# DIVER'S UNLIMITED SUIT

## *HEAT STRESS ASSESSMENT AND A COUNTERMEASURE*

**Biomedical Laboratory**
**Kennedy Space Center, FL 32699**

**Abstract:**

**Donald F. Doerr**
**Chief, Biomedical Engineering**

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The test subjects were fully instrumented with the Konigsburg 8 channel biotelemetry unit. This allowed the collection of ECG, body core temperature (rectal), and five skin temperatures (forehead, right arm, chest, back, and right thigh). A telemetry pallet including the following equipment items was installed in a van that was driven to the field test site: Konigsberg TR5 receiver, Teac MR-40-9 channel FM data tape recorder, Gould - 8 channel strip chart recorder, Fluke 2286A dta logger, HP 78304A ECG oscilloscope, and HP 78209C Cardiotachometer.

Subjects were weighed pre and post test, unsuited, on a Sauter, type D 1200 digital scale to determine sweat loss. Air consumption was determined by weight loss during the test, and confirmed by pressure loss in the vessels. The biotelemetry data was continuously monitored as required by the Human Use Committee to assure that rectal temperature did not exceed 102° F (38.9° C and that ECG waveform was within normal limits for heavy exercise.

The tests were initiated within the laboratory and quickly moved to the hot outdoors. The initial 15 minute outdoor period was spent in an unairconditioned van with windows up. Conditions of nearly 120° F (49° C) simulated those ambient conditions common with delivery to a crash scene via the Blackhawk military helicopter. After departing the van and activating the breathing apparatus, a series of exercises was performed in deep grass while in the sunlight. Wet soil and brush was common.

**TEST PROTOCOL:**

**Time Event**

Weigh subject, Sensor subject for 5 skin temps, rectal temp, ECG Suit subject with long underwear, cool vest (random assignment), DUI Suit Add integrated Harness and AGA Divator breathing apparatus

**[0-5 Min]** Start test, collect baseline data in lab, 74° F (23.3° C) ambient.

**[5-7 Min]** Depart lab, walk down stairs to van, windows up, no A/C, drive to test site.

**[20 Min]** Exit van, don mask, activate air supply

**[26 Min]** Carry stokes litter containing 185 lb (83.9 kg) weight with 1 assistant for 30 meters.

Unload weight. Carry empty litter with I assistant for 200 meters through brush Load mannequin into litter, perform hand strength measurements. Carry 120 lb (54.4 kg) footlocker with 1 assistant for 200 meters through brush. Carry empty litter 200 meters as before. Carry footlocker 200 meters as before. Commence standing recovery.

**[45 Min]** End of Test. Remove mask, hood, SCBA, return to lab De-suit, de-sensor subject. Weigh subject. Hydrate subject

**RESULTS**

This protocol was very difficult and psychologically stressful, especially without the cooling vest. The baseline data was collected during testing without the cooling vest (NV). Comparison was made to the Vest (V) condition. Tests were assigned randomly. Heat stress was high as indicated by average rectal temperatures (Tre) of 38.38 +/- 22° C after the 45 minute protocol. While rectal temperatures were lower with the vest, they were not significantly less. Based upon the average slope of the regression equations describing the increase of Tre with time, the projected time to the 38.8° C (102° F) temperature limit was increased by 11.7 % with the vest. Therefore, operational field time could be increased. Subjects reported, however, considerable relief in apparent heat stress while wearing the vest.

Mean skin temperature (Tsk3), the mean of three skin temperatures (forehead, .arm leg) was significantly higher ($p<0.05$) In Non vest tests (36.4 +/- .51° C) compared to Vest (35.4 +/- .55° C) even when sensors located an the torso, specifically under the vest, were eliminated. One may notice that the curves begin to converge as the phase change material melts. It should be noted that in no case was more than half of the phase change material within the vest melted at the conclusion of the protocol indication that cooling capacity remained. Data, however, was not analyzed because two of the probes (chest, back) were under the cooling vest and their data was considered to be compromised.

Average heart rate was higher in the Non Vest tests than the Vest (135 vs 132 BPM). While not significant, it is interesting because one would have higher heart rates due the workload required to carry the 3.7 kg (8.16 lb.) cooling vest.

Sweat loss, as measured by weight loss, was significantly greater ($p<0.05$) for the Non Vest tests than Vest (1.103 +/- .12 kg vs 0.914 +/- 10 kg). It should also be noted that the vest provided temperature relief only to the torso area, but the black suit covered the entire body. Considerable leg muscle effort was expended.

Air usage, while less for Vest (1.27 kg) than Non vest (1.34 kg), was not statistically different. Again, one may expect the respiratory demands to be greater when carrying the weight of the vest, but air savings were noted.

**SUMMARY**

The use of this phase change material cool vest provided relief from thermal stress in spite of the addition of 3.7 kg weight. Skin temperature and sweat loss were both significantly reduced when the vest was employed. Rectal temperature rate of increase, average heart rate, and respiratory volume were reduced when the vest was used, but not significantly. It should be noted that a larger (than six) sample size may have strengthened this measurement effect.

Use of the vest caused the suit to be somewhat tight on those subjects that were custom fitted to their own suits. There was also some noted loss in mobility, specifically in bending at the waist.

An important advantage of this 65° F (18.3° C) phase change material was its comfort next to the skin compared to products at normal ice (32° F - 0° C). temperatures. In this latter case, vasoconstriction of blood vessels near the skin is observed and it is expected that the ability of the body to radiate heat would be decreased.

At the conclusion of each test, the sixteen envelopes of phase change material were withdrawn from the vest pockets to assess the amount of use or phase conversion. In no case was more than half the (hexadecane) phase change material converted to the liquid state. For this particular application, it would be possible to reduce the amount of material carried by about half, hence a weight savings of 1.8 kg (4 lb.). It would be important to maintain the same amount of skin exposure area during this reduction.

*A major advantage of this technology is the easy maintenance.* The phase change material envelopes can be converted to the solid (frozen) state in ice water in about 15 minutes. *There are no pumps, batteries, tubes, or valves to fail.*

User acceptance was excellent, an important feature of any personal protective equipment. The psychological relief from heat stress was subjectively very good with all subjects positively responding.

Subsequent to this series to tests, the vest was tested under the Category I Propellant Handier's Ensemble. It was comfortably worn under the environmental control unit and provided significant (subjective) heat stress relief. The vest is now worn under Category I and Category IV PHE at the propellant farm at the Cape Canaveral Air Station.