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# **The Management of Heat Stress for the Firefighter**

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**Defence R&D Canada - Toronto**

External Client Report

DRDC Toronto ECR 2004-051

2005-01-10

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The research described in this report was approved by the DRDC Human Research Ethics Committee and was conducted in conformity with the Tri-Council Policy Statement: Ethical Conduct for Research Involving Humans

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## Abstract

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This report provides a summary of research conducted through a grant provided by the Workplace Safety Insurance Board of Ontario. The research was divided into two phases; first, to define safe work limits for firefighters wearing their protective clothing and working in warm environments; and, the second, to examine strategies to reduce the thermal burden and extend the operational effectiveness of the firefighter. For the first phase, subjects wore their protective ensemble and carried their self-contained breathing apparatus (SCBA) and performed very light, light, moderate or heavy work at 25°C, 30°C or 35°C. Thermal and evaporative resistance coefficients were obtained from thermal manikin testing that allowed the human physiological responses to be compared with modeled data. Predicted continuous work times were then generated using a heat strain model that established limits for increases in body temperature to 38.0°C, 38.5°C and 39.0°C. Three experiments were conducted for the second phase of the project. The first study revealed that replacing the duty uniform pants that are worn under the bunker pants with shorts reduced the thermal strain for activities that lasted longer than 60 minutes. The second study examined the importance of fluid replacement. The data revealed that fluid replacement equivalent to at least 65% of the sweat lost increased exposure time by 15% compared with no fluid replacement. The last experiment compared active and passive cooling. Both the use of a mister or forearm and hand submersion in cool water significantly increased exposure time compared with passive cooling that involved only removing most of the protective clothing. Forearm and hand submersion proved to be most effective and produced dramatic increases in exposure time that approximated 65% compared with the passive cooling procedure. When the condition of no fluid replacement and passive cooling was compared with fluid replacement and forearm and hand submersion, exposure times were effectively doubled with the latter condition. The slide rule that was generated can be used by Commanders to determine safe work limits for their firefighters during activities that involve wearing their protective clothing and carrying their SCBA.

## **Résumé**

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## Executive summary

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Firefighters face a trade-off between personal protection and thermal strain when performing firefighting activities. As a result, there is a requirement to develop methods for keeping firefighters' thermal strain below critical levels during work in firefighting protective clothing (FPC). Although the heat-stress of wearing FPC has been described, no one has attempted to define safe work limits for firefighters in different ambient conditions. This research study was designed in conjunction with the Toronto Fire Service to establish safe work guidelines for Toronto firefighters wearing FPC and SCBA (self-contained breathing apparatus) at ambient temperatures representative of summer conditions in Toronto. In addition, active and passive cooling strategies combined with different levels of hydration were examined. All heat-stress trials were conducted in the climatic facility at DRDC Toronto. In the first phase of the research, three different ambient temperatures (25°C, 30°C and 35°C, 50% R.H.) were examined with subjects exercising at four different work intensities (Heavy, Moderate, Light, and Very Light) in order to define the thermal strain associated with wearing FPC and SCBA. An additional trial at 35°C was completed during each of these workloads with station pants replaced with shorts. Additional testing in the second phase of the research utilized an ambient temperature of 35°C with 50% R.H. and the light work to examine the importance of hydration and cooling strategies to extend operational capabilities of the firefighter. Replacing station pants with shorts significantly reduced heat strain and increased exposure time during work activities that lasted beyond 60 minutes. The incorporation of active cooling during scheduled rest significantly reduced the heat strain associated with any given task. Hydration was found to play a role in reducing the thermal strain while wearing FPC and SCBA in the heat. It appears that even partial fluid replacement can have beneficial effects, increasing exposure time. Ultimately, the implementation of active cooling (forearm submersion) and hydration strategies will help to reduce the occurrence of heat related injury and possibly myocardial infarction in active firefighters. The findings from this research led to the generation of a slide rule that can be used by Commanders to determine safe work limits for their firefighters during activities that involve wearing their FPC and SCBA.

McLellan, T.M. and G.A. Selkirk. 2004. Heat Stress Management for Firefighters. 2004-051 DRDC Toronto.

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## Acknowledgements

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The authors would like to express their gratitude to the personnel from the Toronto Fire Services who participated in the heat-stress trials. Their time and effort in this investigation were crucial to its success. We also extend a special thank-you to our Toronto Fire Services liaison, Captain Tim Metcalfe, for his help with subject recruitment and scheduling. In addition, we would like to acknowledge the efforts of District Chiefs John Lane and David Ross, and the Toronto Professional FireFighters Association, for their ongoing help and support throughout the project. The assistance and technical support of Mrs. I Smith, Mr. J. Pope, Mrs. D. Kerrigan-Brown, Mr. R. Limmer and Mr. J. Hilton were crucial to the successful completion of these trials. Additional thanks to Dr. P. Tikuisis for his mathematical analysis and Dr. Gonzalez (USARIEM) for conducting thermal manikin testing.

This Project was funded by a research grant provided by the Workplace Safety and Insurance Board (Ontario).

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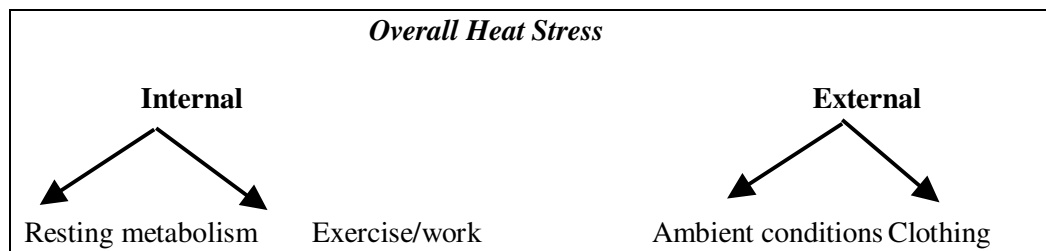


# 1. Introduction

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Humans are homeothermic creatures, and regulate their body temperature within a narrow range over the entire course of their lives. When heat is generated by increased activity, humans are generally successful in maintaining a thermal steady state by activating heat-loss mechanisms to dissipate the excess heat. A hot, humid environment and/or the wearing of protective clothing, however, imposes a major stress on the body's ability to maintain thermal stability during work, due to a decrease in the temperature and water vapour pressure gradients between the body and the environment, thus impairing heat exchange. Hyperthermia, or the rise in body temperature, can eventually lead to heat-related injury and illnesses such as heat cramps, exertional heat collapse, heat exhaustion and heat stroke; the latter condition can be fatal if medical treatment and cooling are not provided immediately.

Heat stress refers to the **heat load** on the body. As illustrated below, there are two sources of heat stress: internal and external. Internal heat stress is the heat generated by metabolism and is determined mainly by exercise or the intensity of work. External heat stress is that from the environment and includes the insulative effects of clothing.



For the firefighter, internal heat production can vary from more prolonged light work involved with pump operations or light sweeping during cleanup activities, to shorter bursts of high intensity work such as carrying equipment up stairs, carrying a collapsed victim or advancing a charged hose line. The ambient conditions can also vary from the extremes of a high radiant heat load with live fire exposure to the normal ambient temperatures that often reach temperatures well above 30°C during the summer months. In 1987, changes in legislation led to the development of new protective clothing standards by the NFPA. These new clothing standards offered greater protection for the firefighter from the external hazards of their occupation, i.e., exposure to hazardous materials and extreme radiant heat for short periods of time. However, the new clothing ensembles had to have a greater thickness and reduced water vapour permeability to meet the protective standards. As a result, the dissipation of internal heat production was reduced. Therefore, although this new clothing offered greater protection from external hazards it placed the firefighter at greater risk of succumbing to hyperthermia and heat illness.

Heart attack is the number one cause of death for in-line fire fighters. An increase in body temperature places an additional strain on the heart to pump greater volumes of blood to the skin to promote heat loss to the environment. Any strategy or intervention

that reduces the heat stress of wearing protective clothing should reduce the strain on the heart and hopefully reduce the incidence of heart attack for the firefighter.

The following guide is a summary of research that was conducted at Defence Research and Development – Toronto with funding provided through a grant from the Workplace Safety Insurance Board of Ontario. The aims of this research project were twofold; first, to establish safe work limits for a range of ambient conditions representative of the warm summer conditions in the Toronto area; and second, to propose strategies that would reduce the heat stress of wearing the protective ensemble and increase the safety of the firefighter. Although we could not simulate the radiant heat of a live fire in our climatic facilities, we realized that greater than 95% of the firefighter's time while encapsulated does not involve direct exposure to extreme heat. The reader must remain cognizant of this fact and remember that our safe work limits are not intended for use during direct exposure to live fire. Our intervention strategies that are proposed, however, would be applicable in any environment that the firefighter must wear their protective clothing.

## 2. Phase 1

### 2.1 Establishing Safe Work Limits

This first phase of our research project involved recruiting 40 volunteers from the Toronto Fire Service. Over 70 volunteers were screened initially such that the physical characteristics and aerobic fitness levels of our selected participants were sufficiently diverse to ensure that our findings would be applicable to all firefighters. Subjects were assigned to one of four groups (with 10 subjects (9 male and 1 female) in each group) that performed very light, light, moderate or heavy exercise while wearing their protective clothing and carrying their SCBA. All subjects performed a familiarization trial and three experimental trials that involved randomly assigned exposures to 25°C, 30°C and 35°C at 50% relative humidity. Heat stress trials continued until body core temperature increased from resting levels (37.0°C) to 39.0°C, heart rate reached 95% of the individual's maximum value, dizziness or nausea precluded further exercise, the subject terminated the exposure due to exhaustion or the investigator terminated the trial because of safety concerns for the subject. Each heat stress exposure involved repeated 20-min bouts of work followed by a 10-min simulated SCBA air cylinder change that incorporated a brief period of no activity where the subject could remove their face shield and respirator and drink some water. Once the heat stress exposure had ended, subjects remained seated in the environmental conditions for a further 30-min recovery period with their helmet, face shield, respirator, SCBA, jacket, flash hood and gloves removed. The overpants were not removed but the Velcro was opened across the groin area.

The table below provides the mean exposure times at the three environmental conditions for the four groups.

*Table 1. Mean values ( $\pm$  standard error) for exposure times in minutes at the ambient temperatures of 25°C, 30°C and 35°C with 50% relative humidity for the four groups performing very light, light, moderate or heavy work.*

<b>Group</b>	<b>25°C</b>	<b>30°C</b>	<b>35°C</b>
<b>Heavy</b>	56.4 (4.4)	47.4 (3.3)	40.7 (2.3)
<b>Moderate</b>	91.9 (8.5)	65.4 (3.7)	54.0 (3.5)
<b>Light</b>	134.0 (9.3)	77.1 (3.1)	67.3 (3.0)
<b>Very Light</b>	196.1 (12.9)	121.2 (8.4)	86.8 (5.1)

Clearly, as the amount of internal heat production increased from very light to heavy work exposures times were reduced. Of note, however, is the impact of the environmental temperature on the magnitude of this reduction. Exposure times varied approximately 2-fold among the four work rates at 35°C whereas exposure times varied almost 3.5-fold at 25°C. At the cooler temperatures, there is a greater potential for heat

loss to the environment and a greater potential for the sweat that is produced on the skin surface to move through the clothing layers and be evaporated. This is especially true at the lower rates of heat production.

At the same time as these laboratory trials were being conducted, an associate at a US Army research laboratory agreed to perform thermal manikin testing of the new protective clothing ensemble purchased by the Toronto Fire Service. The purpose of this thermal manikin testing was to generate thermal resistance and water vapour permeability coefficients that could be used in a mathematical heat strain model to predict core temperature increases in different environmental conditions. Model predictions were then compared to the human data collected during the laboratory trials. The predicted responses were in close agreement to the mean responses observed during the laboratory trials. As a result, we felt confident in using the model to predict times for core temperature to increase to certain levels under environmental conditions that were not specifically studied in the laboratory trials. Three sets of tables were then generated that predicted the time required for core temperature to increase to 38.0°C, 38.5°C and 39.0°C. The latter rise in core temperature is considered by the US Army to be associated with the risk of a 5% incidence of heat casualties and it is the core temperature that is used by the Canadian Director of Nuclear, Biological and Chemical (NBC) Defence to predict work times in NBC protective clothing. This set of prediction tables for the Toronto Fire Service was defined as their “maximal operational limit”. A set of predictions for a rise in core temperature to 38.0°C was also included since provincial ministry guidelines have adopted the American Conference of Government Industrial Hygienists (ACGIH) recommendations for the management of heat stress in the workplace. However, the Toronto Fire Service would not be governed by these ministerial guidelines under conditions of emergency rescue and response. Nevertheless, we have defined this set of prediction tables as “no risk of heat illness”. A third set of prediction tables have been developed for an increase in core temperature to 38.5°C. This set of predictions have been defined as “normal operations, low risk of heat stress” and give the Toronto Fire Service greater flexibility than the restrictions imposed by ministry guidelines for planning emergency response operations.

In the slide rule that was produced, these prediction tables (shown below) for the time required for core temperature to increase to 38.0°C, 38.5°C and 39.0°C were colour-coded as green, yellow and red, respectively. All of the continuous work times included a 10-min period of reduced activity to simulate the time required to change a cylinder of air following each 20-minutes of work. These tables served as inserts in the slider rule that displayed predicted continuous work times for different environmental conditions and work rates. The front cover of the slide rule is also shown below.

**2.1.1 Green - No risk of heat illness (time in minutes for core temperature to increase to 38.0°C) for very light (VL), light (L), moderate (M) or heavy (H) work.**

Green				Green				Green				Green			
Dry				Moderate				Humid				Very Humid			
VL	L	M	H	VL	L	M	H	VL	L	M	H	VL	L	M	H
107	69	52	39	104	68	51	38	101	67	50	37	98	63	50	37
90	62	48	36	86	60	47	35	83	59	46	35	81	67	45	34
77	56	44	34	74	54	43	33	71	52	42	32	67	51	41	31
67	51	41	32	63	49	40	30	60	47	39	29	58	45	37	28
60	46	38	29	55	44	37	28	51	42	35	26	48	40	33	25
52	42	35	27	48	39	33	25	45	37	31	22	42	35	29	20
46	38	32	24	43	35	30	21	39	33	27	18	36	30	24	15

**2.1.2 Yellow – Normal Operations, Low risk of heat illness (time in minutes for core temperature to increase to 38.5°C) for very light (VL), light (L), moderate (M) or heavy (H) work. NL refers to no limit or at least five hours of continuous work.**

Yellow				Yellow				Yellow				Yellow			
Dry				Moderate				Humid				Very Humid			
VL	L	M	H	VL	L	M	H	VL	L	M	H	VL	L	M	H
NL	134	85	58	NL	130	83	56	NL	125	82	56	NL	117	80	56
NL	110	75	53	234	106	75	52	204	101	73	51	186	98	71	50
161	93	69	50	144	87	66	48	133	84	64	47	122	81	62	46
120	80	62	46	109	76	60	44	100	71	57	42	92	68	54	40
97	70	56	42	87	65	53	40	80	61	50	37	72	57	48	35
80	62	51	38	72	57	49	35	65	53	44	31	60	49	41	27
69	55	46	33	61	50	42	28	55	45	38	24	50	41	33	20

**2.1.3 Red – Maximal Operational Limit, Some risk of heat illness (time in minutes for core temperature to increase to 39.0°C) for very light (VL), light (L), moderate (M) or heavy (H) work. NL refers to no limit or at least five hours of continuous work.**

Red				Red				Red				Red			
Dry				Moderate				Humid				Very Humid			
VL	L	M	H	VL	L	M	H	VL	L	M	H	VL	L	M	H
NL	NL	141	82	NL	NL	139	81	NL	NL	134	79	NL	255	130	78
NL	233	117	75	NL	205	113	73	NL	196	110	71	NL	173	106	69
NL	162	102	68	NL	144	97	66	NL	136	93	64	NL	126	88	62
NL	125	88	62	233	113	83	59	183	106	81	56	155	98	75	53
169	103	78	56	141	93	73	52	121	85	68	49	107	79	64	45
125	86	69	50	105	78	64	45	92	71	58	40	82	65	53	35
98	75	61	43	84	67	55	36	74	59	49	30	65	53	42	25

**2.1.4 Front Cover of Slide Rule**


**Commanders Guide for Continuous Work Times for Firefighters**

<p><b>Work Intensity</b>          Very Light = VL          Light = L          Moderate = M          Heavy = H</p>	<p><b>Humidity</b>  <b>Dry</b> (≤ 20%)  <b>Moderate</b> (21-40%)  <b>Humid</b> (40-64%)  <b>Very Humid</b> (≥ 65%)</p>	<p><b>Instructions for Use</b></p> <ol style="list-style-type: none"> <li>Select desired <b>work intensity</b> and <b>heat stress colour</b> (see inside of insert for definition).</li> <li>Adjust slide rule until appropriate combination of <b>humidity, heat stress colour and work intensity</b> appear.</li> <li>For specific temperature range <b>continuous</b> work times are provided that include <b>ten minute rest periods</b> for rehydration and change of air cylinders.</li> <li>Upon obtaining a <b>continuous limit</b> refer to <b>rehab guidelines</b> on back.</li> </ol> <p><b>Examples of work intensity for Emergency and Training Operations</b> (include but are not limited to)</p> <p><b>Heavy</b> – Victim carry, advancing with charged hose line, roof ventilation and stair climb with equipment.</p> <p><b>Moderate</b> – Primary search, overhaul, aerial and ground ladder set-up and vehicle extrication.</p> <p><b>Light</b> – Pump operations, light sweeping.</p> <p><b>Very Light</b> – Incident command staff.</p>
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<p><b>Heat Stress</b></p> <p style="background-color: yellow; text-align: center; padding: 2px;"><b>Yellow</b></p> <p><b>Humidity</b></p> <p style="background-color: yellow; text-align: center; padding: 2px;"><b>Moderate</b></p> <p><b>Temp (°C)</b></p> <table border="1" style="font-size: small;"> <thead> <tr> <th></th> <th>VL</th> <th>L</th> <th>M</th> <th>H</th> </tr> </thead> <tbody> <tr> <td>≤15</td> <td>NL</td> <td>130</td> <td>83</td> <td>56</td> </tr> <tr> <td>16-20</td> <td>234</td> <td>106</td> <td>75</td> <td>52</td> </tr> <tr> <td>21-25</td> <td>144</td> <td>87</td> <td>66</td> <td>48</td> </tr> <tr> <td>26-30</td> <td>109</td> <td>76</td> <td>60</td> <td>44</td> </tr> <tr> <td>31-35</td> <td>87</td> <td>65</td> <td>53</td> <td>40</td> </tr> <tr> <td>36-40</td> <td>72</td> <td>57</td> <td>49</td> <td>35</td> </tr> <tr> <td>≥41</td> <td>61</td> <td>50</td> <td>42</td> <td>28</td> </tr> </tbody> </table>		VL	L	M	H	≤15	NL	130	83	56	16-20	234	106	75	52	21-25	144	87	66	48	26-30	109	76	60	44	31-35	87	65	53	40	36-40	72	57	49	35	≥41	61	50	42	28	<p><b>Yellow = Normal Operations</b></p> <p><b>NL = No Limit</b> (5 or more hours ~ 300 min)</p> <p><small>*Work times do not include direct exposure to the radiant heat of a live fire.</small></p>
	VL	L	M	H																																					
≤15	NL	130	83	56																																					
16-20	234	106	75	52																																					
21-25	144	87	66	48																																					
26-30	109	76	60	44																																					
31-35	87	65	53	40																																					
36-40	72	57	49	35																																					
≥41	61	50	42	28																																					

This Project was funded by a research grant provided by the Workplace Safety and Insurance Board (Ontario) © Her Majesty The Queen in Right of Canada 2003.



The window in the slide rule shows the yellow or normal operational limits. The continuous work times that are displayed in the window reflect values for the different intensities of work defined as very light (VL), light (L), moderate (M) and heavy (H).

The humidity level in the window shown above is defined as moderate or between 21% and 40%. As an example, the slide rule predicts continuous work times of 60 minutes for moderate work at ambient temperatures between 26°C and 30°C. Thus, commanders should expect that firefighters could work for the equivalent of 2 cylinders of air before approaching a core temperature of 38.5°C, assuming each cylinder lasts 20 minutes and there is a 10-min period that follows each 20-min work period to allow an exchange for a fresh cylinder of air. As another example, commanders should not expect firefighters to perform continuous heavy work for the equivalent of 2 cylinders of air at ambient temperatures above 25°C since exposure times are less than 50 minutes (the time required for two 20-min work periods and a 10-min period to change cylinders). At ambient temperatures at or below 25°C, work times are close to or exceed 50 minutes and thus firefighters could safely perform continuous heavy work for the equivalent of two cylinders of air before core temperature would be approaching 38.5°C.

In addition to establishing these continuous work times, it was clear that alternative strategies were necessary to assist with the reduction in core temperature after achieving exposure limits. **A passive 30-minute recovery period with most of the protective clothing removed did little to promote cooling while still exposed to the warm ambient environment. The data also revealed that heart rate should not be used to indicate the extent of the thermal strain for the firefighter during the recovery period.**

## 3. Phase 2

### 3.1 Replacing Station Uniform Pants with Shorts

One option to reduce the heat stress associated with wearing a protective clothing ensemble is to remove some of the clothing layers that comprise the ensemble. The clothing layers that are removed, however, cannot affect the protection and safety of the ensemble provided to the firefighter. Recent evidence from the New York City Fire Department has shown that the replacement of the duty uniform long pants and shirt worn under the bunker clothing with shorts and a T-shirt did not increase the incidence of burn injury. In addition, their analyses revealed that medical leave for heat exhaustion also decreased when shorts and T-shirt were worn under the bunker clothing.

Our focus was to provide physiological evidence that replacing the duty uniform long pants with shorts improved exposure time during heat stress. To accomplish this, 24 of the subjects tested in phase 1 performed an additional trial while wearing shorts under their bunker pants and exercising at 35°C. Our data revealed that both core temperature and heart rate were significantly reduced once exposure times exceeded 1 hour. In addition, as Table 2 shows below, exposure times were significantly increased 10-15% for the lighter activities that involved wearing the protective clothing for longer periods of time. **The important message is that the longer the protective ensemble needs to be worn the greater will be the advantage of replacing the duty uniform pants with shorts.**

Table 2 *Mean values (± standard error) for exposure times in minutes at 35°C with 50% relative humidity for the four groups performing very light, light, moderate or heavy work while wearing either duty uniform long pants or shorts under the bunker pants.*

Group	Long Pants	Shorts
Heavy	40.8 (2.4)	43.5 (2.2)
Moderate	53.5 (3.7)	54.2 (3.4)
Light	65.8 (3.9)	73.3 * (3.4)
Very Light	83.5 (4.7)	97.0 * (5.1)

\* Significant difference between long pants and shorts.

### 3.2 Hydration

Fluid replacement during work in the heat is critical for 2 reasons; first, to maintain sweat rates to promote evaporative cooling; and, second, to maintain blood volume

such that the heart can continue to send warm blood to the skin to assist with the transfer of body heat to the environment. In addition, fluid replacement following work in the heat is critical to restore body fluid levels to normal such that the individual does not begin a subsequent exposure in the heat in a dehydrated state.

Fifteen of our subjects from phase 1 returned to perform another familiarization trial and 4 experimental trials that involved wearing their protective ensemble and performing light exercise at 35°C. The experimental trials manipulated the amount of cool water that was provided throughout the heat stress and included either no fluid, or 1/3, 2/3 and full fluid replacement determined from the sweat rates measured during the familiarization trial. Subjects performed two 20-min bouts of light exercise that were separated by a 10-min simulated SCBA cylinder change. Following this 50-min cycle, subjects removed most of their protective clothing (except for their boots and bunker pants) and then sat for a 20-min passive recovery period. If subjects were able to continue at this point, they then re-encapsulated in their protective ensemble and began the 50-min cycle of exercise all over again. The 50-min of exercise and 20-min of passive recovery continued until one of our end-point criteria were reached that was described previously. The exception was that core temperature was allowed to increase to 39.5°C during the exercise phase of these experiments. Aliquots of fluid were provided immediately prior to beginning the heat-stress exposure, during the simulated SCBA cylinder change and at the beginning of the passive rest recovery.

Table 3 below shows the effects of fluid replacement on exposure time. Remembering that some of the exposure time was spent resting, the table also shows the impact of fluid replacement on work time. Exposure times were increased approximately 20% when either two-thirds or full fluid replacement was provided and these improvements approached 25% when work time was calculated.

Table 3 *Mean values (± standard error) for exposure times and work times at 35 °C with 50% relative humidity while subjects performed light work while wearing their firefighting protective ensemble and received either no fluid or one-third, two-thirds or full fluid replacement.*

	Fluid Replacement			
	No Fluid	One-Third	Two-Thirds	Full
<b>Exposure Time (min)</b>	95.3 (3.8)	104.2* (5.8)	112.9* (5.2)	111.8* (3.5)
<b>Work Time (min)</b>	65.3 (3.8)	74.2 (5.8)	82.9* (5.2)	82.6* (3.5)

\* Significantly different from the no fluid trial.

Subjects reported gastric discomfort when they were asked to consume large volumes of fluid and most were unable to consume the equivalent of the full-fluid replacement aliquots. In addition to reducing core temperatures and heart rates, fluid replacement also conferred another advantage to the subjects. Fluid replacement allowed subjects to attain higher core temperatures during the work periods that involved weight-bearing activity. When fluid was not provided, most subjects ended their trials during a rest

period and complained of being dizzy when they attempted to stand up and re-encapsulate. In contrast, almost all of the subjects ended their exposure during a work period when two-thirds of full fluid replacement was provided. **This is an important safety issue because it means that firefighters will be less likely to succumb to exertional collapse as core temperature rises to high levels if fluid is consumed. Another important message is that any amount of fluid replacement volume is better than no fluid replacement for slowing the rise in core temperature and allowing individuals to work longer in the heat while wearing protective clothing.**

### 3.3 Cooling

Our findings from the first phase of the research project revealed that alternative cooling strategies were necessary to help reduce core temperature during periods of rest recovery when the firefighter was able to remove most of their protective clothing. Our subjects performed a familiarization trial and three experimental heat-stress exposures that involved passive cooling or active cooling with either a mister or forearm and hand submersion in cool water. The experimental design was similar to that described above for the study on hydration. The different cooling strategies were applied during the 20-min rest recovery periods. During all trials, subjects received a volume of fluid that was equivalent to the amount of sweat lost during the familiarization trial.

As previously described, the passive rest recovery involved removing most of the protective clothing and sitting for 20 minutes while exposed to the ambient conditions of 35°C and 50% relative humidity. The mister (Versa Mist®), as shown in Figure 1, delivered a fan-propelled fine mist vapor at a rate of 2000 cubic feet per min. Subjects were seated approximately 5 feet in front of the mister where the wind speed at the point of contact for the subjects was  $1.94 \text{ m}\cdot\text{s}^{-1}$  ( $7 \text{ km}\cdot\text{h}^{-1}$ ). The hand and forearm submersion was accomplished using an insulated tank that was temperature controlled ( $17.4 \pm 0.2^\circ\text{C}$ ) prior to submersion in order to simulate hose-line water temperature. During submersion, subjects leaned over the tank with hands and arms submerged to the elbow joint for 20 min (Figure 2).

Both cooling methods significantly reduced core temperature and heart rates during the heat-stress exposure and extended exposure and work times. As shown in Table 4 below, these positive effects were most dramatic when forearm and hand submersion was used to cool the subjects during the rest periods. Compared with passive cooling, forearm and hand submersion extended exposure times 65% and total work time by 60%. In addition, more subjects ended their trial that involved the forearm and hand cooling because they were physically exhausted from having to carry their SCBA for such a long time rather than because they had attained dangerously high core temperatures.



*Figure 1* Representation of the mister used during the cooling trials.



*Figure 2* Representation of the hand and forearm submersion in cool water.

**Table 4** Mean values ( $\pm$  standard error) for exposure times and work times at 35°C with 50% relative humidity while subjects performed light work while wearing their firefighting protective ensemble and received either passive cooling or active cooling with either a mister or forearm and hand submersion during rest periods.

	Cooling Method		
	Passive	Mister	Forearm and Hand Submersion
<b>Exposure Time (min)</b>	108.0 (3.59)	139.1* (8.28)	178.7* (13.00)
<b>Work Time (min)</b>	78.0 (3.59)	95.1* (4.96)	124.7* (7.94)

\* Significantly different from the other cooling methods.

**Compared with the condition of providing passive cooling and no fluid replacement** (see Table 3), **providing fluid replacement together with forearm and hand submersion during recovery periods effectively doubled exposure and work times.** Thus, providing fluid and active cooling with forearm and hand submersion in cool water are easy and very effective ways to manage the heat stress of wearing firefighting protective clothing.

## 4. Recommendations

### 4.1 Safe Work Limits

1. When wearing firefighting protective clothing, a major issue of contention is the length of time that an individual can work before succumbing to exertional collapse or heat exhaustion. In fact, the main goal should be to set work limits in such a way that the individual approaches but never reaches this state.
2. If operational requirements permit, Commanders should rotate responsibilities for their firefighters between heavier and lighter work tasks. This would be an effective method to reduce the average workrate and thereby extend total work time.
3. At ambient temperatures above 25°C, passive recovery is not recommended as a means to promote effective body cooling and to reduce core temperature. Furthermore, during passive recovery in warm or hot environments, HR **should not** be used as an indicator for the extent of heat strain being experienced by the firefighter.

### 4.2 Pants Versus Shorts

1. Replacing the duty uniform pants that are worn under the bunker pants with shorts will reduce the heat strain during work efforts that last in excess of 60 minutes. Together with the previous work conducted in support of the New York City Fire Department, we recommend the implementation of this practice for the Toronto Fire Service and other fire departments considering this option.

### 4.3 Hydration Strategies

1. Fluid replacement recommendations are given below for a 90 kg individual and are based on a 70% fluid replacement schedule.

Prior to donning your protective ensemble (if possible) and during **every SCBA cylinder change**, consume a minimum of,

200 mL (7 ounces) of water for ambient temperatures of 25°C or below,  
300 mL (10 ounces) of water for ambient temperatures of 25°C to 30°C,  
400 mL (13 ounces) of water for ambient temperatures of 30°C and above,

Regardless of environmental condition, 500 mL (16 ounces) of water should be consumed during the final rehabilitation period.

2. **Recommended volumes will be proportionally higher or lower depending on individual body mass.** To determine replacement volumes for a different body mass, divide the recommended absolute volume by 90 kg and then multiply by the new mass. As an example, at ambient temperatures above 30°C, fluid replacement volumes after

each cylinder change should approximate 300 mL (and not 400 mL) for a 70 kg individual.

3. The use of electrolyte and carbohydrate sport drinks, such as Gatorade® or Powerade®, will promote more effective body rehydration than the use of water alone. The use of these sport drinks should be encouraged especially at the end of the work shift to ensure that firefighters return to work the next day in a normal hydrated state and are not still dehydrated from the prior day's activities.

#### 4.4 Forearm and Hand Submersion

1. Firefighters should remove their SCBA, helmet/hood, facepiece, gloves and jacket and open their pants. They then should submerge their forearms and hands in cool water with their hands open and fingers extended for 20 minutes.
2. Approximately two-thirds of the body cooling will occur in the first 10 minutes of submersion. Thus, rehabilitation procedures should aim for a minimum of 10 and a maximum of 20 minutes of cooling.
3. The effectiveness of the body cooling is dependant on the water temperature. Our recommendations are based on expected in-line hose temperatures around 18°C. Cooler water temperatures will promote faster body cooling whereas the reverse will be true with the use of warmer water. In-line hose temperatures may vary throughout the year and fire services should be aware that these variations may impact on the cooling provided to the firefighter through forearm and hand submersion.

A summary of these recommendations is included on the back cover of our slide rule as shown below.

**Guide for Fluid Replacement, Rehabilitation and Personnel Management**

<p><b>Signs and Symptoms of Heat Illness</b></p> <p><b>Heat Exhaustion</b> – Excessive fluid loss leading to fatigue, weakness, pale clammy skin, circulatory collapse, low blood pressure, nausea, headache, dizziness and possible fainting. Refer to EMS for assessment.</p> <p><b>Treatment</b> – Stop activity, lie individual down, remove clothing, replenish fluids and provide active cooling.</p> <p><b>Heat Stroke</b> – Body temp in excess of 40°C, disorientation and unconsciousness.</p> <p><b>Treatment</b> – Remove clothing and cool body immediately by immersing in water, wrapping in wet cool clothing or wetting skin with cool water. Refer to EMS for evacuation to medical facility, while continuing to cool during transfer.</p>	<p><b>Fluid Replacement (for an 90 kg individual)</b> – <i>Note:</i> values will be proportionally higher or lower depending on individual body mass</p> <p>Prior to donning PPE (if possible) and during every cylinder change, consume a minimum:</p> <ul style="list-style-type: none"><li>200 mL (7 ounces) of water for ambient temperatures of 25°C or below</li><li>300 mL (10 ounces) of water for ambient temperatures of 25°C to 30°C</li><li>400 mL (13 ounces) of water for ambient tepeatures of 30°C and above</li></ul> <p>Regardless of environmental condition, 500 mL (16 ounces) of water should be consumed during the final rehabilitation period.</p> <p><b>Rehabilitation Strategy</b> – Forearm Submersion (water temp ~10°C-20°C)</p> <p>Remove SCBA cylinder, helmet/hood, facepiece, gloves and jacket and open pants. Submerge forearms in cool water with hands open and fingers extended for 20 min.</p> <p>During submersion, fluids should be administered in order to maximize the duration of hand submersion and cooling capacity.</p> <p><b>Personnel Management</b> – Following the first rehab session, personnel returning to work need an additional cooling session following each subsequent cylinder of air.</p> <p>Before returning to Heavy or Moderate work an intervening assignment of light work and cooling should be completed.</p> <p>Continuous rotation of personnel between lighter and heavier work is strongly recommended.</p>
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## **List of symbols/abbreviations/acronyms/initialisms**

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ACGIH	American Conference of Government Industrial Hygenists
DND	Department of National Defence
FPC	Firefighting Protective Clothing
H	Heavy
L	Light
M	Moderate
NFPA	National Fire Prevention Association
NBC	Nuclear, Biological and Chemical
SCBA	Self Contained Breathing Apparatus
VL	Very Light