. Three life rafts were tested: two with an inflatable floor and one with a non-inflatable floor. Eight subjects of both genders were used to evaluate the thermal resistance of the floors because humans provide adequate heat transfer and pressure on the floors of the life rafts. Skin heat flow and temperatures were recorded from 4 sites on each subject, namely the right and left buttocks and the right and left calves. The results were averaged from the last 10 min of the 1-hour immersion in 5°C water. The results showed that on average, the skin heat loss and temperatures for the four sites were respectively lower by 33% (74 W/m^2) and higher by 12°C for the inflatable floors as compared to the non-inflatable floors. This resulted in a floor thermal resistance 10 to 12 times higher for the inflatable floors (0.71 ± 0.25 and 0.60 ± 0.16 Clo) as compared to the non-inflatable floor (0.06 ± 0.01 Clo). In conclusion, a life raft with an inflatable floor will significantly reduce the heat loss and the likelihood of developing hypothermia during deployment in cold water when compared to a life raft with a non-inflatable floor.

Résumé

Cette étude a pour but d'établir, en utilisant des êtres humains comme source de chaleur, la différence entre la résistance thermique du fond gonflable et celle du fond non gonflable des radeaux de sauvetage individuels destinés au système d'évacuation du CF188 des Forces canadiennes. Trois radeaux de sauvetage étaient mis à l'essai : deux avaient un fond gonflable et le troisième un fond non gonflable. Huit sujets, hommes et femmes, servaient à évaluer la résistance thermale des fonds, car les êtres humains fournissent suffisamment de transfert et de pression de chaleur aux fonds des radeaux de sauvetage. Le flux de chaleur et la température cutanée étaient relevés à quatre endroits sur chaque sujet, soit aux fesses gauche et droite et aux mollets gauche et droit. On a fait la moyenne des résultats obtenus au cours les dix dernières minutes de l'immersion d'une heure dans de l'eau à 5 °C. Les résultats ont montré que pour les radeaux à fond gonflable, la moyenne des pertes de chaleur cutanée et celle des températures de la peau aux quatre endroits visés était respectivement de 33 % (74 W/m^2) moins élevée et de 12 % plus élevée que pour le radeau de sauvetage à fond non gonflable. Cela signifie que la résistance thermale des fonds gonflables est de 10 à 12 fois plus grande (0,710,25 et 0,60 ± 0,16 Clo) que celle du fond non gonflable (0,06 ± 0,01 Clo). Bref, un radeau de sauvetage à fond gonflable réduira considérablement la perte de chaleur et la probabilité de souffrir d'une hypothermie pendant un déploiement dans de l'eau froide comparativement à un radeau de sauvetage à fond non gonflable.

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Executive summary

DCIEM was tasked by DTA 3-6-3 to evaluate different life rafts for use in the CF188 Escape System of the Canadian Forces. More specifically, our Section was tasked to evaluate the difference in thermal resistance of inflatable and non-inflatable floors of 3 different types of life rafts. Eight subjects of both genders were used to evaluate the thermal resistance of the floors because humans provided adequate heat transfer and pressure on the floors of the life rafts, which render the evaluation more realistic. Skin heat flow and temperatures were recorded from 4 sites on each subject, namely the right and left buttocks and the right and left calves. These data, in addition to the water temperature, allow us to calculate of the thermal resistance of the floor system of the different life rafts. The results were averaged from the last 10 min of the 1-hour immersion in 5°C water. The results showed that on average, the skin heat loss and temperatures for the four sites were respectively lower by 33% (74 W/m^2) and higher by 12°C for the inflatable floors as compared to the non-inflatable floors. This resulted in a floor thermal resistance 10 to 12 times higher for the inflatable floors (0.71 ± 0.25 and 0.60 ± 0.16 Clo) as compared to the non-inflatable floor (0.06 ± 0.01 Clo). In conclusion, a life raft with an inflatable floor will significantly reduce the heat loss and the likelihood of developing hypothermia during deployment in cold water when compared to a life raft with a non-inflatable floor. It was recommended from this study to adopt a life raft with an inflatable floor if the survivability has to be comparable with the current one-man life raft. However, if the aircrew wear an immersion suit with sufficient thermal insulation, an inflatable floor is possibly not necessary in the life raft.

Sommaire

L'IMED a été chargé par le DTA 3-6-3 d'évaluer divers radeaux de sauvetage en vue d'une utilisation sur le système d'évacuation du CF 1888 des Forces canadiennes. Plus précisément, notre section a été chargée d'évaluer la résistance thermique du fond gonflable et du fond non gonflable de trois différents types de radeau de sauvetage. Huit sujets, hommes et femmes, servaient à évaluer la résistance thermale des fonds, car les êtres humains fournissent suffisamment de transfert et de pression de chaleur aux fonds des radeaux de sauvetage. Le flux de chaleur et la température cutanée étaient relevés à quatre endroits sur chaque sujet, soit aux fesses gauche et droite et aux mollets gauche et droit. On a fait la moyenne des résultats obtenus au cours les dix dernières minutes de l'immersion d'une heure dans de l'eau à 5 °C. Les résultats ont montré que pour les radeaux à fond gonflable, la moyenne des pertes de chaleur cutanée et celle des températures de la peau aux quatre endroits visés était respectivement de 33 % (74 W/m^2) moins élevée et de 12 % plus élevée que pour le radeau de sauvetage à fond non gonflable. Cela signifie que la résistance thermale des fonds gonflables est de 10 à 12 fois plus grande (0,71 ± 0,25 et 0,60 ± 0,16 Clo) que celle du fond non gonflable (0,06 ± 0,01 Clo). Bref, un radeau de sauvetage à fond gonflable réduira considérablement la perte de chaleur et la probabilité de souffrir d'une hypothermie pendant un déploiement dans de l'eau froide comparativement à un radeau de sauvetage à fond non gonflable. À la suite de cette étude, des recommandations ont été formulées selon lesquelles on devrait choisir un radeau de sauvetage à fond gonflable si on veut que la capacité de survie soit comparable à celle qu'offre le radeau de sauvetage individuel actuel. Toutefois, si l'équipage porte une combinaison flottante pourvue d'une isolation thermique suffisante, il ne serait peut-être pas nécessaire que le radeau de sauvetage ait un fond gonflable.

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Acknowledgements

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1. Introduction

DCIEM was tasked by DTA 3-6-3 through project tasking directive 11680-12188-81 "CF188 Life Raft Evaluation" to determine the acceptability of the current and various new life rafts for sea survival for CF188 use. The main objective of the project was to find a replacement to the current life raft that will be lighter and will take less packing volume without compromising the aircrew survivability at sea.

A sub-project was given to HPP with the objective to measure the thermal resistance of the floor of the current and various new life rafts. Since heat loss from aircrew will mainly occur through the floor of the life rafts during exposure to the sea conditions, the thermal resistance of the floor could be a crucial factor for the survivability at sea, particularly if the aircrew does not have proper protection from his/her immersion suit.

2. Methods

Subjects. Eight healthy subjects (4 males and 4 females) participated in the study over a two-week period. Their anthropometric information is presented in Table 1. No special restrictions were imposed to the subjects since this was not primarily a physiological investigation. The protocol (DCIEM #L-292, 2001) was approved by the DCIEM Human Ethics Committee before the beginning of the study.

Table 1. Subject information

SUBJECT NUMBER	AGE	HEIGHT (M)	WEIGHT (KG)
1	41	1 68	83 9
2	35	1 57	55 0
3	31	1 6	59 0
4	44	1 57	45 4
5	26	1 73	70 3
6	28	1 88	97 5
7	42	1 83	99 6
8	31	1 77	76 0
Mean	**34.8**	**1.70**	**73.3**
SD	**6.8**	**0.12**	**19.7**

Life rafts. Three different life rafts were tested during the study. Life raft #1 was the JPATS (Part # 44195001) manufactured by RFD Limited (Belfast, Northern Ireland). The JPATS is a single skin floor life raft made of high frequency welded polyurethane proofed nylon fabrics. Life raft #2 was the LRU23P (Part # 40061001) also manufactured by RFD Limited. The LRU23P is an inflatable floor life raft made of high frequency welded polyurethane proofed nylon fabrics. Life raft #3 is the CF one-man life raft manufactured by TULMAR Safety Systems Inc (Hawkesbury, Ont., Canada). The CF life raft is an inflatable floor life raft made of polychloroprene-coated nylon fabric.

Before each test, all life rafts were inflated to the recommended pressure according to the inflation test procedure of the Canadian Forces Technical Orders (CFTO C-22-305-000/MF-000) (2.0 psi for the buoyancy chamber and 0.33 psi for the inflatable floor). In addition, a leak check was performed at the beginning of every test day to ensure that the life rafts would maintain the recommended pressure for the duration of the tests.

Four temperature sensors (thermistor type 44004; Mallinckodt, St-Louis, MO) were fixed on the floor of each life raft. Two of them were taped (Transpore surgical tape) on the lower surface of the floor at the exact location where the subjects would be sitting in the life raft. For the life rafts with the inflatable floors (life rafts #2 and 3), one of the sensors on each surface was fixed over the bladder and the other was fixed over the joint.

Procedures. The subjects were tested on three occasions over a two-week period. Each subject was tested at the same time of the day and the selection of the life raft under investigation was selected randomly. The tests were conducted in the EDU static tank at DCIEM.

Before the tests were performed, the subjects were asked to enter each life raft from the water. This would result in water ingress into the life raft. The subjects were then asked to bail out as much water as possible from the life raft using the bailing system provided with each life raft (life raft #1 and 2 had a water bailer integrated to the floor while life raft #2 had a detached water bailer). Then, the volume of the leftover water was measured for each life raft and averaged for all the subjects. It was observed that the life rafts would contain an average of 3, 4.5 and 7 L of water for life rafts # 1, 2 and 3, respectively. The corresponding amount of water was then introduced inside each type of life raft at the beginning of each test. This procedure will ensure that a more realistic thermal resistance will be measured at the floor of each life raft.

At the beginning of each test the subjects, dressed with T-shirt and short pants, were instrumented with 4 heat flow transducers (HFT model HA 13-18-10-P©, Concept Engineering, Old Saybrook, CT, USA). Two HFT were fixed with tape (Transpore surgical tape) on the buttocks (one on the left and the other on the right side over the short pants) and two others over each calf (one on the left and the other on the right) of the subjects. These sites were used because they were normally in contact with the floor of the life raft. The heat flow transducers provided estimates of skin temperatures and heat loss at those sites over the one-hour exposure. The subjects were then dressed with long sleeved fleece top, an arctic parka folded up to the hips, wool socks and neoprene boots. The purpose of the clothing was to keep the subjects thermally comfortable despite the direct contact of the buttocks and legs with the floor of the life rafts. Once instrumented, the subjects boarded the life raft from the edge of the pool, sat on the floor of the life raft and water at 5°C was poured into the life raft. Three, 4.5 and 7 L of water was poured into the life raft #1, 2 and 3, respectively. The subjects stay still in the life raft for one hour. The temperature of the water in the pool was maintained at 5°C while the air temperature was maintained around 24°C.

The data was collected using a data acquisition system and averaged over 1 minute period (model 3457A data acquisition control unit; Hewlett Packard).

Thermal resistance calculation. The thermal resistance of the floor system for each life raft was calculated using the following equation:

$$R = ((Tsk - Tw)/Hsk)/0.155$$

Where R is the thermal resistance of the floor system during the last 10 min of the 60 min immersion test (in Clo) including the thermal resistance of the floor of the life raft and the water boundary layer under the life raft; Tsk is the average skin temperature for the 4 sites (in °C); Tw is the water temperature about 1 foot below the surface of the water (in °C), Hsk is the average skin heat loss from the 4 sites (in W/m^2).

Statistics. A one-factor (life raft model) repeated-measures analysis of variance was used to compare the skin temperature, skin heat loss and floor insulation. When a significant effect was found ($p < 0.05$), a mean contrast test was used to locate significance between the means (using the Greenhouse-Geisser adjusted p-value). When applicable, data are presented as the mean ± SD. The level of statistical significance was set at $p<0.05$, unless otherwise stated.

3. Results

The air and water temperature during the tests averaged 24.27 ± 0.42 °C and 5.23 ± 0.11 °C, respectively, and no difference was observed between the life raft conditions.

Figure 1 presents, for the three life raft conditions, the average temperature calculated from the last 10 min of the 1-hour immersions for the 4 body sites. It is observed that the skin temperatures during the test using the life raft #1 with the non-inflated floor had the lowest values (7.3 ± 0.1°C) as compared to the ones with the life rafts # 2 (19.8 ± 1.6°C) and # 3 (19.4 ± 6.8 °C) with the inflatable floor. No difference was observed between life raft #2 and #3 conditions, except for the buttock temperatures that tend to be lower for the life raft #3 possibly because of the largest amount of water in that life raft (7L for life raft #3 versus 4.5L for life raft #2). The same trend is observed for the heat flow (Fig. 2) where the values were higher for the life raft #1 condition as compared to life raft #2 and #3, except for the heat flow from the buttock in life raft #3 that is higher than life raft #2. Again, this can be explained by the largest volume of water in the life raft #3 as compared to the life raft #2.

Figure 3 presents the surface temperature of the life rafts for the last 10 min of the tests. It shows that the temperatures of the lower surface were similar for all life rafts. The temperature of the upper surfaces were higher for the life raft #2 and #3 as compared to life raft #1.

Figure 4 show a significant lower thermal resistance for the life raft #1 floor (0.06 ± 0.001 Clo) as compared to life raft #2 (0.71 ± 0.25 Clo) and #3 (0.60 ± 0.16 Clo). No difference was observed between life raft #2 and #3.

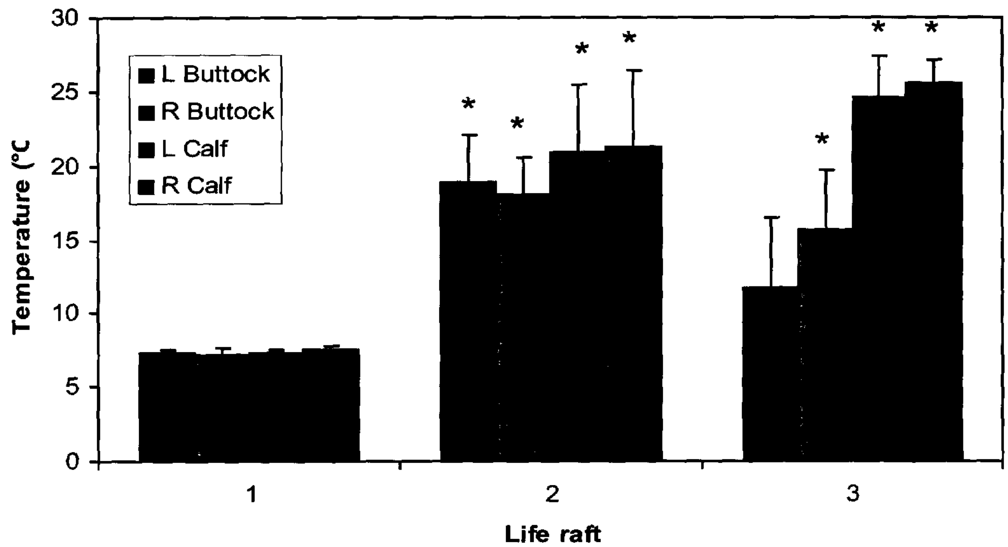

*Figure 1. Average temperature for all subjects (mean ± SD) for the 4 body sites during the last 10-min of the 1-hour immersion for all life raft conditions. *: Significantly different from life raft 1.*

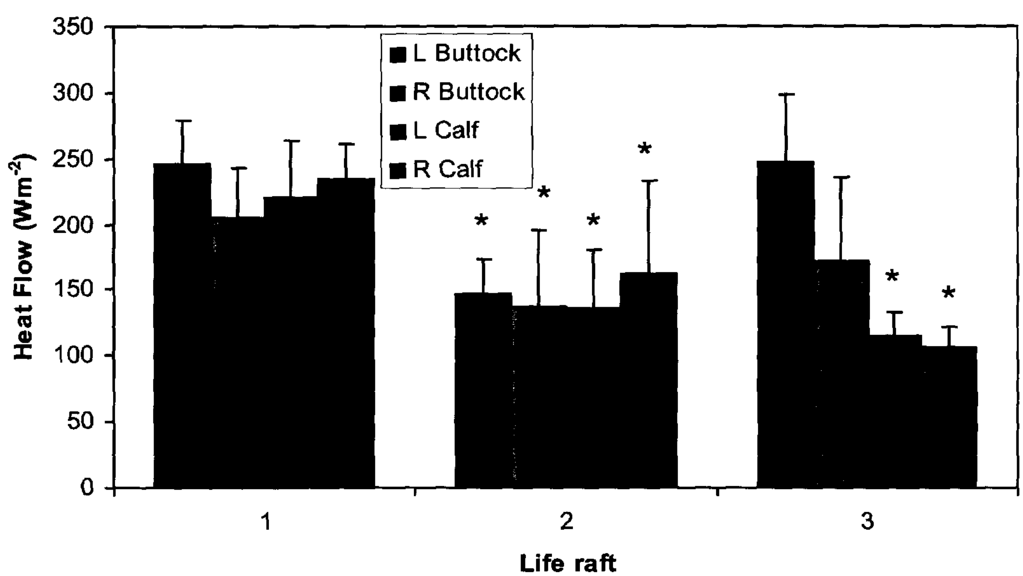

*Figure 2. Average heat flow for all subjects (mean ± SD) during the last 10-min of the 1-hour immersion for all life raft conditions. *: Significantly different from life raft 1.*

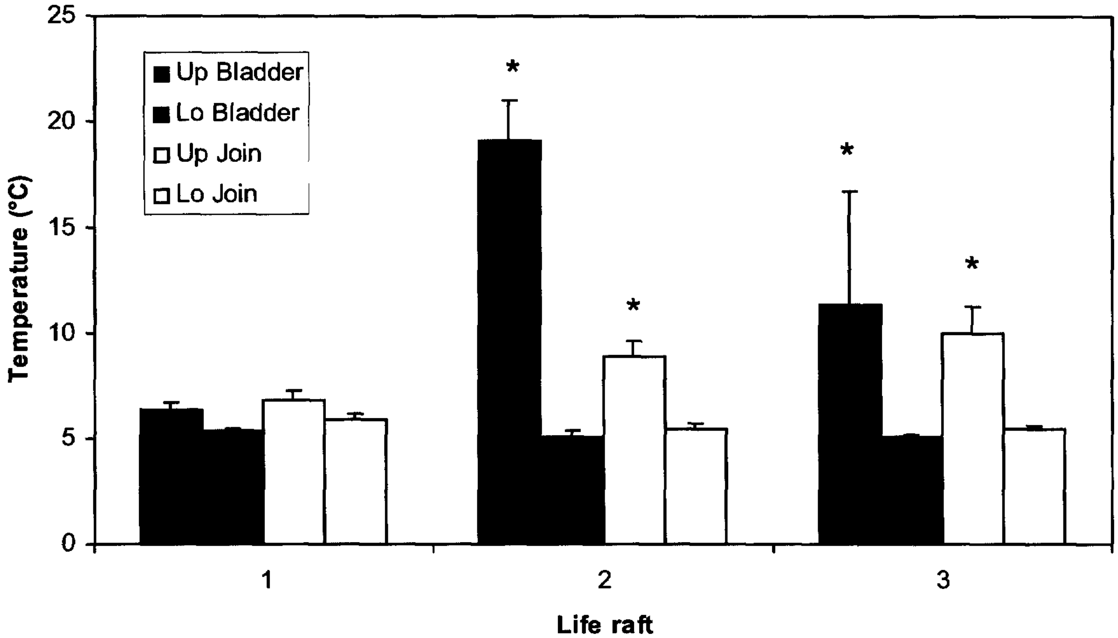

*Figure 3. Average surface temperatures of the floor (mean ± SD) during the last 10-min of the 1-hour immersion for all life raft conditions. *: Significantly different from life raft 1.*

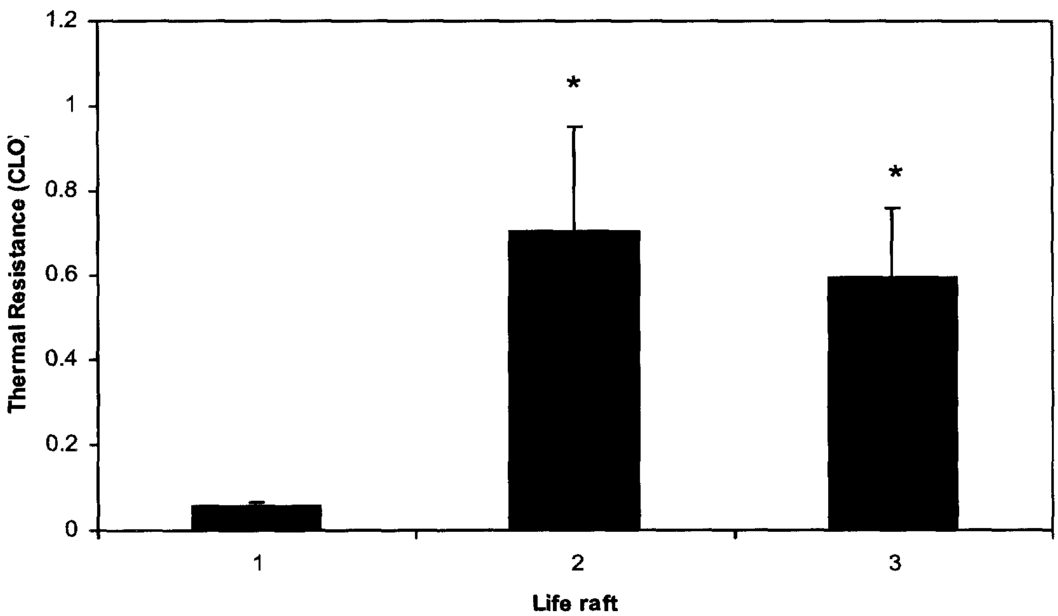

Figure 4. Average thermal resistance of the floor (mean ± SD) calculated during the last 10-min of the 1-hour immersion for all life raft conditions.

4. Discussion

The results of this study show that the thermal resistance of the inflatable floor of a life raft is 10 to 12 times greater than the thermal resistance of life raft floor that is not inflatable. This factor is significant in reducing the heat loss to the water as observed in Figure 2, and to delay the onset of hypothermia.

In this study, particular attention was given to the method used to obtain an estimate of the thermal resistance of the life raft floors. The objective was to obtain a lab estimate that would be as close as possible to the floor insulation observed during a deployment at sea. We used human bodies instead of manikin as heat source to simulate a similar heat loss and the proper pressure in the floor bladders. We introduced water inside the life rafts to promote heat loss from the buttocks as it would likely be the case during an accidental immersion at sea. We also measured the floor insulation of the life rafts as an average from 4 contact sites on the body. This method provided a better overall average of the floor insulation by taking into account 1) the variability in the pressure applied on the floor by the different body parts, 2) the amount of water in contact with the different body parts and 3) the variability in the floor insulation due to the presence of bladders and joints in the cases of inflatable floors.

5. Conclusion

The results of this study clearly demonstrate the importance of an inflatable floor in a life raft to minimize the body heat loss and consequently to minimize the development of hypothermia during the use of a life raft in cold water.

6. Recommendations

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

1. To select a life raft with an inflatable floor which will significantly reduce the heat loss to the water;

2. If the above option is not feasible for reason of bulkiness and weight, and a life raft with a non-inflatable floor is selected, it is recommended that an immersion suit be used by the aircrew. A properly designed immersion suit with 0.75 immersed Clo insulation should be sufficient to protect aircrew in cold water for a minimum of 6 hours. Once on a life raft, the survival time should be prolonged even if the life raft has a non-inflatable floor.

7. References

1. Canadian Forces. 1997. Canadian Forces Technical Orders (CFTO) C-22-305-000/MF-000.

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14 ABSTRACT

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15 KEYWORDS, DESCRIPTORS or IDENTIFIERS

(U) insulation; cold water immersion; heat lost

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