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EVALUATION OF TWO MICROCLIMATE COOLING AIR VESTS ON A HEATED MANIKIN

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13. ABSTRACT *(Maximum 200 words)*

This study compared the newly developed Microclimate Cooling Air Vest (MCAV) to the Combat Vehicle Crewman (CVC) Air Vest on a heated manikin using a sweating skin. At flow rates of 12 and 15 cubic feet per minute, both vests were found to remove an equivalent amount of heat. In addition, the effect of each vest's resistance to air flow (pressure drop) is noted.

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PREFACE

The testing covered by this report was performed in June 1992 to assess the cooling capabilities of the Microclimate Cooling Air Vest (MCAV) as compared to the type classified CVC Microclimate Cooling Air Vest. This effort was conducted on a thermal heated manikin at the U.S. Navy Clothing and Textile Research Facility (NCTRF) in Natick, MA 01760.

The authors appreciate the assistance of Mr. Joseph Giblo (NCTRF), Mr. Gary Proulx, Mr. Mark Wolfson, and Mr. Michael Miller of the Individual Protection Directorate (IPD) at the Natick Research, Development, and Engineering Center (Natick) during this study.

Note: Throughout this report, the energy term 'cooling' is frequently mentioned. Here, however, cooling refers to an energy rate (Watt).

EVALUATION OF TWO MICROCLIMATE COOLING AIR VESTS ON A HEATED MANIKIN

BACKGROUND

The U.S. Army Natick Research Development and Engineering Center type classified a microclimate cooling air vest in 1985. It is an 'over the head' design with a supply umbilical extending from the torso region when worn. Air is distributed to the torso via manifolds and to the neck area by hoses (Figure 1). This vest was developed for use by the Combat Vehicle Crewman (CVC) and is currently used aboard the M1A1 armored vehicle. However, when aviators evaluated this vest they experienced compatibility problems including, but not limited to, potential lap and shoulder harness interference with the umbilical hoses (Ref. 1) and general Aviation Life Support Equipment (ALSE) incompatibilities, such as hose/Clothing and Individual Equipment (CIE) interface.

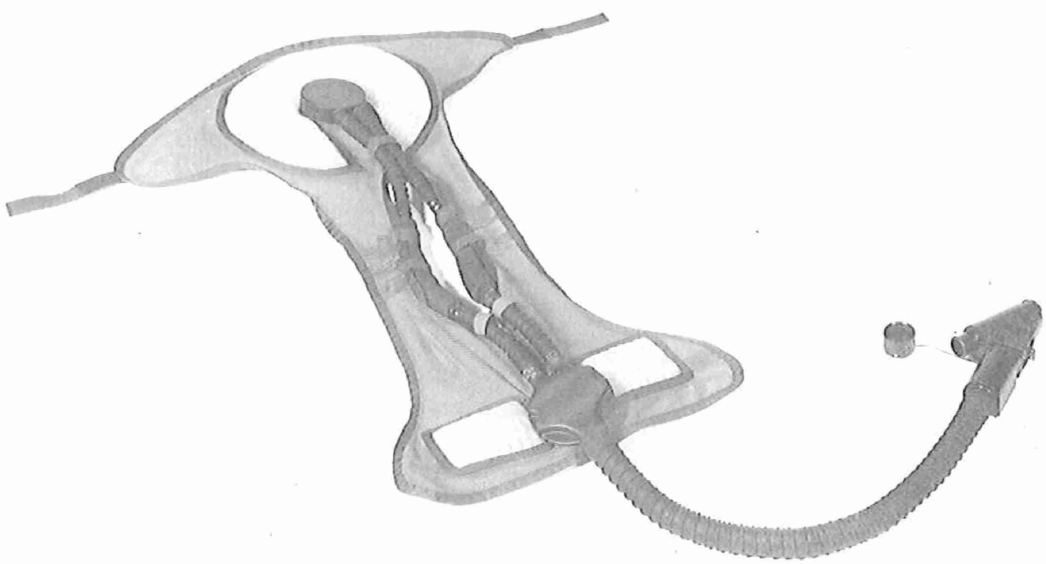

FIGURE 1 - CVC Microclimate Cooling Air Vest

In 1988, an Improved Microclimate Air Vest (IMAV) was developed which eliminated the neck hoses, moved the supply umbilical from the front to the side(s), and changed it to a 'wrap-around' design (Figure 2). The IMAV was subsequently assessed by the aviators and CVC and found to be inadequate primarily because it was too bulky (approximately one-inch thick), difficult to don and doff, and restricted movement (Ref. 1,2).

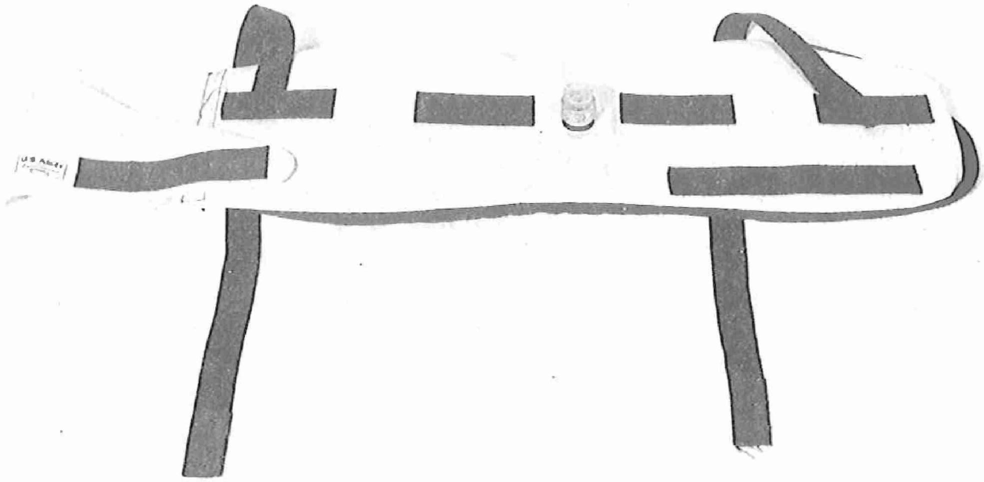

FIGURE 2 - Improved Microclimate Air Vest (IMAV)

In 1991 the redesign of a new air vest was initiated to primarily satisfy aviation requirements (Ref. 3). However, after subsequent iterations, this Microclimate Cooling Air Vest (MCAV) may also meet the requirements of the CVC community and, perhaps, replace the current type classified vest. The MCAV is a 'wrap-around cumberbun' design with a side hose entry. It is about ¼-inch thick and weighs 1.35 pounds (Figure 3).

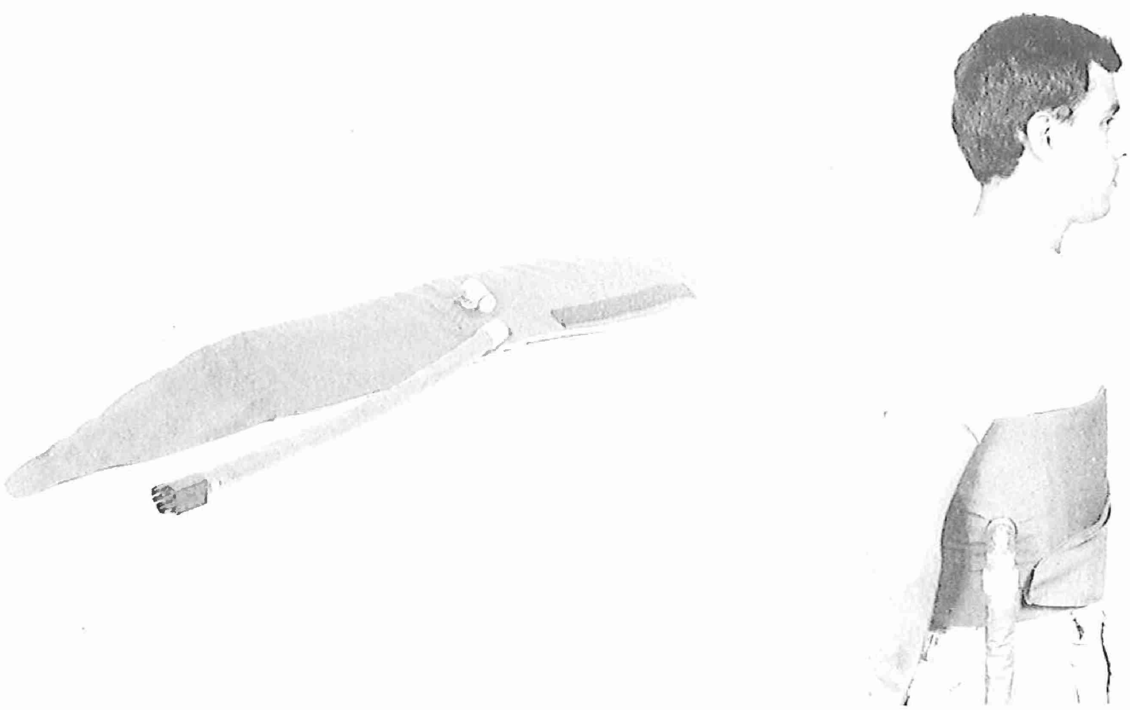

FIGURE 3 - Microclimate Cooling Air Vest (MCAV)

TEST SET UP

In order to fully evaluate the performance of the MCAV in terms of measured cooling (watts) and efficiency, Natick conducted a thermal manikin study at the U.S. Navy Clothing Textile and Research Facility (NCTRF) in June 1992. In this test, the environmental conditions were 95°F, 5 percent relative humidity, and 3.5 mph wind speed. The temperature of the thermal manikin was also maintained at 95°F, so the power supplied to each region to maintain the manikin temperature was in direct response to, and, therefore directly proportional to, the measured cooling. The manikin, which is divided into five heated zones (torso, arms, legs), is covered with a 'sweating skin' consisting of a cotton body suit into which punctured capillary tubes are sewn. Ninety-five degree water was pumped through the tubes at 0.288 gallons per hour to simulate sweat and distributed as follows: 55.56 percent to the torso, 27.78 percent to the legs, and 16.66 percent to the arms.

The air delivery equipment consisted of an EG&G Rotron® blower, water/air heat exchanger, and NESLAB® water recirculator. The air flow rate was monitored by a Datametrics® 810L Flowmeter and controlled by a variable auto transformer which varied the speed of the blower. T-type thermocouples provided temperature measurements of the air entering the vest, recirculating bath, and chamber. The dew point of the cooling air entering the air vest was monitored by a General Eastern® 1100DP Dew Point Hygrometer. All data was collected by an IBM® 386/25 MHz personal computer equipped with a Metrabyte® DAS16F A/D converter with an EXP16 external conditioner and stored in an ASCII data file. The inlet air temperature was maintained at 72±1°F and delivered at 15±0.5 cfm and 12±0.5 cfm. Several ensembles (Table 1) were evaluated using the standard air vest and the MCAV. Each test run was terminated when the input

Table 1. Ensembles Tested

ENSEMBLE	FLOW RATE (cfm)
Air Vest/CVC Coverall	12,15
Air Vest/Battle Dress Overgarment	15
Chemical Protective Undergarment/ Air Vest/CVC Coverall	15
Air Vest/Chemical Protective Undergarment/ CVC Coverall	15
Air Vest/Body Armor/Chemical Protective Undergarment/CVC Coverall	15

power to each region of the manikin was constant for at least 30 minutes. Baseline measurements with no delivered cooling were taken in the final three ensembles using both air vests. This data reflected the evaporative cooling in each case. In each test run, the manikin also wore chemical protective overboots and chemical protective gloves.

DISCUSSION

At the conclusion of each test, a graphical analysis and tabular printout of power input to each region of the manikin versus time was generated. The "average" measured cooling to each region was calculated using Simpson's Rule which accurately approximates the area bound by a curve, the horizontal axis, and the abscissas. From the power curve, the left abscissa was selected as the initial point at which the slope of the power curve became zero (constant power level). Simpson's Rule is defined as:

$$A_s = \frac{h}{3}\left[y_0 + 4y_1 + 2y_2 + 4y_3 + 2y_4 + \ldots + 2y_{n-2} + 4y_{n-1} + y_n\right]$$

which is taken as the approximate value of $\int_a^b f(x)\,dx$

where $f(x) = Ax^2 + Bx + C$.

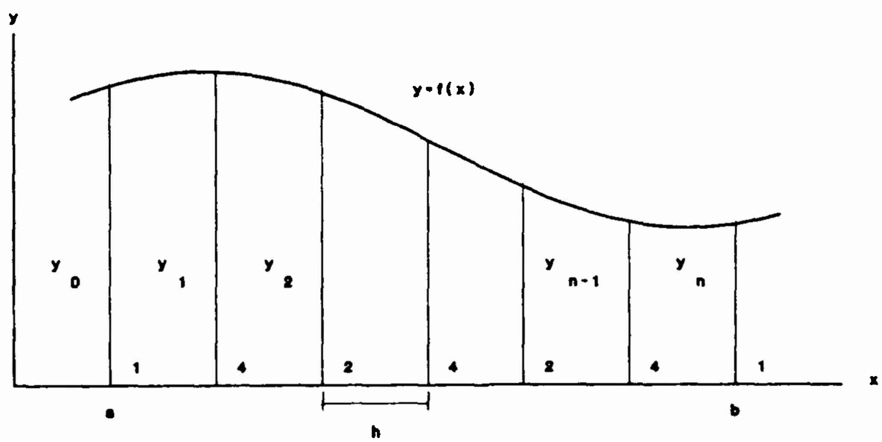

FIGURE 4 - Simpson's Rule Approximation

The area under each curve divided by the time duration represents the average cooling measured by each region of the manikin. Therefore, the sum of these values is equal to the total measured cooling.

In evaluating any microclimate cooling garment, it is important to know its effectiveness which is defined as the cooling measured by the thermal manikin divided by the cooling delivered to the manikin. In a liquid system, the delivered cooling is a straight forward calculation requiring the knowledge of inlet and outlet temperatures and the mass flow rate of the liquid. Substituting these values into the following equation will result in the heat transferred by the garment:

$$ {}_iQ_o = mC_p(T_o - T_i) $$

where Cp is the constant pressure specific heat.

In an air system, however, it is necessary to know the dew point and dry bulb temperatures as well as the flow rate of the air entering and exiting the garment. Since the outlet air is not recaptured (it is an open loop system), it is very difficult to measure these exiting properties when using air permeable clothing systems. Thus, it was assumed that the outlet air was saturated at skin temperature (95°Fdb). The delivered cooling which is based on these assumptions is known as the maximum theoretical cooling. A sample calculation follows:

VARIABLES LIST

T_{db} : Dry bulb temperature (°F)

T_{dp} : Dew point temperature (°F)

RH : Relative humidity

h : Specific enthalpy (Btu/lbda)

P_{da} : Partial pressure of dry air (psia)

P_b : Atmospheric pressure (14.696 psia)

P_{vs} : Saturation vapor pressure (psia)

rho_{da} : Density of dry air (lbm/ft^3)

H : Absolute enthalpy (Btu/min)

q : Volumetric flow rate (ft^3/min)

Q : Heat transfer (Btu/min)

Inlet (i) | Outlet (o)

Given:

$T_{dbi} = 72°F$ | $T_{dbo} = 95°F$
$T_{dpi} = 54°F$ | $T_{dpo} = 95°F$

From the Psychometric Chart at atmospheric pressure:

$RH_i = 52.41\%$ | $RH_o = 100\%$
$h_i = 26.830$ Btu/lbda | $h_o = 63.117$ Btu/lbda

From the saturated steam tables:

$P_{vsi} = 0.3892$ psi | $P_{vso} = 0.8160$ psi

$$P_{da} = P_b - P_{vs}(RH)$$

$P_{dai} = 14.696 - 0.3892(0.5241)$ | $P_{dao} = 14.696 -(0.8160)(1.00)$

$P_{dai} = 14.492$ psia | $P_{dao} = 13.880$ psia

$$rho_{da} = rho_{dab}(P_{da}/P_b)$$

where rho_{dab} : density of dry air at atmospheric pressure (0.07517 lbm/ft^3)

$rho_{dai} = 0.07517(14.492/14.696)$ | $rho_{dao} = 0.07517(13.880/14.696)$

$rho_{dai} = 0.07413$ lbm/ft^3 | $rho_{dao} = 0.07100$ lbm/ft^3

$$H = (h)(rho_{da})(q)$$

$H_i = 26.830(0.07413)(q)$ | $H_o = 63.117(0.07100)(q)$

$H_i = 1.98891(q)$ Btu/ft^3 | $H_o = 4.48131(q)$ Btu/ft^3

$${}_iQ_o = H_o - H_i$$

Let q = 15 cfm.

$${}_iQ_o = (4.48131 - 1.98891)15$$

$${}_iQ_o = 37.386 \text{ Btu/min}$$

Converting to Watts: ${}_iQ_o = 656.965$ W

This is the maximum theoretical cooling. In actuality, the cooling delivered to the manikin is less than this value since the exiting air will never reach skin temperature nor will it be completely saturated. Thus, maximum theoretical cooling is a value that can never be attained. However, as previously mentioned, in the absence of measured data, these assumed values serve as a method of comparison between tests.

RESULTS

Table 2 contains the cooling data for each ensemble using both microclimate cooling vests at an average air flow rate of 15 scfm unless otherwise noted. The measured cooling, maximum theoretical cooling (MTC), percentage of the MTC, and coefficient of performance (COP) of each vest is shown. The different maximum theoretical cooling values are due to the slight variations in the dry bulb and dew point temperature and air flow rate.

Table 2. Thermal Manikin Cooling Data

Ensemble	CVC Vest 15 scfm @ 4.5 in wc*				MCAV 15 scfm @ 2.5 in wc*			
	Meas. (W)	MTC (W)	%MTC	COP	Meas. (W)	MTC (W)	%MTC	COP
Air Vest/CVC Coverall**	275	543.3	50.6	32.21	241	522.4	46.1	51.82
Air Vest/CVC Coverall	289	659.3	43.8	27.30	273	684.8	39.9	46.67
Air Vest/BDO	243	667.3	36.4	22.99	232	660.3	35.1	39.76
CPU/Air Vest/CVC Coverall	181 [114]	662.0	27.3	17.10	186 [113]	664.8	28.0	31.91
Air Vest/CPU/CVC Coverall	286 [114]	659.8	43.3	26.89	296 [113]	656.5	45.1	51.65
Air Vest/BA/CPU/CVC Coverall	293 [113]	602.0	48.7	27.75	264 [104]	617.0	42.8	45.19

* inches of water column
** 12 scfm @ 3.0 in wc (CVC) & 1.65 in wc (MCAV), respectively
[] Baseline measurements
%MTC Measured Cooling/Delivered Cooling
COP Measured Cooling/Input Power

From the percentage of MTC column in Table 2, the standard CVC microclimate cooling air vest may appear more effective, in some cases, than the MCAV. However, in the evaluation of a microclimate cooling garment, other characteristics must be taken into consideration. The pressure drop of a liquid or air microclimate cooling vest is a measure of its resistance to the flow of the cooling medium. A cooling vest with a high resistance to flow is less efficient and forces the cooling equipment (ie. the blower or pump) to "work" harder which results in greater power consumption. In laboratory testing of each vest, the pressure drop across the MCAV was significantly less than the CVC vest. At 12 scfm, the CVC vest has a pressure drop of approximately 3.0 inches of water column (wc) which is 76 percent greater than that of the MCAV (1.7 inches wc - see Figure 5). This information is critical since a reduction in air resistance is directly related to an increase in delivered cooling. If the MCAV is used in conjunction with a cooling system designed for the CVC air vest, the wearer would receive more cooling due entirely to the less resistant MCAV. In fact, a soldier who is being cooled at 12 scfm wearing the CVC air vest will 'gain' 4.5 scfm by donning the MCAV using the same cooling system! This is illustrated in Figure 5 by following the pressure vs. flow curve for the CVC air vest. The pressure drop for this vest is 3.0 inches wc at 12 scfm. If that same pressure drop is applied to the MCAV curve, it translates into a flow rate of 16.5 scfm, thus accounting for the 4.5 scfm differential. Therefore, when considering the total power required by the cooling system versus output cooling delivered by each air vest, the MCAV is <u>much more efficient</u> in cooling the individual soldier.

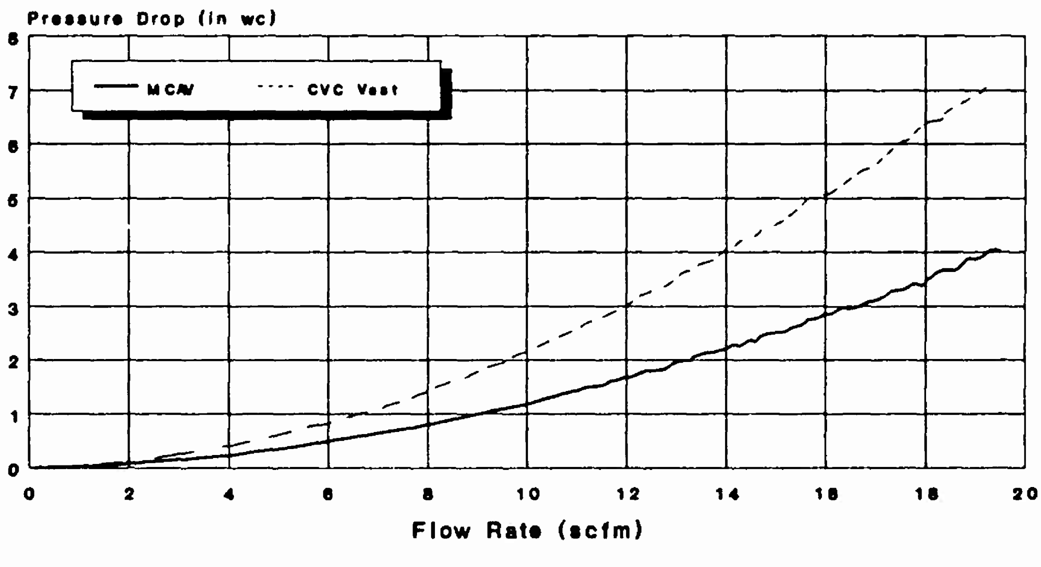

FIGURE 5 - Pressure vs. Flow Rate

The cooling measured by the thermal manikin does not reflect the effects of an air vest's resistance to flow. In order to further illustrate these effects, two scenarios will be examined:

After each test run, the blower speed was adjusted to maintain the desired flow rate when one air vest was replaced by the other. The MCAV required less power (slower blower speed) since it was less resistant to air flow. This is critical if a cooling system is being designed around the pressure and flow characteristics of this vest. Thus, a smaller, lighter weight blower/cooling unit using the MCAV will provide about the same cooling as the CVC air vest with a larger, heavier, more power consumptive system.

If, however, the input power to the blower was held constant, the pressure drop effect on the air vests would have dramatically altered the results. The less resistant MCAV would allow significantly more air to flow inside the vest. This is directly related to a substantial increase in absolute cooling, although the vest's efficiency would decrease (vest efficiency decreases with increasing flow rates). Therefore, if the MCAV was connected to a cooling unit capable of supplying 15 scfm to the CVC air vest (4.5 in wc), the flow rate would increase to approximately 20.5 scfm.

To quantify the effect of a vest's resistance to air flow, the COP, which is the ratio of the measured cooling to the input pumping power of the blower, is used. While this is a theoretical value, it takes into account the pressure drop of each vest. A sample calculation follows:

Input Pumping Power = P*q/eff

where P : Back pressure (vest pressure drop)
q : Volumetric flow rate
eff : blower efficiency (assume 50%)

For the MCAV: Pow = (1.65 in wc)(15 scfm)(144 in^2/ft^2)/(27.7066 in wc/psi)(.50)

Pow = 257.27 ft lb/min = 5.813 W

Coefficient of Performance = Measured Cooling/Input Power

COP = 273/5.813

COP = 46.96

A similar calculation for the CVC air vest at the same flow rate yields a COP of 27.34 which is a decrease of nearly 42%.

Table 2 also presents data which may help to resolve the issue of where the Chemical Protective Undergarment (CPU) should be worn. When it is worn under either air vest, a substantial decrease in cooling (37%) was observed.

CONCLUSION

The thermal manikin test data indicates that the CVC microclimate cooling air vest and the MCAV are equally effective in removing heat when conditioned air is delivered at 12 and 15 standard cubic feet per minute at 72°F. However, the individual soldier will receive more absolute cooling from the MCAV when used with a constant pressure air supply unit. Conversely, less electrical power will be required to attain a desired level of cooling if the soldier dons the MCAV.

This document reports research undertaken at the US Army Natick Research, Development and Engineering Center and has been assigned No. NATICK/TR-93/009 in the series of reports approved for publication.

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