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**OFFENSIVE FOG WATER ATTACK REDUCES FIREFIGHTING TIME  
AND HEAT STRAIN DURING SHIPBOARD FIREFIGHTING**

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## SUMMARY

### Problem.

The goal of shipboard firefighting is to gain control of the fire threat and prevent its spread. Traditionally, this is accomplished using the direct (DIR) attack method. In this approach water is applied to the base of the fire as either a straight-stream or narrow-angle fog. However, this approach is not advantageous for fires shielded by obstructions, fires with multiple fire sources, or fires of low visibility. Normally, heat, smoke, and gases associated with these types of fires do not prevent entry into the fire space. However, these conditions can force firefighters from the fire space and/or prolong the time required to locate the fire. Use of a fog (FOG) attack method, where a medium angle fog is delivered upward onto the overhead burning gases, has the potential to maintain the thermal balance of the overhead gas layer and improve visibility. These benefits should allow firefighters to locate more rapidly the seat of the fire and extinguish the flames. However, controversy surrounds use of the FOG attack method because of its potential to create steam and possibly increase heat strain and risk of heat-related injuries.

### Objective.

The purpose of this study was to compare the use of two shipboard firefighting attack methods, direct (DIR) straight-steam water and fog (FOG), on firefighter heat strain.

### Approach.

Fire tests were conducted aboard the Ex-USS Shadwell (LSD-15), Mobile, AL. Eight males and four females aged  $31 \pm 4$  yr served as subjects. Subjects wore Nomex coveralls and the single-piece U.S. Navy firefighting ensemble and respired from an A-4 Oxygen Breathing Apparatus. Data logger recordings were made of heart rate (HR), rectal ( $T_{re}$ ), chest ( $T_{ch}$ ), arm ( $T_{ar}$ ), hand ( $T_{ha}$ ), finger ( $T_{fi}$ ), thigh ( $T_{th}$ ), foot ( $T_{fo}$ ), and big toe ( $T_{to}$ ) temperatures during alternating DIR and FOG fire tests.

During DIR, the hose team attempted to advance immediately to the fire source and apply water as a straight stream (narrow angle fog) to the seat of the fire. During FOG, the team entered the fire compartment and attempted to discharge medium angle ( $60^\circ$ ) fog spray in three short bursts (2 to 3 s) at a  $45^\circ$  angle upwards onto the overhead burning gases. This was followed by application of a straight stream of water (nozzle angle  $30^\circ$ ) to the seat of the fire. Statistical analysis included t-tests for matched pairs and analysis of covariance with peak dependent values adjusted for baseline resting values. The alpha level equalled 0.05.

### Results.

Fire space upper level air temperatures at time of entry averaged ( $\pm$ SD)  $591 \pm 43^{\circ}\text{C}$ . During DIR, the attack team was not able to control the fire and therefore the conditions for flashover evolved. This required the attack team to evacuate the space and conduct further attacks from the compartment doorway. During FOG, the attack team was able to control the fire within 2 min and complete final extinguishing of flames with all attack team personnel inside the fire compartment. Thus, firefighting time was significantly ( $p < .05$ ) less for FOG ( $9.1 \pm 0.6$  min) compared to DIR ( $10.9 \pm 0.6$  min).

FOG peak  $T_{re}$  ( $\bar{X} = 38.2^{\circ}\text{C}$ ),  $T_{ch}$  ( $\bar{X} = 39.6^{\circ}\text{C}$ ), and  $T_{ar}$  ( $\bar{X} = 40.0^{\circ}\text{C}$ ) were lower ( $p < .05$ ) compared to DIR ( $38.5^{\circ}\text{C}$ ,  $40.4^{\circ}\text{C}$ ,  $41.0^{\circ}\text{C}$ , respectively). However, differences between DIR and FOG for peak  $T_{ba}$  ( $\bar{X}s = 40.2^{\circ}\text{C}$ ),  $T_{fi}$  ( $\bar{X}s = 41.6^{\circ}\text{C}$ ),  $T_{th}$  ( $\bar{X}s = 38.2^{\circ}\text{C}$ ),  $T_{fo}$  ( $\bar{X}s = 36.8^{\circ}\text{C}$ ), and  $T_{to}$  ( $\bar{X}s = 36.6^{\circ}\text{C}$ ) were nonsignificant. Peak HR for FOG ( $X = 171$  bpm) was lower ( $p < .05$ ) than DIR ( $X = 185$  bpm). Differences between DIR and FOG for rates of increase of all measures were nonsignificant.

### Conclusions.

Compared to DIR, use of FOG reduced upper air compartment temperature which allowed attack team personnel to complete flame extinguishment from within the compartment. This lead to a shorter firefighting time and lower firefighter heat strain.

## INTRODUCTION

The principal objective of shipboard firefighting is to gain control of the fire, thereby preventing or minimizing spread of the fire. There are two basic methods of attack that firefighters use to control fires (Naval Sea System Command, 1993). They are the direct (DIR) attack and the indirect attack. The DIR attack is preferred for an incipient or growing fire. It is most often used when firefighters can advance into the immediate fire area and attack the fire without the need to maneuver around obstructions. In the DIR attack method, water is placed onto the seat of the fire as straight stream or narrow angle (30°) fog. The indirect attack method is used when heat, gases, and smoke from a growing or advanced fire makes access into the fire space difficult. This approach is preferred for the post flashover or fully developed fire scenario.

There are, however, a wide range of fires for which the DIR or indirect attack methods are not advantageous. These include: (1) growing or steady state fires where the seat of the fire is shielded from DIR attack by obstructions, (2) growing or steady state fires where there are multiple fires sources scattered about a space, and (3) low visibility fires where heat and smoke conditions obscure the seat of the fire. The heat, smoke, and gaseous conditions associated with these fire scenarios typically do not prevent entry into the fire space. However, the time that it takes to maneuver within the fire space in order to locate and directly attack the seat of the fire increases the possibility that the fire will continue to grow. This increases the potential of the fire to develop flashover conditions.

A possible solution to fires shielded by obstructions, fires with multiple fire sources, or fires of low visibility is the application of an offensive fog (FOG) attack. Normally, a FOG attack, using either a medium or wide nozzle angle, is limited to defensive situations or general cooling of the overhead gas layer (Grimwood, 1992). It has been argued that FOG streams dispersed at an angle greater than 30° and discharged onto the overhead gases can disrupt the thermal balance of the overhead layer, create a smoke layer which can reduce firefighter visibility, and promote firefighter thermal discomfort (Knapp, 1996). However, others (Williams et al., 1994) have argued that when properly executed, this tactic has the advantage of cooling the hot gas layer without generating excessive amounts of steam, and reducing disruption of the thermal balance within the fire space. The net effect is to maintain conditions within the fire space, thereby allowing firefighters to continue with their efforts to locate and extinguish the fire source.

Heat strain is a major problem for personnel engaged in shipboard firefighting activities (Bennett et al., 1993). For the firefighter, any factor that prolongs firefighting increases heat

strain and the risk of fire or heat-related injury. At this time, little information is available evaluating the impact of DIR and FOG attack methods on firefighter heat strain. Thus, the purpose of this study was to compare the use of two shipboard firefighting water attack methods, direct straight stream (DIR) and offensive fog (FOG), on firefighter heat strain.

## METHODS

### Fire Test Series.

The fire tests were part of the 1994 Fleet Doctrine Evaluation Test Series devoted to evaluating the use of offensive FOG as a method for controlling a growing fire threat. The tests were developed and conducted by the Navy Technology Center for Ship Safety and Survivability, Naval Research Laboratory (NRL). The tests occurred aboard the Ex-USS Shadwell (LSD-15), a decommissioned vessel used for damage control research, located at Little Sand Island, Mobile, AL (Carhart & Williams, 1988).

### Experimental Design.

Eight fire tests conducted over 5 days were used to evaluate the effect of DIR and FOG on firefighter heat strain. During this time, subjects fought four fires using the DIR attack and four fires using the FOG attack in alternating order. Due to rotation of attack team personnel, only four of the eight fires were conducted using the same team members.

### Clothing Ensembles.

Fire retardant coveralls (Nomex) served as the undergarment for all subjects. During firefighting, safety and hose team members were dressed in the standard Navy firefighting ensemble (FFE). The FFE consisted of a single-piece heavy insulated fire retardant suit, leather gloves, rubber boots, flash hood, and hard helmet. Subjects respired from an A-4 Oxygen Breathing Apparatus (OBA).

### Subject Volunteers.

Eight male and four female active duty U.S. Navy personnel served as subject volunteers. Three groups of subjects were used to form three attack teams. All subjects were fleet personnel and included a damage control team from the Precommissioning Unit of the USS Russell (DDG 59), a team of Propulsion Examination Board (PEB) members from both the Atlantic and Pacific Fleets, and an all-female team made up of firefighting instructors from Fleet Training Command Treasure Island and Repair Party members from the USS Emory S. Land (AS 39). Each team consisted of a team leader, a nozzleman, a hoseman, and a plugman or back-up.

Prior to the start of the test series, all subjects completed a medical history questionnaire. All potential subjects were screened for medical contraindications to firefighting by a medical officer prior to participation in this study. The study protocol was reviewed and approved by the Committee for the Protection of Human Subjects at the Naval Health Research Center. All subjects gave their voluntary consent, reviewed a privacy act statement, and signed an informed consent prior to participation. Body height and weight were measured using a standard medical scale. Body surface area (BSA) was calculated using height and weight according to a regression equation developed by DuBois (Carpenter, 1964). The physical characteristics of the subjects are presented in Table 1.

Table 1. Physical characteristics of the subjects.

Subj.	Gender	Age (yrs)	Height (cm)	Weight (kg)
1	male	29	176.5	84.4
2	male	33	190.5	93.4
3	male	32	177.8	79.4
4	male	24	172.7	74.8
5	male	30	175.3	79.4
6	male	36	177.8	79.4
7	male	30	190.5	95.2
8	male	35	190.5	88.4
Mean $\pm$ SD		31.0 $\pm$ 4.0	181.4 $\pm$ 7.7	84.3 $\pm$ 7.4
9	female	27	154.9	56.7
10	female	36	165.1	63.5
11	female	31	165.1	73.9
12	female	30	167.6	65.8
Mean $\pm$ SD		31.5 $\pm$ 3.0	163.2 $\pm$ 5.6	65.0 $\pm$ 7.1

#### Physiological Measurements.

During each DIR and FOG fire test, physiological responses were recorded from 4 subjects serving as the firefighting hose team members. Prior to each test, subjects inserted a rectal thermistor to a depth of 20 cm. Skin thermistors were placed over the right shoulder and upper right chest, top of the right hand, side of the right index finger, middle of the right thigh,

instep of the right foot, and outside of the right big toe. HR was recorded using a bipolar chest electrode configuration. HR was also recorded using a electronic transmitter/receiver system (Polar USA, Stamford, CT 06902). During each test, heart rate (HR), rectal ( $T_{re}$ ), chest ( $T_{ch}$ ), arm ( $T_{ar}$ ), hand ( $T_{ha}$ ), index finger ( $T_{fi}$ ), thigh ( $T_{th}$ ), foot ( $T_{fo}$ ), and big toe ( $T_{to}$ ) temperatures were recorded continuously for each subject by a Squirrel data logger (Science/Electronics, Miamisburg, OH 45342). The data logger was worn over the coveralls and underneath the FFE of the hose team members.

#### Test Protocol.

On test days, all subjects attended a prefire meeting to discuss the fire suppression scenario. Subjects were then prepared for recording of physiological responses. After ignition of the fire and sounding of the shipboard damage control alarm, subjects dressed for firefighting on the ship's fo'c'sle. After dressing, subjects transported hoses and equipment to the fire space, set-up smoke curtains and ventilating fans, and conducted firefighting activities. During each fire test, the team leader followed in order by the nozzleman, hoseman, and plugman moved into the fire space. Termination of the test was followed by a recovery period where subjects were cooled and rehydrated. This was followed by a postfire brief to discuss the firefighting attack methods and procedures.

#### Fire Test Scenarios.

The objective of the tests was to develop a realistic fire threat that would provide a severe challenge to the hose team attempting a traditional DIR attack using a straight stream of water. The fire threat developed represented a growing or steady state Class A fire that had three fire sources dispersed about the fire compartment. The fire threat was typified by flames rolling across the overhead and upper layer temperatures in the range of 500°C to 600°C. These conditions increase the potential for flashover in the fire space.

The fire compartment volume was approximately 2,600 cu. ft. The fuel load consisted of three wood cribs, six particle board panels, and 18 newspaper filled cardboard boxes. The wood cribs were ignited by n-heptane pool fires. Obstructions were placed between the fire sources and the entry point to the fire compartment. These obstructions forced the attack hose team to advance well into the space before being able to apply water directly onto the seat of the fire.

For DIR, the hose team with the nozzle set at an angle of 30° attempted to advance to the fire source and apply, in a series of two or five short bursts lasting 2 to 3 s, a straight stream of water to the seat of the fire. For FOG, the hose team entered into the fire compartment 1.2 to 1.8 m, took a crouched position, set the nozzle angle to a medium angle (60°) and discharged the FOG spray at 45° into the overhead burning gases. Water was discharged in a series of two or three short bursts lasting 2 to 3 s. After fire knockdown, the nozzle was adjusted to an angle of 30° and the team advanced towards the fire and applied a straight stream of water (DIR attack) to the seat of the fire.



### Statistical Analysis

Evaluation of the FOG and DIR methods was based on comparison of matched-pair physiological responses from one DIR and one FOG test. Statistical analyses included t-tests and analysis of covariance with the peak dependent variable values adjusted for preentry resting values. Significance was accepted at an alpha level of 0.05.

## RESULTS

Prior to the sound of the fire alarm, firefighters rested in the crew mess. During this time baseline physiological responses were recording. Upon the sound of the alarm, firefighters moved quickly to the repair locker to commence prefirefighting activities. During this time, firefighters dressed in FFE and OBA, transported hoses and equipment to the fire space, and set-up smoke curtains and ventilating fans. Performance of these activities increased the HR and body temperatures of all firefighters. As expected, differences in baseline or prefire entry physiological responses between DIR and FOG tests were nonsignificant. The combined means are presented in Table 2.

Table 2. Comparison of combined DIR and FOG baseline and preentry body temperatures and heart rate.

Variable	Baseline	Preentry	Comparisons
$T_{re}$ (°C)	$37.4 \pm 0.2$	$37.6 \pm 0.2$	$p < .05$
$T_{ch}$ (°C)	$34.2 \pm 0.8$	$36.6 \pm 0.2$	$p < .05$
$T_{ar}$ (°C)	$34.5 \pm 0.8$	$36.3 \pm 0.9$	$p < .05$
$T_{ha}$ (°C)	$30.2 \pm 1.4$	$33.3 \pm 1.9$	$p < .05$
$T_{fi}$ (°C)	$26.8 \pm 2.8$	$32.8 \pm 2.3$	$p < .05$
$T_{th}$ (°C)	$32.3 \pm 1.1$	$34.6 \pm 1.1$	$p < .05$
$T_{fo}$ (°C)	$29.6 \pm 1.8$	$31.6 \pm 2.7$	$p < .05$
$T_{to}$ (°C)	$25.3 \pm 1.8$	$27.8 \pm 2.8$	$p < .05$
HR (bt•min <sup>-1</sup> )	$76 \pm 12$	$133 \pm 22$	$p < .05$

Fire compartment temperatures in the overhead at the time of entry averaged ( $\pm$ SD)  $580 \pm 47^{\circ}\text{C}$  for the DIR tests. During DIR, average upper and lower air compartment temperatures ranged between  $600^{\circ}\text{C}$  and  $400^{\circ}\text{C}$ , respectively, during the first 2 min of the attack. During DIR, the attack team was not able to control the fire and therefore the conditions for flashover evolved and required the attack team to evacuate the space and continue the attack from the doorway. After retreating from the compartment and during subsequent attack from the doorway, average upper and lower air compartment temperatures ranged between  $400^{\circ}\text{C}$  and  $200^{\circ}\text{C}$ , respectively, throughout the remainder of the attack.

Fire compartment temperatures in the overhead at the time of entry averaged ( $\pm$ SD)  $602 \pm 48^{\circ}\text{C}$  for the FOG tests. During FOG, average upper and lower air compartment temperatures decreased immediately with the first series of burst such that by the second minute both upper and lower temperatures averaged  $350^{\circ}\text{C}$ . Additional bursts of FOG further reduced these temperatures to less than  $200^{\circ}\text{C}$  throughout the remainder of the attack. During FOG, the attack team was able to control the fire within 2 min and extinguish all flames from within the fire compartment. Thus, firefighting time (Figure 1) was significantly ( $p < .05$ ) less for FOG ( $9.1 \pm 0.6$  min) compared to DIR ( $10.9 \pm 0.6$  min).

Actual firefighting, including initial and all subsequent water attacks from inside and outside the fire space, promoted increases in HR and body temperatures (Table 3). Analysis of peak dependent variable responses for DIR and FOG recorded for actual firefighting, adjusted for differences in baseline values using analysis of covariance methods are shown in Table 3. FOG peak  $T_{re}$ ,  $T_{ch}$ , and  $T_{ar}$  were significantly lower ( $p < .05$ ) compared to DIR, respectively (Figure 2). However, there were no differences between DIR and FOG for peak  $T_{ha}$ ,  $T_{fi}$ ,  $T_{th}$ ,  $T_{fo}$ , or  $T_{to}$  (Figure 3). Peak HR for FOG was also significantly lower ( $p < .05$ ) than DIR (Figure 4).

Table 3. Comparison of peak body temperatures and heart rate during actual firefighting between DIR and FOG.

Variable	DIR	FOG	Comparisons
$T_{re}$ ( $^{\circ}\text{C}$ )	$38.5 \pm 0.1$	$38.2 \pm 0.1$	$p < .05$
$T_{ch}$ ( $^{\circ}\text{C}$ )	$40.4 \pm 0.2$	$39.6 \pm 0.2$	$p < .05$
$T_{ar}$ ( $^{\circ}\text{C}$ )	$41.0 \pm 0.3$	$40.0 \pm 0.3$	$p < .05$
$T_{ha}$ ( $^{\circ}\text{C}$ )	$40.9 \pm 0.5$	$39.5 \pm 0.5$	n.s.
$T_{fi}$ ( $^{\circ}\text{C}$ )	$43.2 \pm 1.0$	$40.1 \pm 1.0$	n.s.
$T_{th}$ ( $^{\circ}\text{C}$ )	$38.3 \pm 0.2$	$38.1 \pm 0.2$	n.s.
$T_{fo}$ ( $^{\circ}\text{C}$ )	$37.4 \pm 0.4$	$36.3 \pm 0.4$	n.s.
$T_{to}$ ( $^{\circ}\text{C}$ )	$37.1 \pm 0.5$	$36.0 \pm 0.5$	n.s.
HR ( $\text{bt}\cdot\text{min}^{-1}$ )	$183 \pm 4$	$171 \pm 4$	$p < .05$

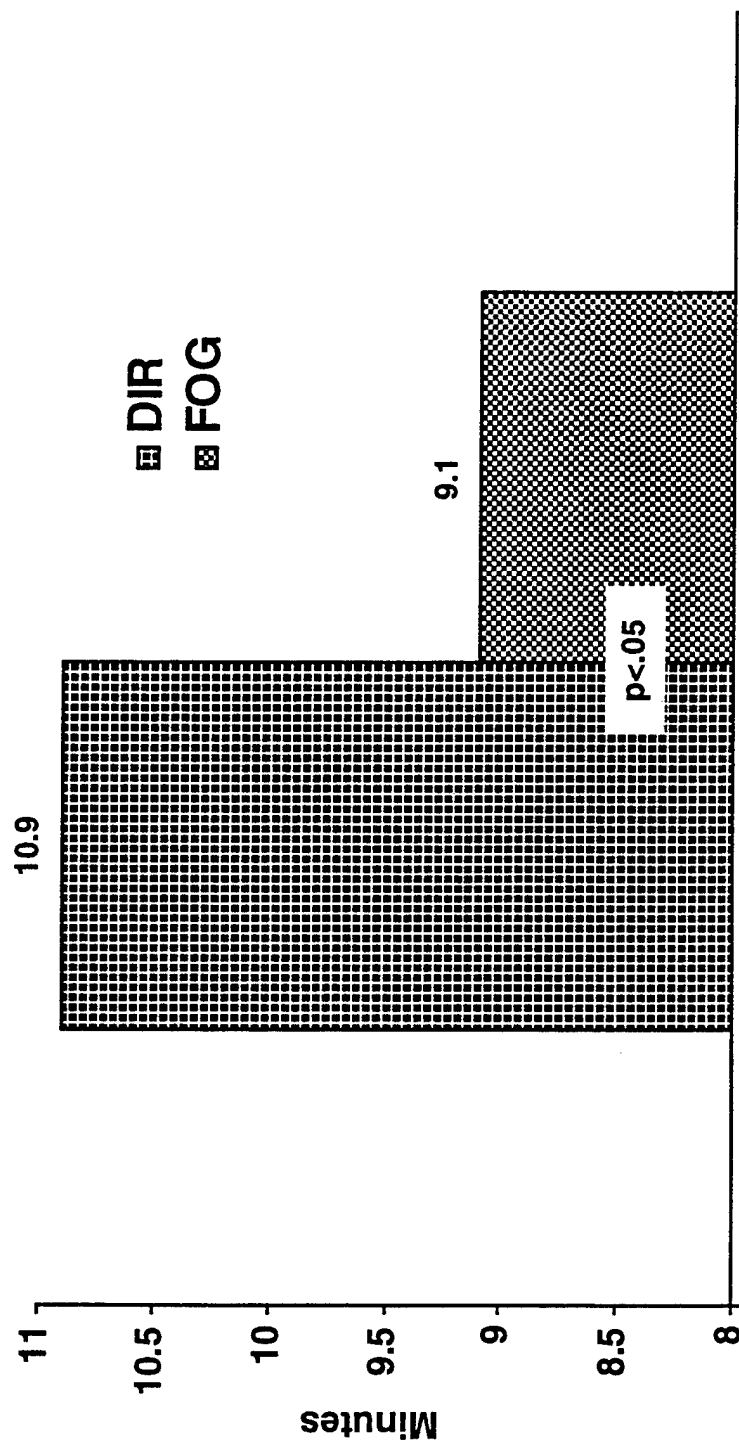
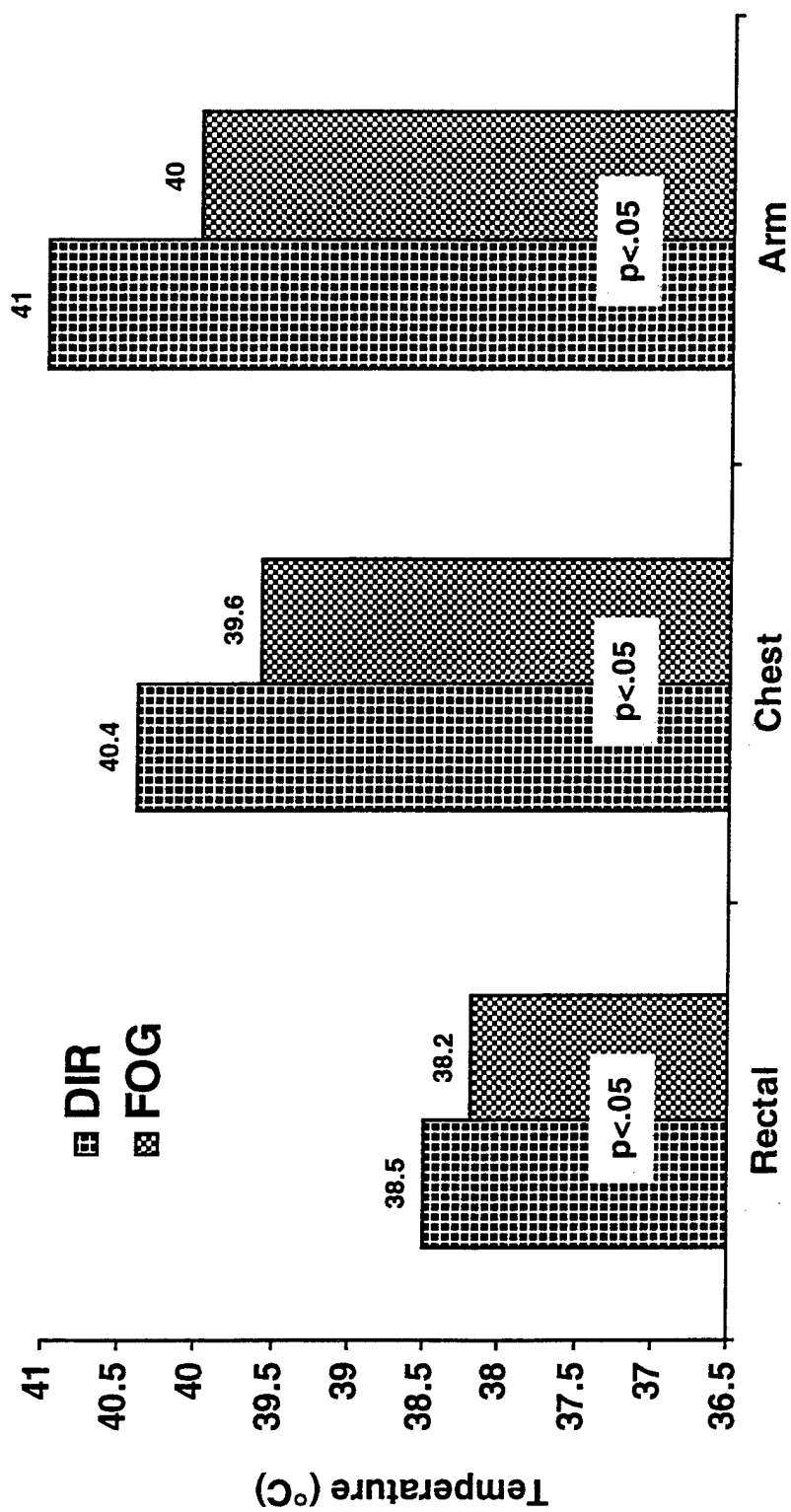


Figure 1. Comparison of firefighting time for DIR vs. FOG attack



**Figure 2. Comparison of peak temperatures for DIR vs. FOG attack**

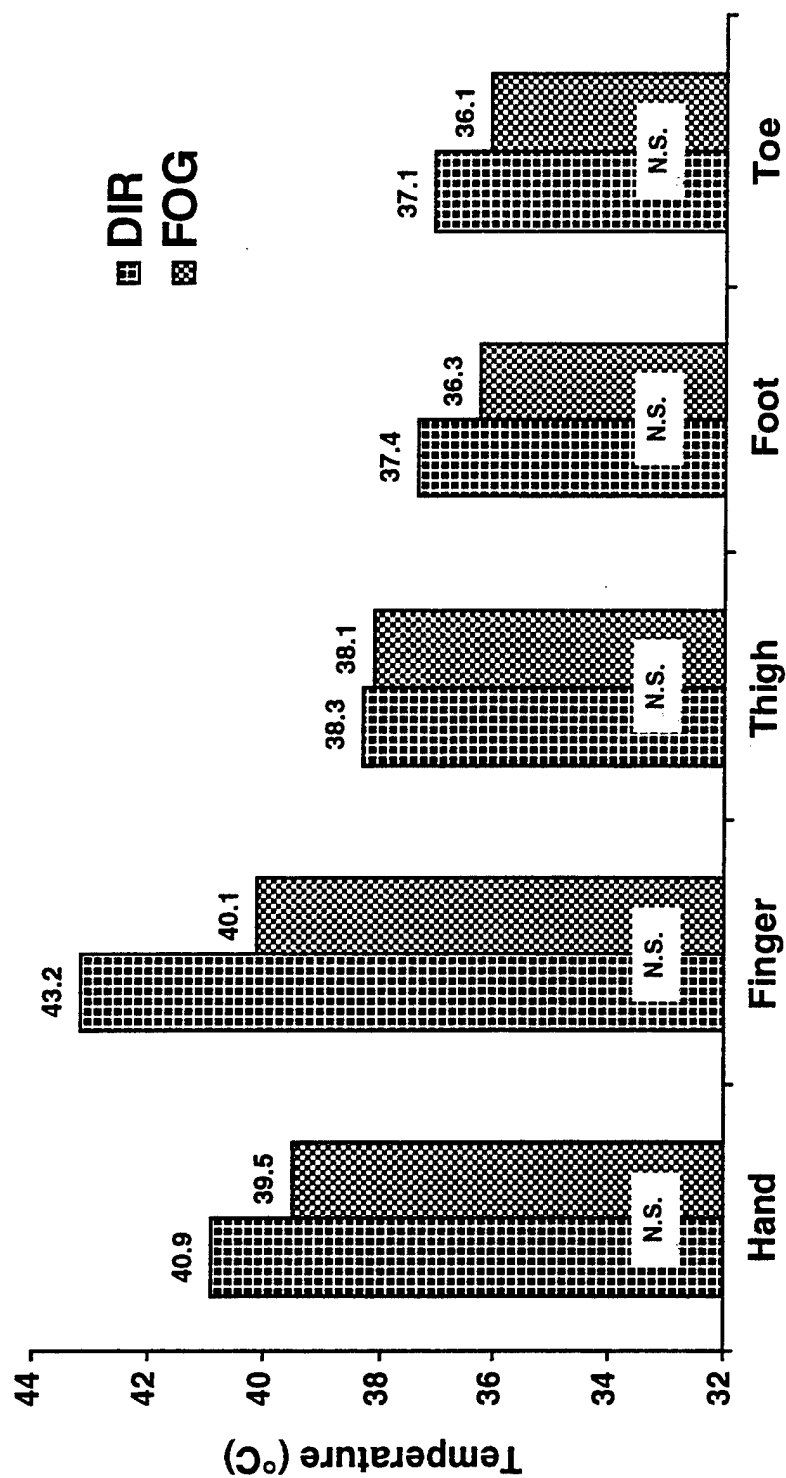


Figure 3. Comparison of peak temperatures for DIR vs. FOG attack

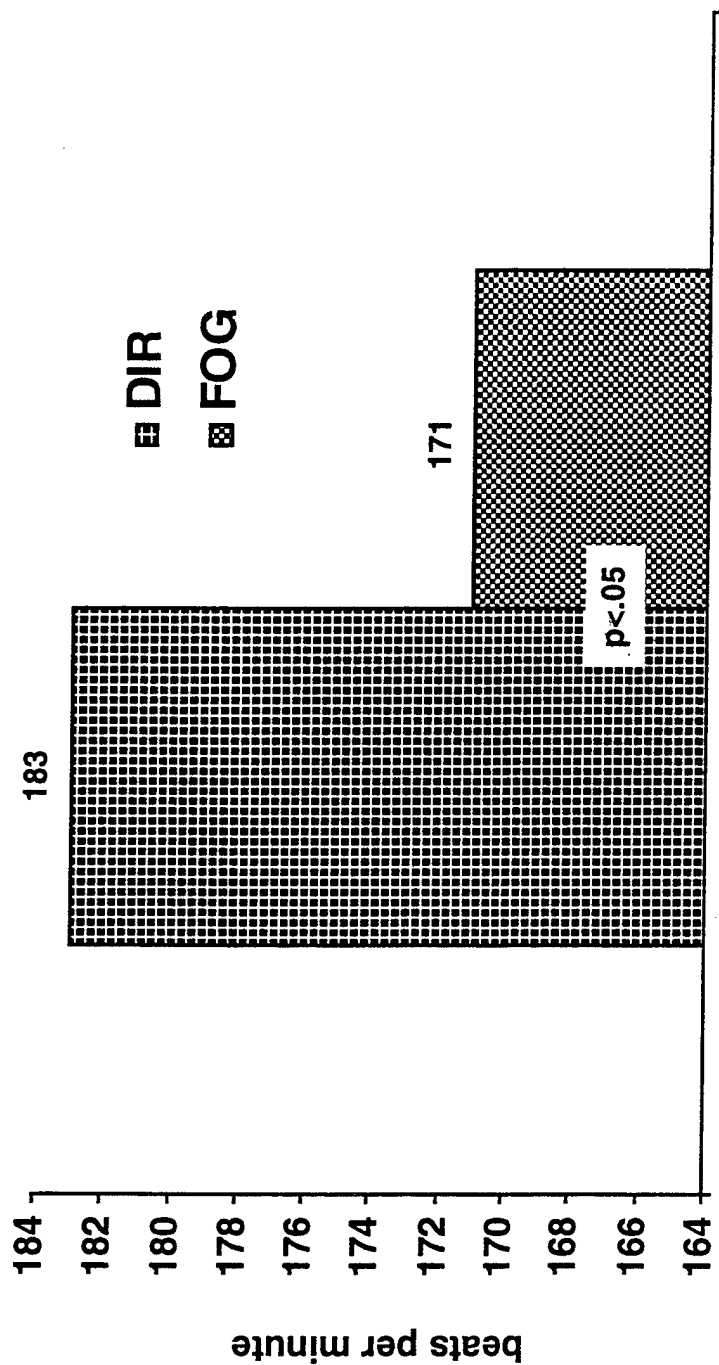


Figure 4. Comparison of peak heart rate for DIR vs. FOG attack

Analysis of the rates of increases in all dependent variable responses for DIR and FOG are shown in Table 4. Differences between DIR and FOG for rates of increase of all dependent measures were nonsignificant.

Table 4. Comparison of in fire rates of increases of body temperatures and HR between DIR and FOG.

Variable	DIR	FOG	Comparisons
$T_{re} (^{\circ}\text{C}\cdot\text{min}^{-1})$	$0.09 \pm 0.04$	$0.07 \pm 0.02$	n.s.
$T_{ch} (^{\circ}\text{C}\cdot\text{min}^{-1})$	$0.36 \pm 0.12$	$0.32 \pm 0.07$	n.s.
$T_{ar} (^{\circ}\text{C}\cdot\text{min}^{-1})$	$0.41 \pm 0.11$	$0.34 \pm 0.19$	n.s.
$T_{ha} (^{\circ}\text{C}\cdot\text{min}^{-1})$	$0.69 \pm 0.19$	$0.63 \pm 0.40$	n.s.
$T_{fi} (^{\circ}\text{C}\cdot\text{min}^{-1})$	$1.17 \pm 0.40$	$1.08 \pm 0.34$	n.s.
$T_{th} (^{\circ}\text{C}\cdot\text{min}^{-1})$	$0.38 \pm 0.16$	$0.27 \pm 0.11$	n.s.
$T_{fo} (^{\circ}\text{C}\cdot\text{min}^{-1})$	$0.50 \pm 0.17$	$0.40 \pm 0.24$	n.s.
$T_{to} (^{\circ}\text{C}\cdot\text{min}^{-1})$	$1.09 \pm 0.40$	$0.91 \pm 0.31$	n.s.
HR ( $\text{bt}\cdot\text{min}^{-1}$ )	$15 \pm 2$	$12 \pm 2$	n.s.

## DISCUSSION

Compared to DIR, firefighting time was almost 2 min shorter using the offensive FOG water attack method. Only one of four fires was successfully extinguished using the DIR method, while three of four fires were successfully extinguished using FOG. These differences were related to the impact of DIR and FOG on firefighting performance.

During DIR, the hose team entered the compartment and conducted an initial attack consisting of two to five short bursts (lasting 2 to 3 s) of narrow angle fog directed to either the seat of the fire or off the compartment ceiling and bulkheads. This attack would temporarily knock down one or two of the fire sources, but never completely extinguish any fire source. During most DIR tests, the initial attack created heavy steam and reflash conditions. This forced the hose team to retreat from the fire compartment. The hose team would then regroup, replace the nozzleman, and attempt a second attack from the doorway using two to three quick bursts of water. This would usually produce more steam and again force the hose team to back away from the door. The team would then change the nozzleman, deliver another series of short bursts of water to the fire source, and try to reenter the compartment. However, heat and steam conditions would invariably force the hose team to retreat from the doorway. At this point, the hose team would either regroup, change the nozzleman and try another attack, or quit the attack all together. In only one out of four DIR fire tests did the initial attack lead to a rapid and complete

termination of the total fire threat. In the remaining tests, the safety team was required to complete final extinguishment of the fire.

During FOG, the hose team would enter the compartment and deliver an initial attack consisting of three short bursts (lasting 2 to 3 s) with a medium angle ( $60^\circ$ ) fog directed at a  $45^\circ$  angle onto flames in the overhead. This was followed by either one of two sequence of events: 1) immediate knock down of the fire, advance to the fire source, delivery of a straight stream of water (DIR attack) and extinguishment of all fire sources, or 2) increase in steam conditions, reduction in visibility, replacement of the nozzleman, delivery of another series of straight streams of water which extinguished all fire sources. At no time during any FOG was the attack team forced from the fire space. During FOG, the attack team was able to control the fire within 2 min and completely extinguish flames within 10 min.

Farley et al, (1996), reported for the same fires tests, that analysis of the wood crib thermocouple and average overhead temperatures indicated that the offensive FOG attack method was the best method to control the overhead fire threat. With FOG, overhead air temperatures were immediately reduced by  $200^\circ\text{C}$  to  $250^\circ\text{C}$ . This was followed by continued cooling throughout the duration of the fire attack. Because cooling of the overhead gases was accomplished first, flashover potential was reduced. As a result, the hose team was able to locate the fire sources rapidly and extinguish three of the four test fires in an average of 9 min after entry into the fire space.

In contrast, the overhead fire compartment temperatures were reduced initially during DIR, but quickly rebounded to their original values. Usually, flashover occurred within 2 min after entering the fire compartment. This always forced the hose team to retreat from the fire space, regroup, and attempt a second entry into the fire compartment. On one occasion the second attack created additional steam necessitating a third reentry and attack. Consequently, the hose team required more time to locate the fire sources, delaying the DIR attack.

During DIR, heat flux measurements indicated that thermal balance of the upper air layer was disturbed sufficiently to impose a serious heat and steam threat to the hose team members (Farley et al., 1996). FOG produced a lesser amount of disturbance to the thermal layer. With FOG, the initial attack cooled the upper layer enough to decrease the heat flux level. While steam was produced with FOG, hose team members described it as a "moist" steam rather than a "hot" penetrating steam. The impact of FOG on the thermal balance of the overhead gases was further evident in that none of the hose team members reported suffering burns during FOG, while several members experienced minor first degree burns to the hands, wrists, face, neck, and back during DIR.

Use of FOG to reduce overhead air temperatures and control thermal balance allowed firefighters to locate and extinguish the fire sources more rapidly. As a result, firefighters using FOG spent a shorter amount of time in the heat of the fire compartment. The shorter firefighting time for FOG also resulted in a lower level of heat strain, as indicated by lower peak  $T_{re}$ ,  $T_{ch}$ , and  $T_{ar}$ , compared to DIR. There was a tendency for FOG peak  $T_{ha}$ ,  $T_{fi}$ ,  $T_{th}$ ,  $T_{fo}$ , and  $T_{to}$  values to be



lower than DIR. However, within-group variances were too large to produce significant differences between FOG and DIR. Thus, our findings indicate that the lower heat strain during the FOG attack method was confined to the body core, torso, and upper arm surface regions of the body.

Since FOG produced lower peak  $T_{re}$ ,  $T_{ch}$ , and  $T_{ar}$ , we calculated the rates of increase in  $T_{re}$ ,  $T_{ch}$ , and  $T_{ar}$  to see if the lower peak values were dependent upon the duration of actual firefighting heat exposure. This analysis revealed that differences in the in fire rates of increase in  $T_{re}$ ,  $T_{ch}$ , and  $T_{ar}$  were nonsignificant between DIR and FOG. Thus, the similar rates of increase in these temperatures for FOG and DIR indicate that the lower heat strain using FOG was directly related to the shorter firefighting time in the fire compartment.

The shorter firefighting time for FOG also had a significant impact on firefighter HR responses. While baseline and prefire entry HR values were similar for DIR and FOG, peak HR during active firefighting was significantly lower for FOG than DIR. However, the rates of increase in HR were similar between DIR and FOG. Thus, the lower HR with FOG was directly related to the shorter firefighting time.

## SUMMARY

In conclusion, our findings show that the offensive FOG attack method, when properly executed, has the potential to reduce the heat strain of personnel during shipboard firefighting. Use of the FOG attack, discharged in short bursts as a medium angle spray and directed upwards onto the overhead burning gases, was the best method to control overhead temperatures. Dressing in the standard Navy FFE and OBA, performance of preparatory firefighting activities, and execution of actual firefighting procedures produced a high level of individual heat strain. However, compared to DIR, use of FOG reduced firefighting time by almost 2 min. With FOG the attack team was able to stay in the fire compartment and put the fire out, while with DIR the attack team was always driven from the fire space and required to make additional attacks outside of the fire space. The reduced firefighting time for FOG was associated with a reduced level of individual heat strain as indicated by lower peak HR,  $T_{re}$ ,  $T_{ch}$ , and  $T_{ar}$ . However, the rates of increase for body temperatures were similar for DIR and FOG, suggesting that the lower peak values for FOG were directly related to the shorter firefighting time. Since the FOG attack method has the capacity to reduce heat strain, it may also contribute to a lower incidence of heat-related injuries for personnel engaged in shipboard firefighting operations.

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12a. DISTRIBUTION/AVAILABILITY STATEMENT  Approved for public release; distribution is unlimited.			12b. DISTRIBUTION CODE	
13. ABSTRACT (Maximum 200 words)  The purpose of this study was to compare two firefighting methods, direct (DIR) and fog (FOG), on personnel heat strain. Eight males and four females (31 ± 4 yr) served as subjects. Subjects wore Navy firefighting ensemble and respired from an A-4 OBA. Measures included heart rate (HR), rectal ( $T_{re}$ ), chest ( $T_{ch}$ ), arm ( $T_{ar}$ ), hand ( $T_{ha}$ ), finger ( $T_{fi}$ ), thigh ( $T_{th}$ ), foot ( $T_{fo}$ ), and big toe ( $T_{to}$ ) temperatures. During DIR, the hose team attempted to apply water as a straight stream to the fire. During FOG, the team entered the fire space, placed a medium angle spray (short bursts) upwards onto the overhead gases, and then applied a straight stream of water on the fire. Upper air temperatures at time of entry averaged (±SD) 591 ± 43°C. During DIR, the attack team was unable to control the fire, and was forced to leave the space and conduct further attacks from the doorway. During FOG, the attack team was able to put out the fire quickly with all personnel inside the fire space. Firefighting time was less ( $p < .05$ ) for FOG (9.1 ± 0.6 min) compared to DIR (10.9 ± 0.6 min). FOG peak $T_{re}$ ( $\bar{X}$ = 38.2°C), $T_{ch}$ ( $\bar{X}$ = 39.6°C), and $T_{ar}$ ( $\bar{X}$ = 40.0°C) were lower ( $p < .05$ ) compared to DIR (38.5°C, 40.4°C, 41.0°C, respectively). Peak HR for FOG ( $X$ = 171 bpm) was lower ( $p < .05$ ) than DIR ( $X$ = 185 bpm). Compared to DIR, FOG reduced air temperatures which reduced firefighting time and lower heat strain.				
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