NRC-CNRC
Institute for Ocean Technology

Human Performance in Immersion Suits

Jonathan Power[1]
António Simões Ré[1]

1. National Research Council – Institute for Ocean Technology (NRC-IOT)

Presentation Outline

1. NRC-IOT Marine Safety Research Program
2. Human Responses to Cold Water Immersion
3. Review of Literature
4. NRC-IOT Research
5. Prescriptive vs. Performance
6. Existing Knowledge Gaps – Standards & Performance
7. Observations for Ways Forward

1. NRC-IOT Marine Safety

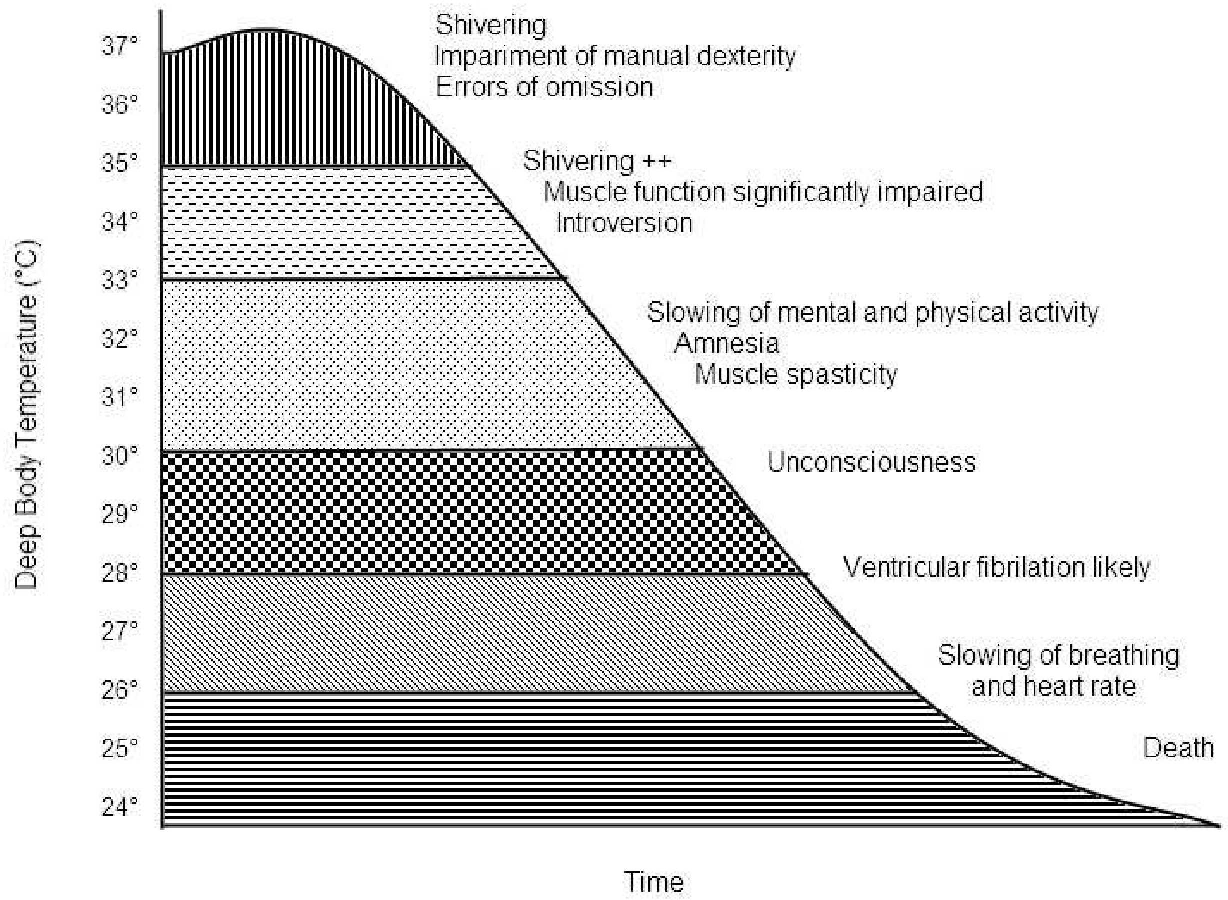
- Marine Safety Research Program – characterization of safety equipment performance in extreme conditions.
- Assessment of new technologies for survival in harsh environments.
- Goal – address knowledge gap between performance in calm water testing and real conditions.

NRC·CNRC
Institute for
Ocean Technology

2. Human Responses to Cold Water Immersion

- Sudden immersion in cold water – a significant risk.
- Most common response is hypothermia.
- Hypothermia is assumed to be the cause of death.
- Other physiological responses are often cause of death (e.g. CSR – Cold Shock Response).
- Important to understand the physiology in emergency situations for increased chances of survival.

Hypothermia



Adapted from Golden, F.S.C. and M.J. Tipton, *Essentials of Sea Survival.* 2002.

Cold Shock Response

- Upon sudden immersion – series of physiological responses occur – Cold Shock Response (CSR).
- R*eflexive* response caused by sudden cooling of the torso (Burke 1991).
- CSR – responsible for majority of cold water immersion fatalities.
- Lightly clothed people can take 30 min to develop hypothermia (Hayward 1984).
- People can perish in less time.

Cold Shock Response

- CSR results in:
    1. Large, involuntary gasp (Goode 1975)
    2. Hyperventilation (Hayward 1984)
    3. Increased heart rate (Keatinge 1964)
    4. Vaso-constriction (Barcroft 1943)

- 1 & 2 – result in increased chance aspirating water.
- 3 & 4 – pose a threat to people with pre-existing cardio-vascular conditions.

Protection

- Immersion suits – designed to reduce thermal shock, delay onset of hypothermia, provide flotation, and minimize risk of drowning (CAN/CGSB 65.16-2005).
- Two different suit systems:
  - Immersion suit systems (CAN CGSB 65.16-2005).
  - Helicopter transportation suit systems (CAN/CGSB 65.17-99).
- Required by regulatory bodies.

NRC·CNRC Institute for Ocean Technology

3. Review of Literature
(1 of 4)

- Waves can increase cooling (Hayes 1985)
  - Suggested a more definitive experiment would be required.
- Later experiment used lifeboats and RHI boats to simulate rough sea conditions (Steinman et al. 1987)
  - Wet suits, rate of deep body temperature drop was greater in waves; result not seen with immersion suits.
- **Conclusion:** rough seas may result in significantly lower survival times that those estimated in calm water (Steinman et al. 1987).

Review of Literature
(2 of 4)

- Steinman et al. – lacked controlled laboratory conditions; every subject did not see the same environment.
- Tipton investigated effects of 15cm waves, $3.1 m \cdot s^{-1}$ wind, and spray in 4°C water on 10 male volunteers in two diffe rent helicopter passenger suits during 4 hour immersions.
- One suit style resulted in 71.5min immersions, second gave 189.5min.
- Tipton concluded – possibility exists to overestimate survival times based on lab conditions that do not recreate the stresses in a real emergency (Tipton 1991).
- **Suggested this limitation could be reduced if lab testing could be made more realistic.**

Review of Literature
(3 of 4)

- In Tipton's study, one suit had 1.32 liters of leakage, second had 2.2 liters.
- Tipton & Balmi investigated effects of water leakage.
- 0.5 litres of water over the torso – 30% reduction in clothing insulation (Tipton & Balmi 1996).
- 0.5 litres applied over the limbs resulted in same change in Db_T as measured with no water leakage (Tipton & Balmi 1996).

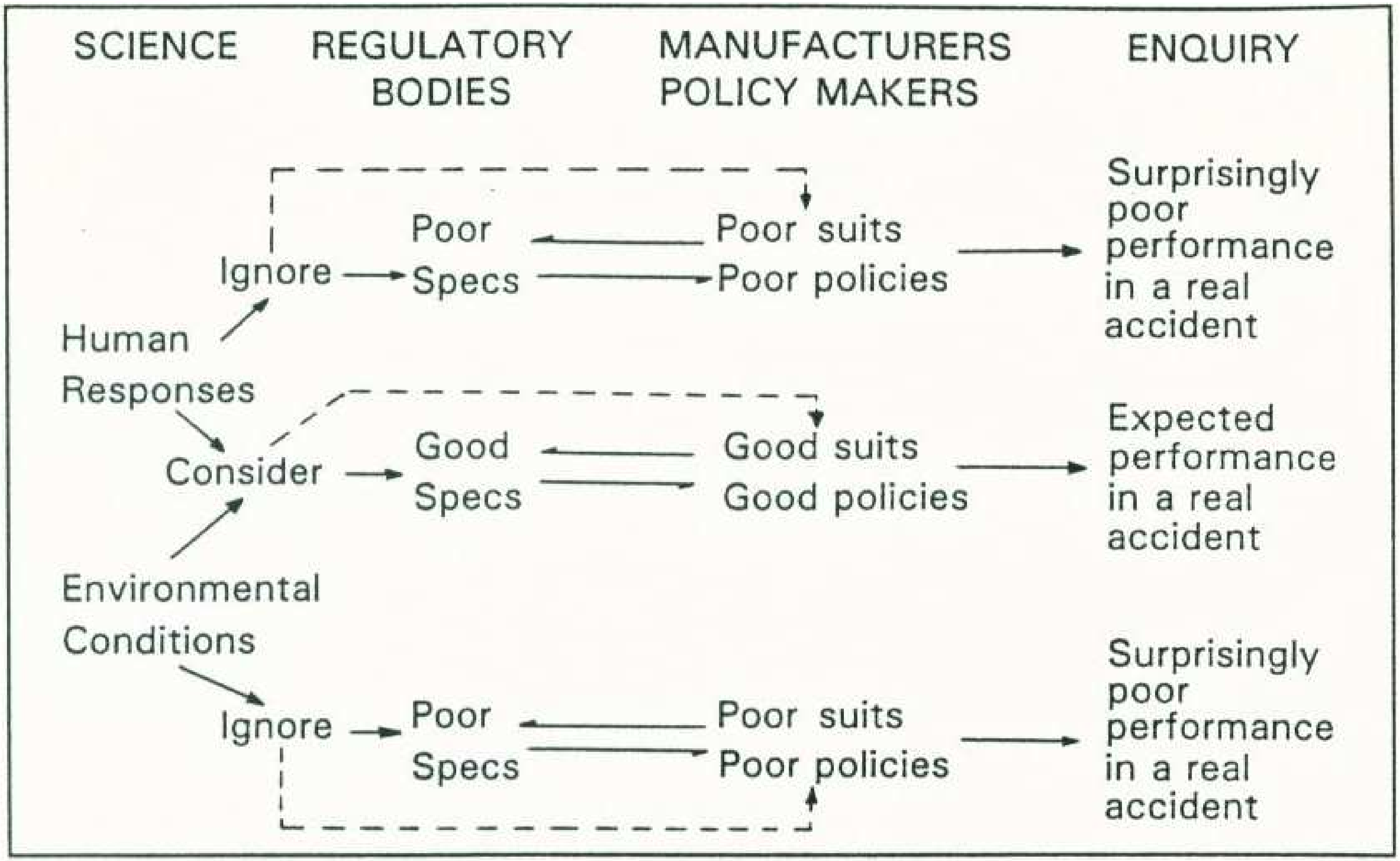
Review of Literature
(4 of 4)

- Ducharme & Brooks investigated effects of varying wave heights on heat flow.
- 6 volunteers performed one hour immersions in waves ranging from 0-70cm; No change in Db_T.
- Heat flow was affected by wave height: waves 30cm and higher produced significantly greater values compared to calm (Ducharme & Brooks 1998).
- Concluded that total thermal resistance of dry immersion suits is decreased by waves, compared to calm.
- **Further studies are necessary to determine practical limit of this reduction.**

Review of Literature Summary

- Earlier work has shown importance of suits (Hayward 1984).
- Later studies had variable environments which possibly resulted in a lack of conclusive results being produced.
- Studies in laboratory conditions showed that wind and waves would result in degradation in immersion suit performance.
- Tipton recommended that test standards must recreate the tasks which may have to be undertaken and the environmental conditions (Tipton 1991).

Review of Literature Summary



Tipton, M.J., *Immersion fatalities: hazardous responses and dangerous discrepancies.* J R Nav Med Serv, 1995. 81(2): p. 101-7.

4. NRC-IOT Research

- Multi-year project (2007-present) to investigate the effects of weather conditions on human performance.
  - Objective: measure human thermal responses to wind and wave conditions while in immersion suits.
- The project used NRC-IOT facilities to create realistic, repeatable conditions to address the knowledge gap that exists between the calm water testing standards, and real world conditions.

Phase 1 – Mar 2008

- Examined human thermal responses in 4 separate conditions during one hour immersions.
- 12 Participants performed immersions in calm water, wind only, waves only, and wind + waves.
- Wave spectrum was created using data collected from a wave buoy deployed on the south west coast of the Grand Banks.
- CORD Group Ltd's thermal manikin tested simultaneously.
- Measured skin temperature, heat flow & deep body temperature.

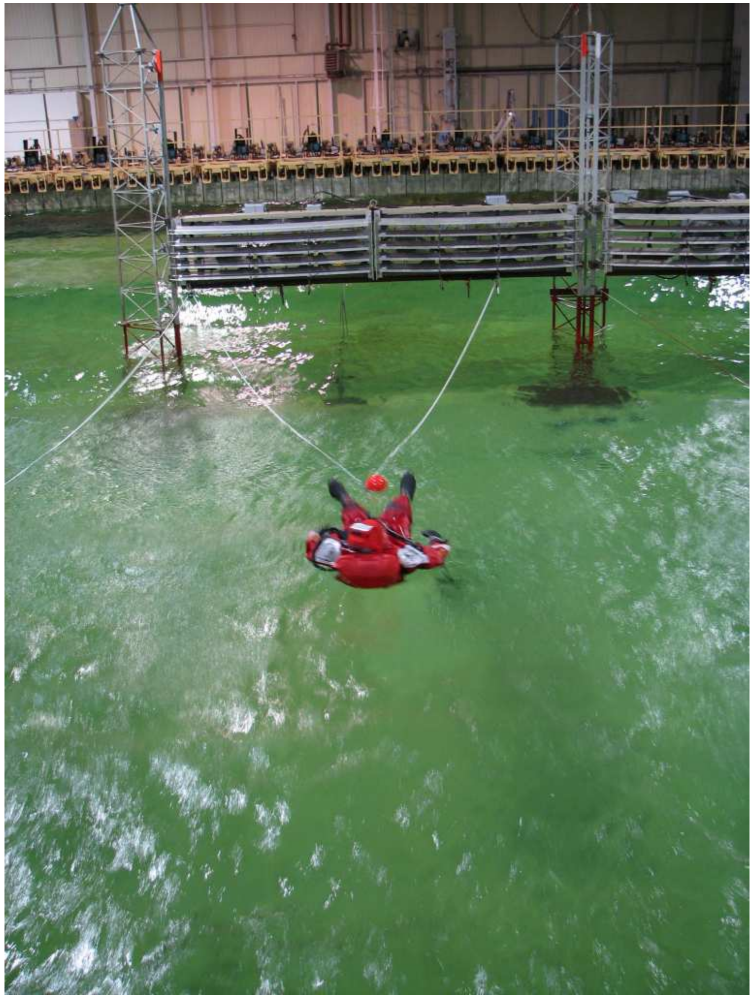
Phase 1 Conditions

Condition	Wind Speed ($m \cdot s^{-1}$)	Max Wave Height (m)	Mean Water Temp (SD) (℃)	Mean Air Temp (SD) (℃)
Calm	0	0	10.9 (0.6)	18.0 (0.4)
Wind	4.24	0	10.9 (0.6)	18.0 (0.4)
Waves	0	0.67	10.8 (0.7)	17.6 (0.4)
Wind + Waves	4.24	0.67	11.1 (0.7)	18.1 (0.4)

NRC·CNRC
Institute for
Ocean Technology

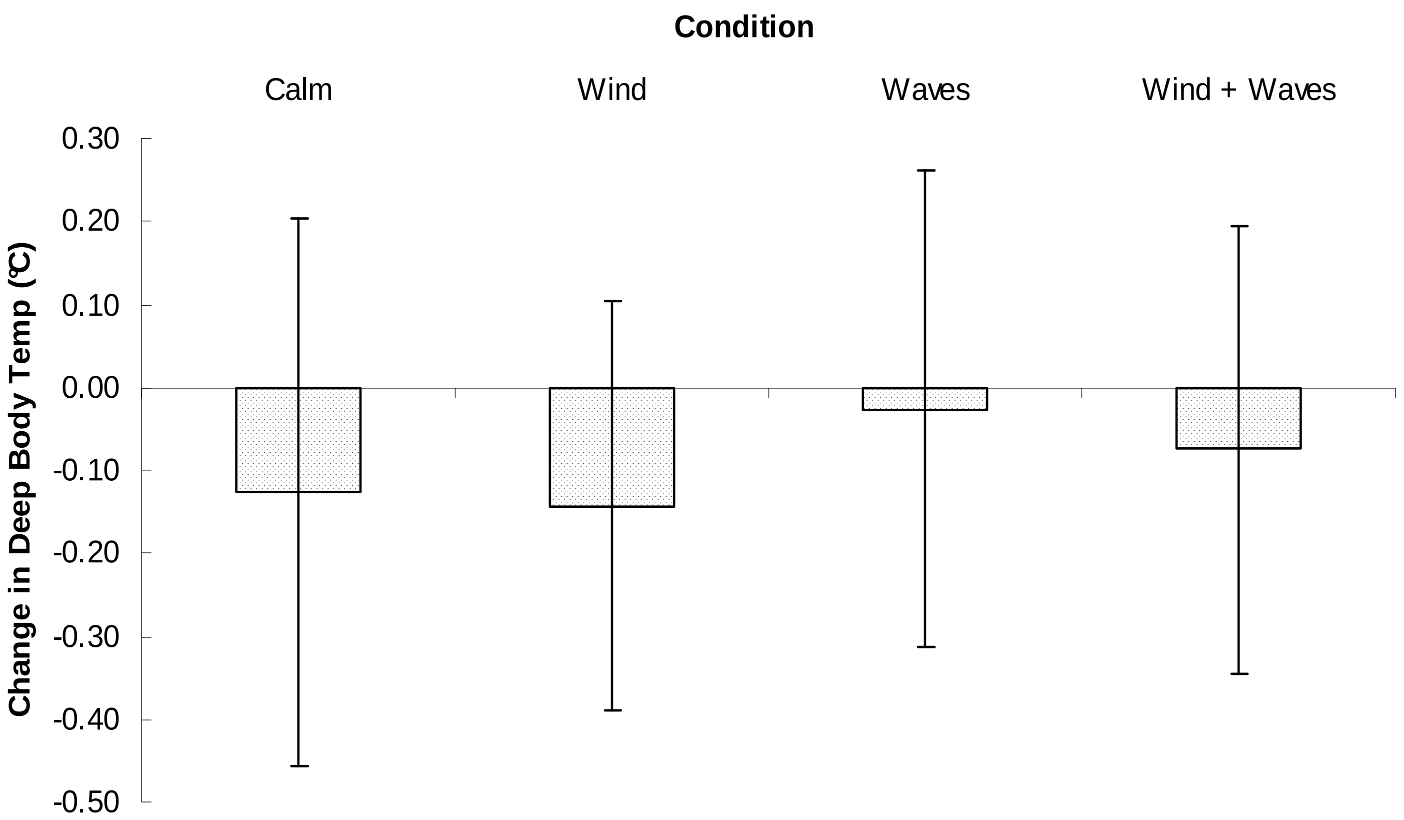
Phase 1 – Setup

Phase 1 – Setup



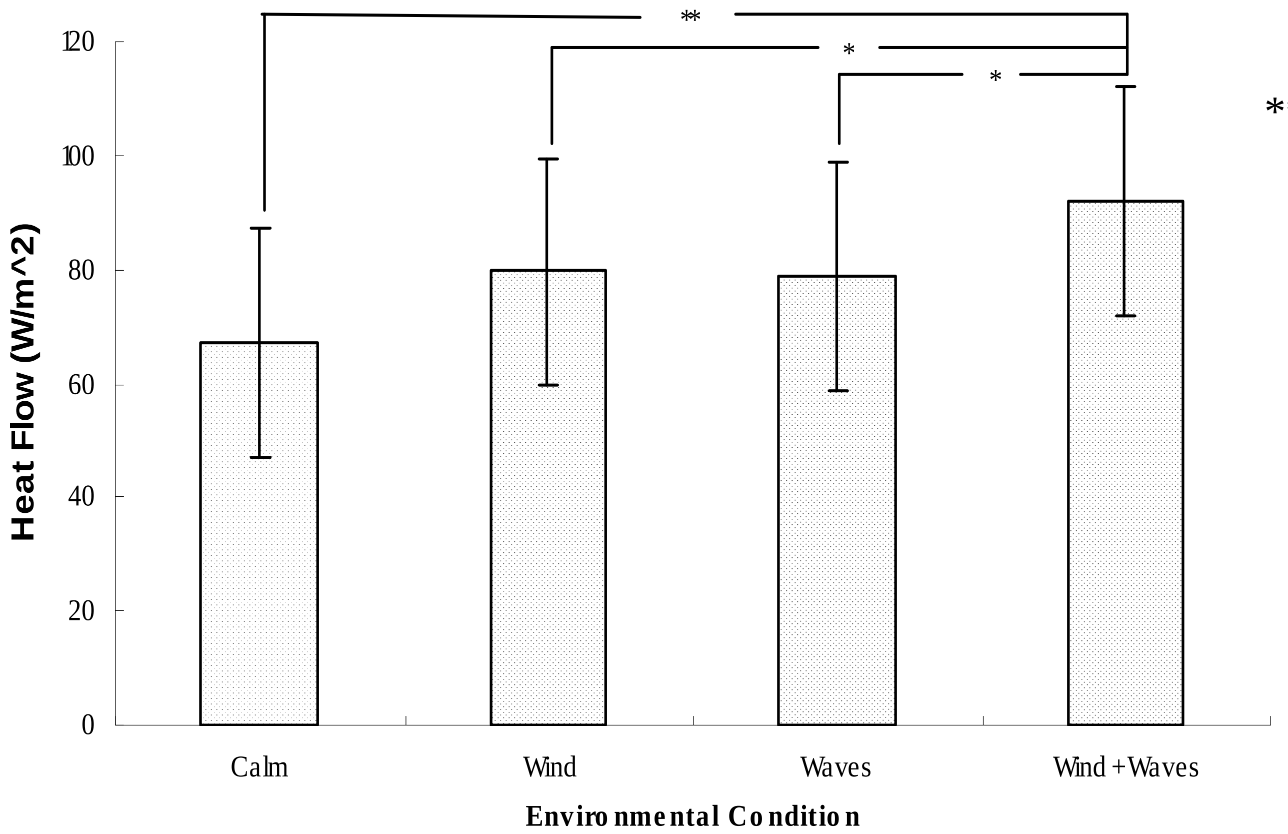

JP_WAVE_001
11MAR08 09:28:39.1393 BEAM

Phase 1 Results



Mean change in Deep Body Temperature during 1-hour immersions. (*n*=12)

Phase 1 Results

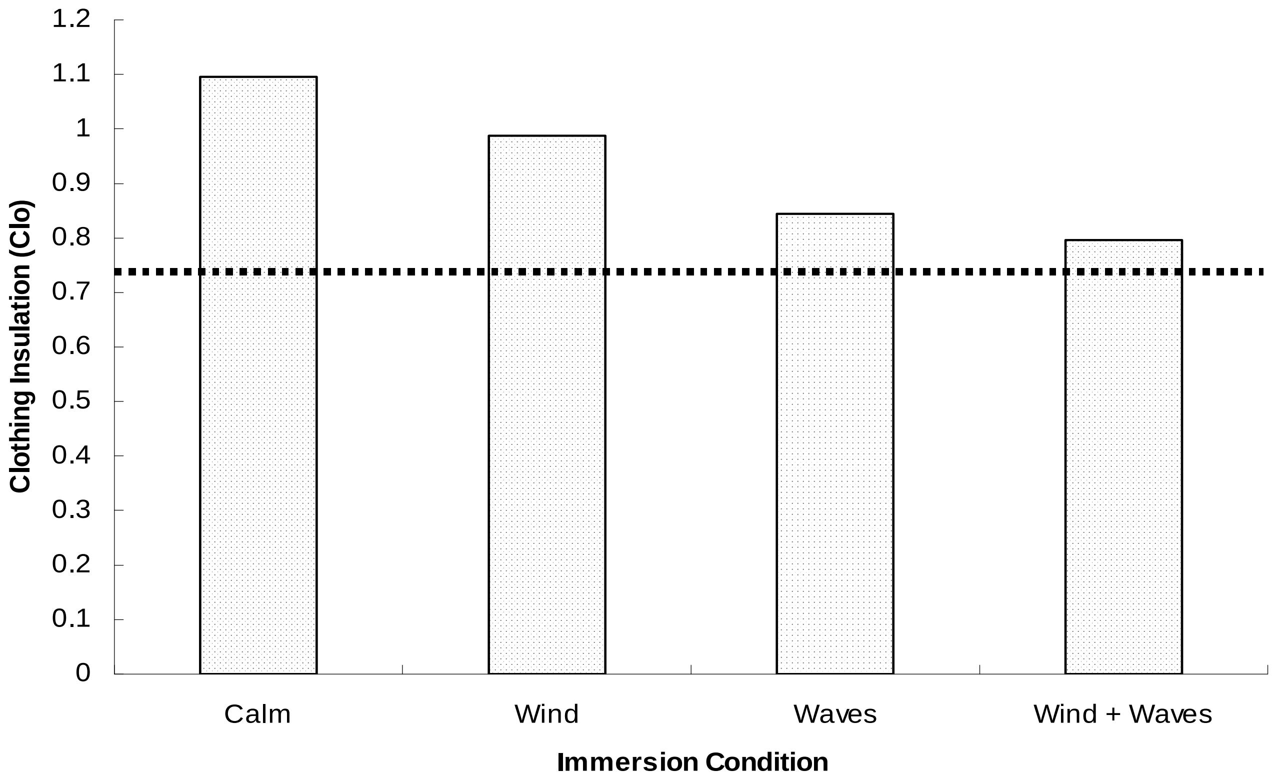


* = P < 0.05

** = P < 0.001

Mean body skin heat flow at the end of 1-hr immersion (*n*=12).

Phase 1 Results



Clothing insulation of immersion suit measured by TIM – CORD’s manikin

Phase 1 - Conclusions

- No significant difference in air or water temperature
- No significant change in Db_T across all immersion conditions.
- Mean skin heat flow was significantly greater in W+W condition compared to all other conditions.
- W+W caused a 37% increase in mean skin heat flow compared to calm conditions.
- W+W caused a 20% reduction in Clo value (measured by TIM) compared to calm.
- **Results show that wind and waves will significantly increase the amount of heat lost to the environment.**

NRC·CNRC
Institute for
Ocean Technology

Phase 2 – Mar 2009

- Investigated if *varying weather conditions* will cause a significantly greater increase in heat flow in a linear fashion.
- 3 immersion conditions – Calm, Weather 1, and Weather 2.
- Weather 2 wave spectrum same as used in previous experiment.
- Immersion durations extended to 3-hours.
- Metabolic rate measured to calculate participant energy expenditure.

Phase 2 - Conditions

Condition	Mean Wind Speed ($m \cdot s^{-1}$)	Max Wave Height (m)	Mean Water Temp (SD) (℃)	Mean Air Temp (SD) (℃)
Calm	0	0	11.1 (0.2)	17.2 (0.5)
Weather 1	3.5	0.34	10.9 (0.4)	17.4 (0.4)
Weather 2	4.6	0.67	10.9 (0.3)	17.3 (0.4)

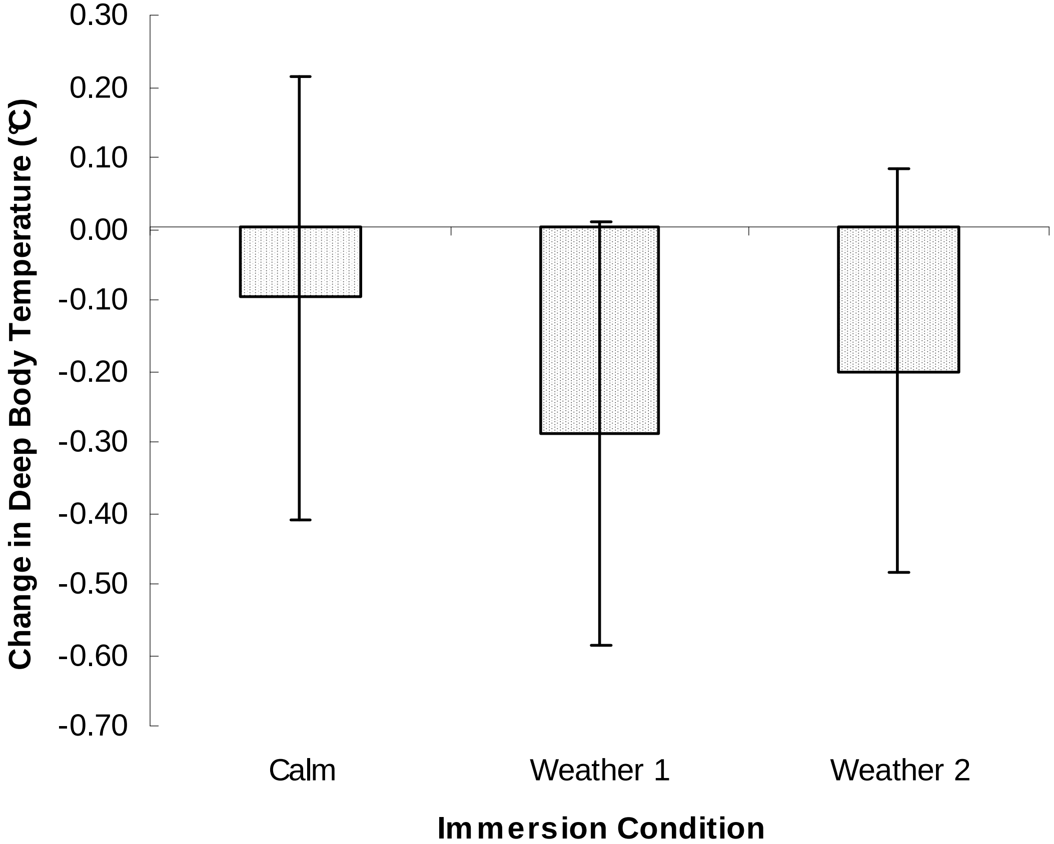
NRC·CNRC
Institute for
Ocean Technology

Phase 2 - Setup

NRC·CNRC
Institute for
Ocean Technology

Phase 2 - Setup

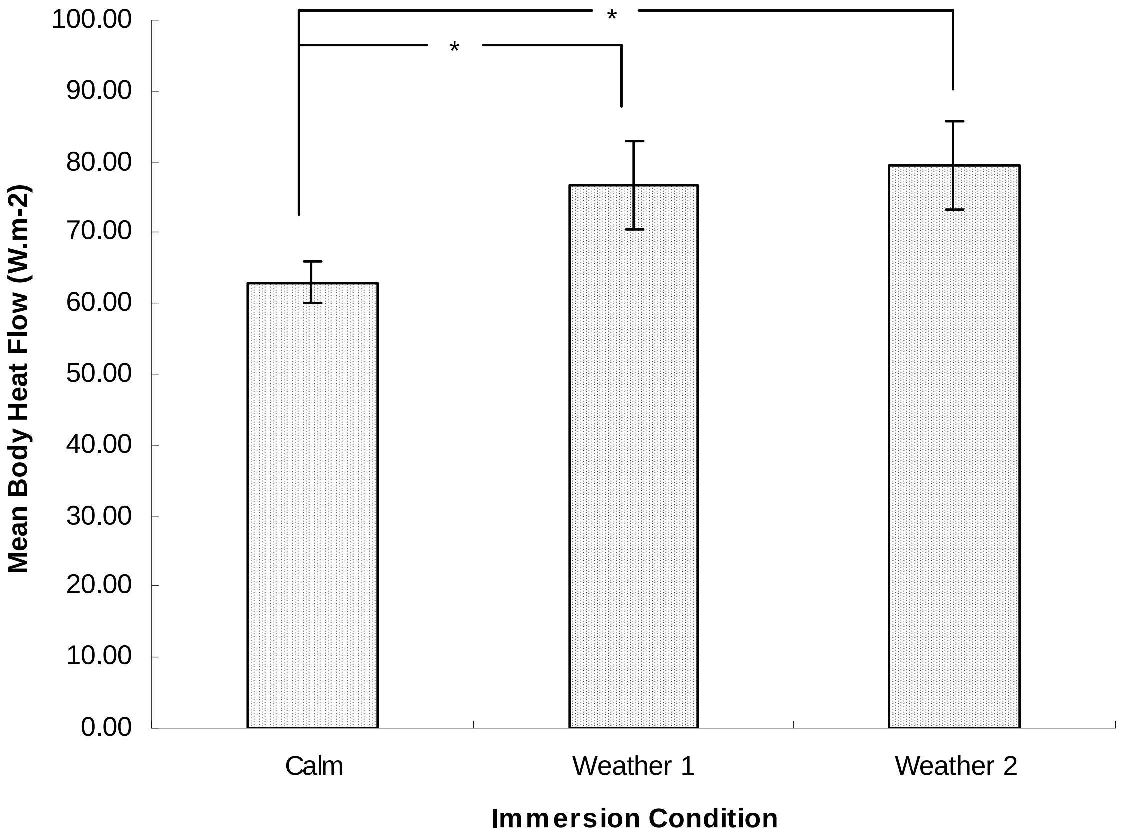
Phase 2 - Results



Mean change in Deep Body Temperature over 3 hour immersion (n = 12)

NRC·CNRC
Institute for Ocean Technology

Phase 2 - Results



* = P < 0.05

Mean body skin heat flow at the end of the 3 hour immersions (*n* = 12)

Phase 2 - Conclusions

- No significant differences in change in deep body temperature across all immersion conditions.
- Weather 1 and Weather 2 produced significantly greater increases in mean body skin heat flow compared to calm conditions.
- No significant differences in heat flow between Weather 1 and 2.
- No significant differences in energy expenditure across all immersion conditions.
- Participants were able to successfully thermoregulate in these conditions
  - possible they could no longer do so if conditions increased

Phase 3 – Mar 2010

- Investigated effects of varying weather conditions on human performance *with 500ml of water in the suit* during 3 hour immersions.
- Same weather conditions and setup as in Phase 2
- Objectives:
  - Investigate effect of weather increase with water leakage
  - Determine if water leakage pushes the participants past the thermoregulatory zone?

Phase 3 – Preliminary Results

- Collected data still being analyzed.
- Water temperature was 8℃, air temperature was 16° C (approx.).
- Initial observations:
  - Intense shaking and shivering in participants.
  - Many had blue tinge to their lips.
  - Near hypothermic level drops in deep body temperature.
  - Several participants reported slowing of mental processes (“zoning out”), disorientation, and were slow to respond when checked on during immersion.
  - Many participants had trouble finishing the 3 hour immersions.

NRC-IOT Research Summary

- Wind and waves will significantly increase the heat lost to the environment.
- Participants in our completed studies (Phase 1 & 2) were able to successfully thermoregulate in the given conditions.
- If the temperature of the environment were to change, or the level of suit insulation altered possible that it may exceed people's ability to thermoregulate.
- Testing the thermal protective properties of immersion suits with *people* in calm water pools (Calm conditions) does not provide an accurate assessment of performance in real world scenarios.

5. Prescriptive vs. Performance

- A performance standard is the operator's specification of a solution to achieving a given goal.
- Prescriptive standards require suits to be tested in conditions not representative of where they may actually be used.
  - May lead to knowledge gaps.
- Performance standards may address this gap by requiring tests to be conducted in conditions representative of operational areas.

NRC·CNRC
Institute for
Ocean Technology

Prescriptive vs. Performance

Prescriptive

- **CAN/CGSB-65.17-99, 6.2.5.2:**

  The suit system shall provide thermal protection such that the average body core (rectal) temperature of persons wearing the suit system for 6h in calm, circulating water that is between 0 and 2℃ shall not drop more than 2℃…..

- **CAN/CGSB-65.17-99, 6.2.5.1:**

  When tested in accordance with 8.1.6.2, the mean level of thermal insulation over the body as provided by the suit system which includes test clothing must be not be less than 0.75 immersed Clo.

Prescriptive vs. Performance

Performance

- Assuming suit passed the tests, now approved for use in the following locations:
  - West coast of B.C.
  - Sheltered harbor in P.E.I.
  - Arctic circle
  - East coast of Newfoundland
  - Anywhere else in Canada
- Average environmental conditions vary greatly in each location; yet suit is expected to perform at an acceptable level.
- Was the suit tested in an environment representative of any of the above locations?

Performance Based Approach

- If Standard was performance based….could read as:

  The suit must prevent a 2℃ drop in deep body temperature in conditions representative of the area of operation for the amount of time it would take search and rescue to respond.

  Guidance: *The size and distribution of the test subjects should have anthropometric dimensions equal to that of the workforce using the suit.*

- Area of operation, SAR response assets, and size of people would set the conditions for the testing standard.
- Reduces uncertainty and helps close the knowledge gap between testing conditions and real world scenarios

Prescriptive Based Standards

Advantages	Disadvantages
Easy to create and implement	Compliance may not provide best solution
Provides certainty for operators and regulators as to compliance	Reduces the flexibility to operator to provide best solution
	Does not account for improvements in technology
	Reduces innovative solutions
	Tendency to become passive in approaches to safey

NRC·CNRC
Institute for
Ocean Technology

Performance Based Standards

Advantages	Disadvantages
Puts responsibility for solutions on operators	Requires that the regulators, inspectors, and operators be highly qualified
Provides flexibility in developing solutions	Management system must be adaptive and closely monitored in order to change the system if required
Fosters innovative solutions	Regulators and operators must work together harmoniously to provide the best solutions available
Allows for continuous upgrading of system	
Allows adaption of new technologies	

6. Knowledge Gaps in Existing Standards

- **CAN/CGSB-65.16-2005, 6.8 - Donning Time**:

  Current standards require tests to be completed on stable platforms. Marine abandonment suits are often donned in unstable conditions – may lead to an overestimation of performance.

- **CAN/CGSB-65.17-1999, 6.1.9.2 - Mobility and Hand Dexterity**:

  Standard requires tests to be conducted in water “not less than 18°C”. Vincent and Tipton (1988) reported 2-min hand immersions in 5°C significantly reduced max grip strength.

Knowledge Gaps in Existing Standards

- **CAN/CGSB-65.17-1999, 8.1.3.7- Stability and Floating Characteristics**: Requires all testing to be conducted in calm water pools. Unknown at this time how wave motion will influence stability and flotation.
- **CAN/CGSB-65.17-1999, 8.1.4 - Vertical Positioning**: Conducted in calm water pools. Unknown at this time how wave motion will influence stability and flotation.
- **CAN/CGSB-65.17-1999, 8.1.6.1 - Water Ingress**:

  3m or greater jump, and a 60min swim in calm water. Possibility for rougher conditions to result in more water leakage (CORD Group Ltd. 2009)

NRC·CNRC
Institute for
Ocean Technology

Knowledge Gaps in Existing Standards

- **CAN/CGSB-65.17-1999, 8.1.6.2 - Thermal Protection – manikins**:

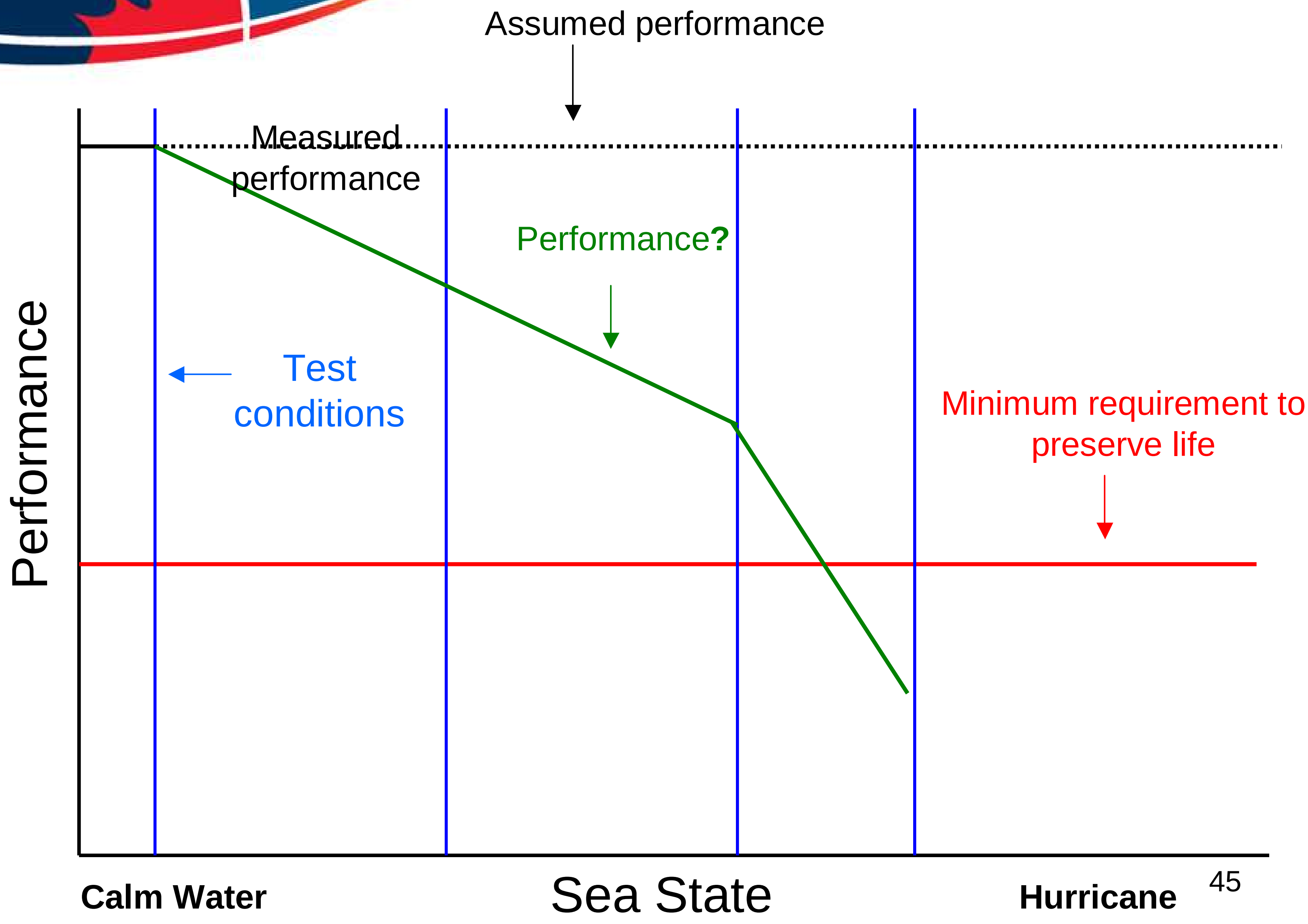
  Tests to be conducted in 40cm waves with a water temperature not less than 3°C than manikin temp. Work conducted by NRC-IOT showed that wind and waves will cause a greater increase in heat flow.

- **CAN/CGSB-65.17-1999, 8.1.7: Thermal Protection –humans**:
  Tests to be conducted in calm, circulating 2°C water. Work conducted by NRC-IOT showed that these conditions produce significantly less heat flow compared to wind and wave conditions.

Knowledge Gaps in Existing Standards

- Knowledge gap exists between testing standards, and real world conditions.
- Prescriptive standards can create these knowledge gaps.
- Knowledge gaps introduce uncertainties to offshore workers' safety.
- Specifying test conditions creates a focused avenue for performance evaluation.
- The assumption is that performance in a prescribed testing standard will be at the same level in any situation

Knowledge Gaps in Existing Standards



NRC·CNRC
Institute for
Ocean Technology

7. Observations for Way Forward

- The difference between the assumed and unknown level of performance is the uncertainty in real world conditions.
- This uncertainty often leads to the “Surprisingly poor performance in a real accident” as mentioned by Tipton (1995).
- Best way to eliminate risk due to uncertainty in human performance in immersion suits is to test in the most realistic, representative conditions possible with the people who will be using them.

Observations for Way Forward

- Examine the cost and feasibility to shift from prescriptive to performance based regulations.
- Holistic design of the transportation environment and its components.
- New fabrics and materials for immersion suits that would allow for increased performance in realistic conditions.
- The redesign of the immersion suits' thermal balance by including "suit vents" as a way of keeping the user more comfortable.
- Development of training simulators for helicopter emergency operations, escape, evacuation and rescue

Observations for Way Forward

- Continuous monitoring and assessment of the offshore work force's anthropometrics and physical capabilities.
- Maintain an on-going database of these parameters that can be transferred back to standards boards and manufacturers to allow for further refinement products.

References

Helicopter Passenger Transportation Suit Systems. CAN/CGSB-65.17-99. Canadian General Standards Board. 1999.

Immersion Suit Systems. CAN/CGSB-65.16-2005. Canadian General Standards Board. 2005.

Barcroft, H. and Edholm, O.G. *The effects of temperature on blood flow and deep temperature in the human forearm.* J. of Physiol. 1943. 102: p.5-20.

Burke, W.E., and Mekjavic, I.B. *Estimation of regional cutaneous cold sensitivity by analysis of the gasping response*. J. Appl. Physiol. 1991. 5. p.1933-40.

Cooper, K.E., S. Martin, and P. Riben, *Respiratory and other responses in subjects immersed in cold water.* J Appl Physiol, 1976. 40(6): p. 903-10.

CORD. *Water Ingress Analysis for Immersion Suits in Canada (TC Report)*. The Cord Group Limited, 2007.

CORD. *Water Ingress Testing for Immersion Suits in Canada: Phase 2 (TC Report)*. The CORD Group Limited, 2009.

Ducharme, M.B. and C.J. Brooks, *The effect of wave motion on dry suit insulation and the responses to cold water immersion.* Aviat Space Environ Med, 1998. 69(10): p. 957-64.

Golden, F.S.C. and M.J. Tipton, *Essentials of Sea Survival.* Windsor, ON, Canada: Human Kinetics. 2002.

Goode, R.C., Duffin, J., Miller, R., Romet, T.T., Chant W., and Ackles, A. *Sudden cold water immersion.* Respir Physiol. 1975. 23: p.301-310.

Hayes, P.A., S. P.J., and R. Crackness. *Reactions to cold water immersion with and without waves*. 645. RAF Instiute of Aviation Medicine, 1985.

References

Hayward, J.S., *Thermal protection performance of survival suits in ice-water.* Aviat Space Environ Med, 1984. 55(3): p. 212-5.

Hayward, J.S. and J.D. Eckerson, *Physiological responses and survival time prediction for humans in ice-water.* Aviat Space Environ Med, 1984. 55(3): p. 206-11.

Keatinge, W.R., McIlory, M.B., and Goldfien, A. *Cardiovascular responses to ice-cold showers.* J. Appl. Physiol. 1964. 19: p.1145-1150

Steinman, A.M., J.S. Hayward, M.J. Nemiroff, and P.S. Kubilis, *Immersion hypothermia: comparative protection of anti-exposure garments in calm versus rough seas.* Aviat Space Environ Med, 1987. 58(6): p. 550-8.

Tipton, M.J., *The initial responses to cold-water immersion in man.* Clin Sci (Lond), 1989. 77(6): p. 581-8.

Tipton, M.J., *Laboratory-based evaluation of the protection provided against cold water by two helicopter passenger suits.* J Soc Occup Med, 1991. 41(4): p. 161-7.

Tipton, M.J., *Immersion fatalities: hazardous responses and dangerous discrepancies.* J R Nav Med Serv, 1995. 81(2): p. 101-7.

Tipton, M.J. and P.J. Balmi, *The effect of water leakage on the results obtained from human and thermal manikin tests of immersion protective clothing.* Eur J Appl Physiol Occup Physiol, 1996. 72(5-6): p. 394-400.

Vincent, M.J. and M.J. Tipton, *The effects of cold immersion and hand protection on grip strength.* Aviat Space Environ Med, 1988. 59(8): p. 738-41.

NRC CNRC

Institute for Ocean Technology

Science at work for Canada

National Research Council Canada

Conseil national de recherches Canada

Canada