

Report of Investigations 8139

An Ice-Cooling Garment for Mine Rescue Teams

By Maria I. De Rosa and Richard L. Stein

Pittsburgh Mining and Safety Research Center, Pittsburgh, Pa.



UNITED STATES DEPARTMENT OF THE INTERIOR

Thomas S. Kleppe, Secretary

BUREAU OF MINES

Thomas V. Falkie, Director

This publication has been cataloged as follows:

De Rosa, Maria I

An ice-cooling garment for mine rescue teams, by Maria I. De Rosa and Richard L. Stein. [Washington] U.S. Bureau of Mines [1976]

13 p. illus., tables. (U.S. Bureau of Mines. Report of investigations 8139)

Includes bibliography.

I. Mine rescue work. I. Stein, Richard L., jt. auth. II. U.S. Bureau of Mines. III. Title. (Series)

TN23.U7 no. 8139 622.06173

U.S. Dept. of the Int. Library

CONTENTS

	<u>Page</u>
Abstract.....	1
Introduction.....	1
Acknowledgments.....	2
The ice-cooling garment.....	2
Experimental test procedure.....	6
Results.....	7
Discussion.....	10
Summary.....	11
References.....	13

ILLUSTRATIONS

1. The ice-cooling garment.....	3
2. Inner side of the ice-cooling garment.....	4
3. Bureau of Mines ice-cooling garment worn with a breathing apparatus.	5
4. Change in deep body temperature with time during exposure with and without the cooling garment to 97° F dry bulb and 89° F wet bulb..	9
5. Change in deep body temperature with time during exposure with and without the cooling garment to 104° F dry bulb and 88° F wet bulb.	9
6. Change in heart rate with time during exposure with and without the cooling garment to 97° F dry bulb and 89° F wet bulb.....	10

TABLES

1. Physical characteristics of the subjects.....	6
2. Environmental temperatures used during the experiments.....	7
3. Initial and final values of deep body temperature and heart rate for subjects with and without the ICG.....	8

AN ICE-COOLING GARMENT FOR MINE RESCUE TEAMS

by

Maria I. De Rosa¹ and Richard L. Stein²

ABSTRACT

High temperatures encountered by mine rescue teams during emergency situations may cause severe physiological strain, hindering the men from carrying out rescue and recovery missions. A prototype ice-cooling garment (ICG) was developed by the Bureau of Mines to alleviate physiological strain due to heat stress. The effectiveness of the garment was tested with acclimatized and unacclimatized subjects at a typical work rate (1,200 Btu/hr) expected during rescue operations and at various hot environments (97° to 113° F dry bulb and 80° to 89° F wet bulb).

During exposures with the ice cooling garment, the subjects were able to maintain a safe deep body temperature of 100.4° F or below. Without the garment, the deep body temperature rose beyond values of 100.4° F, a condition considered unsafe for continuous work in hot conditions. Both heart rate and skin temperature values were lower while wearing the ICG. Subjective observation also indicated a marked benefit by wearing the ICG.

INTRODUCTION

During mine rescue and recovery missions rescue teams often encounter high temperatures which can cause severe physiological strain; in fact, these temperatures may be one of the worst problems to confront the team. For example, during disasters at the Belle Isle salt mine (1),³ the Crane Creek (10) potash mine, and more recently at the Somerset coal mine (8), rescue and recovery teams were forced to drastically shorten their operation time because of severe exhaustion due to heat stress. At Somerset, the normal mission of 2 hours was shortened to 25 minutes because the teams could not cope with the 120° F dry bulb temperature of the air.

Several types of cooling garments have been developed to alleviate heat stress problems encountered by workers in hot environments. One type of

¹Industrial hygienist.

²Supervisory chemist.

³Underlined numbers in parentheses refer to items in the list of references at the end of this report.

garment uses cold water that is mechanically pumped and channeled through thin tubes running throughout the garment (2-5); a second type uses Dry Ice⁴ inserted into pockets (4-6); and a third type, developed in South Africa for gold mine workers, uses ice (9). The South African garment weighs about 10 pounds and consists of an inner poncho-type vest containing 28 pockets of ice, and an outer insulating jacket that minimizes melting of the ice by mine air. None of the available garments were considered to be satisfactory for rescue work; that is, the South African garment is much too bulky to be worn by a rescue worker who must crawl, climb, build stoppings, etc.

Any cooling garment to be used by rescue team workers must (1) be simple and not inclined to mechanical failure, (2) use a coolant that is nontoxic, (3) provide cooling of sufficient duration to match the 2- and 4-hour missions now being scheduled during rescue and recovery operations, and (4) be small and lightweight so as not to overburden the rescue team members who also must wear a rescue breathing apparatus and other gear.

The Bureau of Mines has developed a lightweight and nonbulky prototype ice-cooling garment specifically for rescue team workers. This report describes the garment and presents the results of an exploratory laboratory study investigating the alleviation of the heat stress it achieves.

ACKNOWLEDGMENTS

The authors express their gratitude to Eliezer Kamon and Thomas Bernard of Pennsylvania State University, University Park, Pa., for their most valuable assistance in conducting the experiments and discussing the results.

THE ICE-COOLING GARMENT

The Bureau of Mines ice-cooling garment is a vest that is open on the sides and secured with Velcro strips (figs. 1-3). Cooling is achieved with prefrozen pockets of ice that are attached to the inner part of the garment. The garment is easy to don and allows rescue team members freedom of movement, while the adjustable closure allows the garment to comfortably fit most men.

The garment consists of four layers of materials: an outer and inner layer of rubberized Dacron resistant to abrasion, a middle layer of insulating polyfoam 1/4 inch thick, and a terry cloth layer between the ice pockets and the wearer. The terry cloth material was designed to keep the ice pockets from directly touching the skin, thus preventing discomfort or skin damage.

On the inside of the garment, 14 pockets, attached by a Velcro strip in rows of 3 for the upper part of the garment and in rows of 4 for the lower part of the garment, are pressed onto Velcro strips sewn on the inner garment. Each pocket (6- by 4-inch heavy vinyl) contains a heat-sealed plastic bag containing 10 ounces of tap water, with a total theoretical heat absorption of 600 kcal (2,400 Btu) when frozen at 32° F. The total weight of the ICG was held to a minimum (about 10 pounds) commensurate with a 2-hour rescue mission.

⁴Reference to specific brands is made for identification only and does not imply endorsement by the Bureau of Mines.

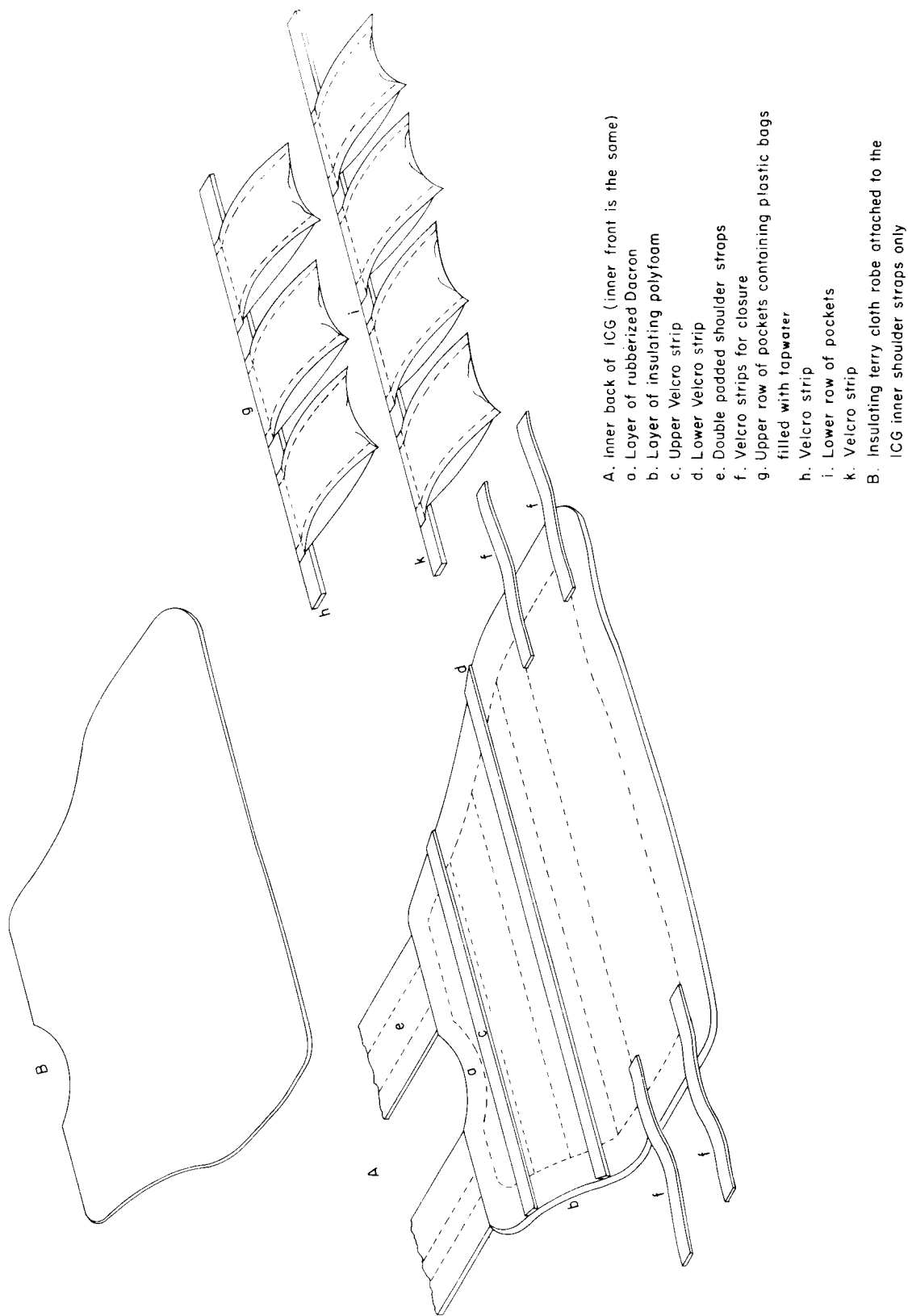


FIGURE 1. - The ice-cooling garment.

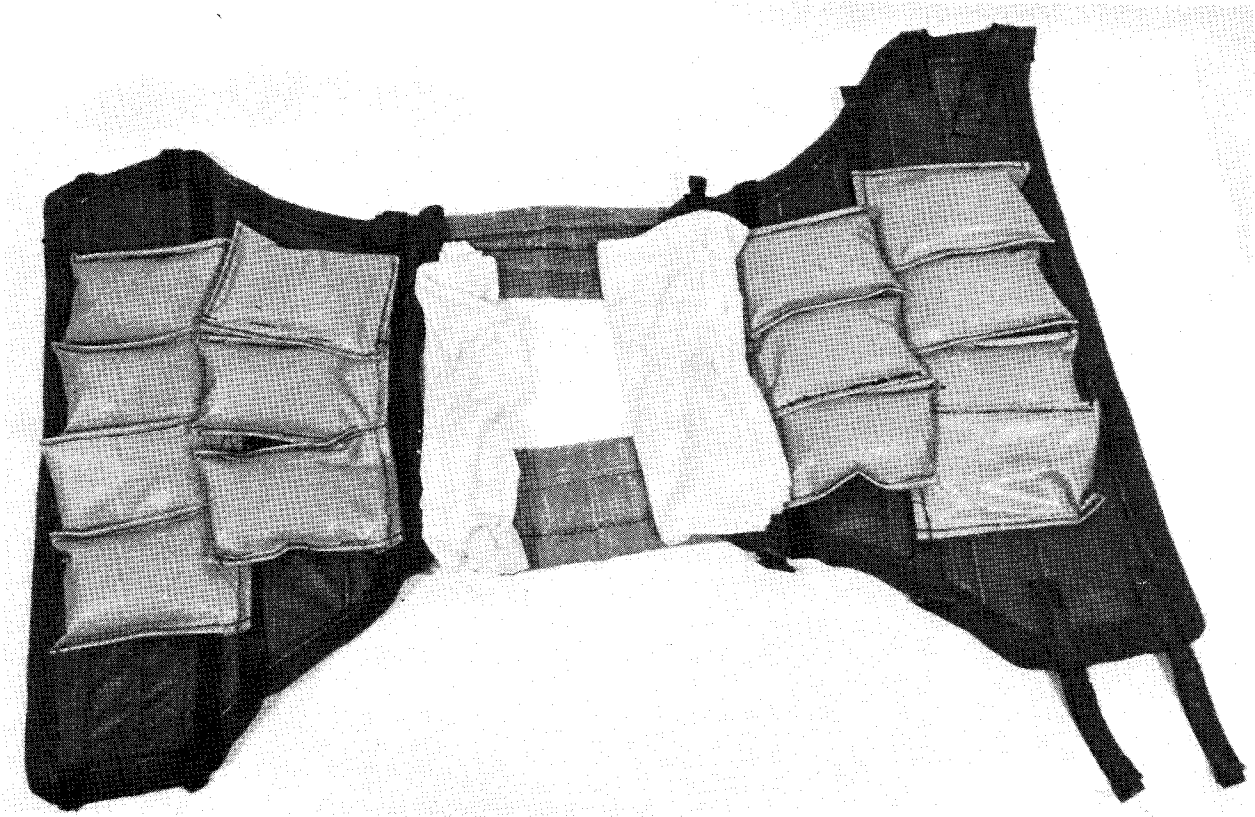


FIGURE 2. - Inner side of the ice-cooling garment.

This pocket design offers several advantages: (1) if a single bag ruptures, the garment is still effective during rescue operations because the other pockets will continue to absorb heat; (2) at the end of a mission individual damaged pockets may be easily removed and replaced immediately; and (3) only the rows of pockets, easily removed from the garment, need to be frozen. Freezing time is about 6 hours using a commercially available freezer.

Finally, the ICG shoulders were doubly padded for comfort when wearing a breathing apparatus.



FIGURE 3. - Bureau of Mines ice-cooling garment worn with a breathing apparatus.

EXPERIMENTAL TEST PROCEDURE

The prototype ice-cooling garment was tested in a climatic chamber at Noll Laboratory, Pennsylvania State University, University Park, Pa.

Five college students participated in the experiments, four unacclimatized and one acclimatized. Unacclimatized subjects were used to simulate the responses of miners unacclimatized to heat who volunteer during rescue or recovery missions, and of unacclimatized rescue team members summoned during mine disaster. The acclimatized subject was used to simulate responses of those miners accustomed to working in hot environmental temperatures, and who may be members of a rescue team during rescue or recovery operations. The subjects' physical characteristics are given in table 1.

TABLE 1. - Physical characteristics of the subjects

	Age, years	Height		Weight, pounds
		Feet	Inches	
Unacclimatized:				
Subject A.....	22	5	9	139
Subject B.....	23	5	9	150
Subject C.....	18	5	9	137
Subject D.....	22	6	1	161
Acclimatized (Subject E)	29	5	7	157

During these tests, each subject wore a cotton undershirt, underwear, socks, tennis shoes, and a light-cotton surgical overall. The surgical overall was worn over the cooling garment. The terry cloth in the ICG was not used here to determine if such a cloth is needed to prevent discomfort or harm to the wearer.

After donning the garment, the subjects entered the climatic chamber and walked on a treadmill at 3.5 mph, corresponding to a work rate of about 1,200 Btu/hr, and an oxygen consumption of about 1 l/min for 2 hours. However, some experiments with unacclimatized subjects without the garment had to be terminated much earlier because severe heat stress symptoms were observed in the subjects.

The subjects were tested twice, once with and once without the garment, under various sets of temperatures typical of hot mines during disasters⁵ (table 2). A period of 4 days was allowed between each experiment for the unacclimatized subjects, and only 1 day for the acclimatized subject.

⁵Lind (7) reports that the most frequent dry- and wet-bulb temperatures to which English teams were exposed during rescue operations ranged between 86° to 113° F dry bulb; 75° to 95° F wet bulb.

TABLE 2. - Environmental temperatures used
during the experiments

	Dry bulb, ° F	Wet bulb, ° F
Unacclimatized	97	89
	104	85
	104	86
	104	88
	113	80
Acclimatized..	97	89
	104	85
	113	85
	113	80

NOTE.--Wind velocity was zero.

These exploratory experiments were conducted to determine if the subjects would have reduced physiological strain by using the ICG compared with situations when the ICG was not used. For this purpose, comparison of deep body temperature, heart rate, skin temperature and sweat loss versus time would provide sufficient information to arrive at conclusions about the effectiveness of the garment.

During each test, deep body temperature (T_{re}), heart rate (HR), and skin temperature (T_{sk}) were recorded continuously. T_{re} was measured with a thermistor inserted in the rectum, and HR was recorded from a chest electrode connected to a cardiograph. T_{sk} was measured by applying thermocouples on six sites: one on each thigh, one on the left arm, one on the chest, one on the back, and one on the forehead. Metabolism was measured by collecting expired air that was analyzed for oxygen consumption. Water warmed to skin temperature was drunk at will from a measuring cup; an average of 700 grams per test was consumed by each subject.

RESULTS

The results are summarized in table 3. In these experiments, the ICG significantly reduced deep body temperature (t-test $p \leq 0.05$) in both acclimatized and unacclimatized subjects. Without the ICG, T_{re} steadily increased throughout the test period. With the ICG, the rate of increase was lower, and after about the first 60 minutes of exposure, a steady-state deep body temperature was observed in both acclimatized and unacclimatized subjects. Typical examples are shown in figure 4 for the acclimatized subject and in figures 4 and 5 for two unacclimatized subjects. The difference between the initial and final T_{re} , with and without the ICG, is a measure of the effectiveness of the ICG in reducing physiological strain. This difference, T_{ICG} is given by

$$T_{ICG} = (T_{re_{final}} - T_{re_{init}}) \text{ without ICG} - (T_{re_{final}} - T_{re_{init}}) \text{ with ICG.}$$

TABLE 3. - Initial and final values of deep body temperature and heart rate
for subjects with and without the ICG

Sub- ject	Dry bulb, ° F	Wet bulb, ° F	Without ICG, ° F		With ICG, ° F		T _{ICG} , ° F	Without ICG, beats/min		With ICG, beats/min		HR _{ICG} , beats/ min	
			Tre _{in}	Delta ¹	Tre _{in}	Delta ¹		HR _{in}	HR _{f in}	Delta ¹	HR _{f in}		Delta ¹
UNACCLIMATED SUBJECTS													
A...	97.0	89.0	99.32	101.84	2.02	98.24	100.04	1.80	+0.22	116	136	20	0
B...	104.0	86.0	99.32	100.85	1.53	99.22	99.86	.54	+ .99	120	135	25	-10
A...	104.0	86.0	98.78	101.3	2.52	99.32	100.4	1.08	+1.44	128	157	3	+26
C...	104.0	88.2	99.86	101.39	1.53	99.68	100.76	1.08	+ .45	150	165	20	-5
A...	104.0	88.2	97.88	100.76	2.88	98.96	100.4	1.44	+1.44	115	153	15	+23
A...	104.0	85.0	99.86	100.94	1.08	98.6	99.32	.72	+ .36	130	156	12	+14
D...	113.0	80.0	99.32	101.3	1.98	99.14	100.4	1.26	+ .72	86	130	41	+3
					⁴ 1.93 5.57			⁴ 1.13 5.39	⁴ .80 5.46		⁴ 27 510.4	⁴ 19 511	⁴ 7 511
ACCLIMATED SUBJECT													
E...	97.0	89.0	98.6	100.4	1.80	98.96	100.22	1.26	+0.54	94	122	6	+22
E...	113.0	85.0	98.6	98.86	1.26	98.78	99.5	.72	+ .54	94	112	6	+12
E...	113.0	80.0	98.0	100.0	2.00	98.96	100.4	1.44	+ .56	88	112	9	+15
E...	104.0	85.0	98.6	100.22	1.62	98.6	99.32	.72	+ .90	92	109	4	+3
					⁴ 1.67 5.27			⁴ 1.03 5.32	⁴ .63 5.15		⁴ 22 54.5	⁴ 9 53.27	⁴ 13 56.8

¹Delta= final - initial.

²T_{ICG} = (Tre_{final} - Tre_{initial}) without ICG - (Tre_{final} - Tre_{initial}) with ICG.

³HR_{ICG} = (HR_{final} - HR_{initial}) without ICG - (HR_{final} - HR_{initial}) with ICG.

⁴Average.

⁵Standard deviation.

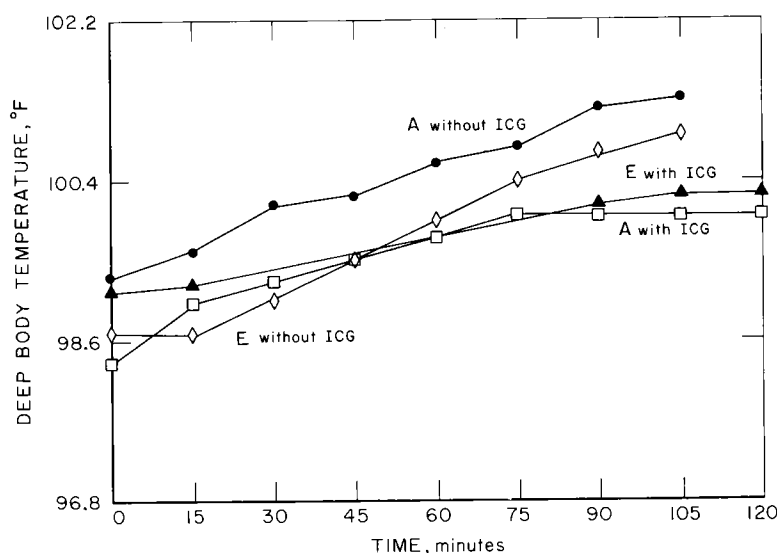


FIGURE 4. - Change in deep body temperature with time during exposure with and without the cooling garment to 97°F dry bulb and 89°F wet bulb.

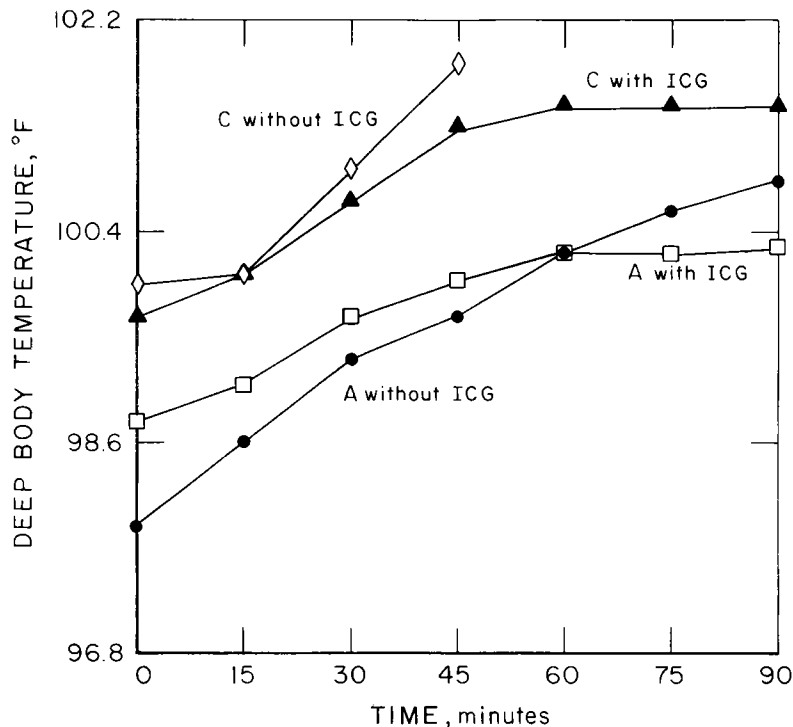


FIGURE 5. - Change in deep body temperature with time during exposure with and without the cooling garment to 104°F dry bulb and 88°F wet bulb.

Data in table 3 indicate that the average T_{ICG} was 0.8° F for unacclimatized subjects and 0.6° F for the acclimatized subject. The smaller T_{ICG} value for the acclimatized subject indicates that the ICG was less effective for that subject. This was expected because the ICG should be of less value to someone who is acclimatized; an acclimatized subject's thermoregulatory system provides more efficient body cooling than the thermoregulatory system of unacclimated people.

The results obtained on heart rate, skin temperature, and weight loss similarly indicate the general effectiveness of the ICG. Typical variations in heart rate with time are shown in figure 6, where a significant (t-test $p < 0.10$) decrease in heart rate is evident when the ICG is being worn. An appreciable decrease in torso skin temperature was observed when the garment was worn; during all tests, an average value of 85° F was observed with the garment compared with 97° F without the garment. The decrease in skin temperature of the extremities was more modest. Average values of 96° F versus 97.5° F with and without the ICG were observed. Sweat loss was depressed significantly with the garment. Average sweat losses of 0.4 and 1.5 kg/hr were observed with unacclimatized and

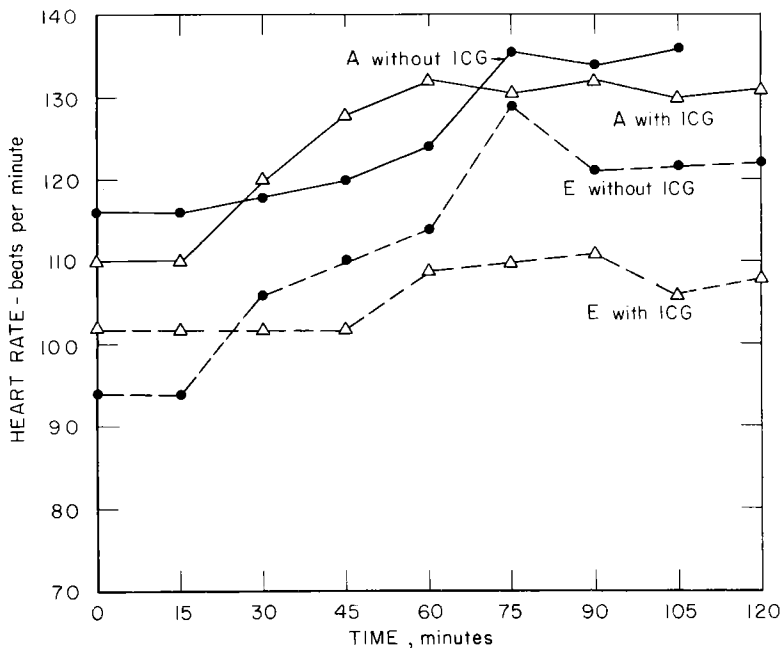


FIGURE 6. - Change in heart rate with time during exposure with and without the cooling garment to 97° F dry bulb and 89° F wet bulb.

unable to stabilize their deep body temperatures and heart rates. During many of the tests without the garment, the subjects began to show the effects of heat stress (skin pallor, fatigue, dizziness) as the deep body temperature and heart rate rose above the permissible exposure limits. The subjects often were unable to work the 2-hour test period, and one test had to be stopped after 45 minutes when the T_{re} of the subject reached 101° F.

However, with the ICG the deep body temperature and heart rate rose at a lower rate during the first hour of exposure, and then stabilized after 30 to 60 minutes at values below the permissible exposure limit. All subjects were able to safely perform continuous work for the 2-hour period.

Similar tests with acclimatized South African Bantu miners were conducted (9). No differences in physiological responses were observed during the first hour of exposure with and without the cooling vest. The disparity between those tests and the results presented here are perhaps due to physiologic differences among the subjects tested and due to the fact that the miners were acclimated to hot environmental conditions.

The students used in these tests were young (average age was 23) and in good physical condition. It is known that physically fit individuals adjust better to heat than unfit people (11). Since most rescue team workers are older and probably less physically fit than students tested here, they should benefit from wearing the ICG to a greater degree than indicated in these tests.

acclimatized subjects during exposures without the garment versus values of 0.2 and 0.5 kg/hr with the ICG.

DISCUSSION

Workers who are exposed daily to high environmental temperatures should not be permitted to exceed a deep body temperature of 100.4° F (3) and a heart rate of about 130 beats per minute. Although only limited data are available on workers who are infrequently exposed, as would be expected for rescue team workers, it is reasonable to assume that these values can be taken as permissible exposure limits.

The results indicate that subjects not wearing the cooling garment were

Several aspects of the ICG require further investigation. For example, at the end of the 2-hour test, the ICG typically had about 50 percent of the ice remaining and the test could have been continued. Tests of longer duration with the ICG are planned.

During the tests, all subjects used the ICG without insulation between the ice pockets and the skin, except for a light cotton shirt, to determine if additional insulation was necessary. While no significant discomfort was reported, the subjects did complain of mild discomfort after the test and skin redness was observed. While this discomfort appears to be minor, it is clear that better insulation between the pockets and the skin is needed. This can be provided by a heavier cotton shirt or, as in the original ICG design, a terry cloth may be attached to the ICG. The type and amount of insulation needed to prevent discomfort while maximizing cooling will be investigated.

Finally, although the tests did not include wearing a rescue breathing apparatus (RBA), the cooling garment and an approved 4-hour RBA have been worn at ambient conditions for about 1 hour in other work; both comfort and mobility were excellent. However, it was noted that the shoulder straps need to be widened slightly to better accommodate the breathing apparatus' straps, and additional padding is needed between the breathing apparatus and the cooling garment, where the breathing apparatus' backpack frame contacts the wearer's back. This could also be accomplished by changing the present location of some of the ice pockets in the center of the back; there appears to be enough space on the upper part of the garment, where the RBA frame does not touch the wearer, in which two small ice pockets may be placed, and/or an additional row of four pockets may be added to the lower back of the garment. This will also increase the cooling power of the ICG.

SUMMARY

A prototype ice-cooling garment to be used by rescue teams during rescue and recovery operations in hot mines has been developed by the Bureau of Mines.

The ICG is a single garment that is easy to don and allows the wearer freedom of movement. The garment consists of four layers of material: an outer and inner layer of rubberized Dacron resistant to abrasion, a middle layer of insulating foam, and a terry cloth to prevent the ice pockets from touching the wearer's skin. Fourteen individual ice pockets placed onto the vest by Velcro strips provide cooling for the wearer. The ice garment weighs approximately 10 pounds and is designed to provide enough cooling to protect the rescue team wearer for a 2-hour rescue mission.

The garment was evaluated by comparing the increase in deep body temperature, heart rate, skin temperature, and sweat rates obtained in acclimatized and unacclimatized subjects with and without wearing the ICG. The ICG was evaluated over a range of temperatures (97° F to 113° F dry bulb, 80° F to 89° F wet bulb) while the subjects worked at 1,200 Btu/hr, a typical long-duration rescue work rate in hot environments.

With the ICG, deep body temperature and heart rate rose at a slow rate, and a physiological steady state was reached after 30 to 60 minutes with values being below the permissible limits of 100.4° F deep body temperature and 130 beats per minute. Sweat loss was cut by about one-half, while skin temperature of the body was reduced. The subjects were not exhausted, and the tests could have been extended beyond the present 2-hour period.

Without the ICG, deep body temperatures rose above the safe limit of 100.4° F, heart rates averaged about 10 to 20 beats per minute more than when wearing the garment, the subjects became exhausted, and some tests had to be stopped before 2 hours.

These results show that the cooling garment helps in relieving heat stress, allowing men to safely perform continuous work in a hot mine for a 2-hour period, a time typical of rescue missions.

REFERENCES

1. Brown, H., J. A. O'Connor, C. M. Dovidas, and R. Capps. Final Report on Major Mine-Fire Disaster Belle Isle Salt Mine, Cargill, Inc., St. Mary Parrish, Louisiana. U.S. Department of the Interior, Bureau of Mines, March 1968, 46 pp.; available for consultation at Bureau of Mines Mining and Safety Research Center, Pittsburgh, Pa.
2. Carpenter, R., and W. R. Winter. A Flight-Rated Liquid-Cooled Garment for Use Within a Full-Pressure Suit. Ch. in Proc. Conf. on Portable Life Support Systems, Moffett Field, Calif., May 11-13, 1971, National Aeronautic and Space Administration Spec. Pub. 302, May 1972, pp. 237-246.
3. Dukes-Dobos, F. Development of Permissible Heat Exposure Limits for Occupational Work. ASHRAE J., v. 15, No. 9, September 1973, pp. 57-62.
4. Esposito, J. J. Description and Evaluation of a Portable Dry Ice Water Conditioned Suit System for Air Crewmen. Ch. in Proc. 1st Conf. on Portable Life Support Systems, Moffett Field, Calif., Apr. 30-May 2, 1969, National Aeronautic and Space Administration Spec. Pub. 234, May 1972, pp. 129-143.
5. Gold, A. J., and A. Zornitzer. Effect of Partial Body Cooling on Man Exercising in a Hot, Dry Environment. Aerospace Med., v. 39, September 1968, pp. 944-946.
6. Konz, S., C. Hwang, R. Perkins, and S. Borell. Personal Cooling With Dry Ice. J. Am. Ind. Hyg. Assoc., v. 9, March 1974, pp. 132-147.
7. Lind, A. R., R. F. Hellon, J. S. Weiner, and R. M. Jones. Tolerance of Men To Work in Hot Saturated Environments With Reference to Mine Rescue Operations. Brit. J. Industr. Med., v. 12, 1955, pp. 296-303.
8. Ramey, R. W., L. R. Miller, T. O. Gunderson, T. G. Muncy, J. H. Phelps, P. W. Butler, G. H. Sides, R. T. Johnson, and D. L. Scott. "Recovery" Somerset Mine. Presented at the 69th Reg. Meeting, Rocky Mountain Coal Min. Inst., Vail, Colo., June 1973, 17 pp.; available for consultation at Bureau of Mines Mining and Safety Research Center, Pittsburgh, Pa.
9. Van Rensburg, A. J., D. Mitchell, W. H. Van Walt, and N. B. Strydom. Physiological Reactions of Men Using Microclimate Cooling in Hot Humid Environments. Brit. J. Ind. Med., v. 29, 1972, pp. 387-393.
10. Westfield, J., L. D. Knill, and A. C. Moschetti. Final Report of Major Mine Explosion Disaster Cane Creek Mine, Potash Div., Texas Gulf Sulfur Co., Grand County, Utah. U.S. Department of the Interior, Bureau of Mines, August 1963, 30 pp.; available for consultation at Bureau of Mines Mining and Safety Research Center, Pittsburgh, Pa.
11. Wyndham, C. H. Adaption to Heat and Cold. Environ. Res., v. 2, 1969, pp. 442-469.