ARMY RESEARCH LABORATORY

Quick Assessment of the Navy Mark V CBR Respirator After 13 Years in Storage

by Ryan J. Felling, Gregory A. Cherry, and Ronald A. Weiss

ARL-TR-3069 **September 2003**

NOTICES

Disclaimers

Army Research Laboratory
Aberdeen Proving Ground, MD 21005-5068

ARL-TR-3069 **September 2003**

Quick Assessment of the Navy Mark V CBR Respirator After 13 Years in Storage

Ryan J. Felling, Gregory A. Cherry, and Ronald A. Weiss
Survivability/Lethality Analysis Directorate, ARL

REPORT DOCUMENTATION PAGE	*Form Approved* *OMB No. 0704-0188*

1. REPORT DATE *(DD-MM-YYYY)* September 2003	**2. REPORT TYPE** Final	**3. DATES COVERED (From - To)** May–June 1997

4. TITLE AND SUBTITLE Quick Assessment of the Navy Mark V CBR Respirator After 13 Years in Storage	**5a. CONTRACT NUMBER**
	5b. GRANT NUMBER
	5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S) Ryan J. Felling, Gregory A. Cherry, and Ronald A. Weiss	**5d. PROJECT NUMBER** Office of Special Technology Task T-510
	5e. TASK NUMBER
	5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) U.S. Army Research Laboratory ATTN: AMSRL-SL-BE Aberdeen Proving Ground, MD 21005-5068	**8. PERFORMING ORGANIZATION REPORT NUMBER** ARL-TR-3069
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	**10. SPONSOR/MONITOR'S ACRONYM(S)**
	11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT

Approved for public release; distribution is unlimited.

13. SUPPLEMENTARY NOTES

14. ABSTRACT

This study was a quick assessment of the Mark V CBR respirator for its fit factor and physiological effectiveness using two volunteer subjects. The assessment included tests for fit factor, vision, and carbon dioxide buildup during exercise. Having been manufactured in 1984, the ability of this respirator to provide adequate nuclear, biological, and chemical and hazardous materials protection for civil authorities was questionable. Three of these respirators still in their original packages were supplied for testing. The assessment indicated that the masks should be discarded or used only for training.

15. SUBJECT TERMS

Mark V, respirator, storage effects, physiology, vision, CBR, NBC, fit factor

16. SECURITY CLASSIFICATION OF:			**17. LIMITATION OF ABSTRACT**	**18. NUMBER OF PAGES**	**19a. NAME OF RESPONSIBLE PERSON** Ronald A. Weiss
a. REPORT UNCLASSIFIED	**b. ABSTRACT** UNCLASSIFIED	**c. THIS PAGE** UNCLASSIFIED	UL	16	**19b. TELEPHONE NUMBER** (*Include area code*) 410-278-5709

Standard Form 298 (Rev. 8/98)
Prescribed by ANSI Std. Z39.18

Contents

List of Figures

List of Tables

1. Introduction

The Navy Mark V chemical, biological, and radiological (CBR) gas masks evaluated in this expedient assessment were supplied by the Los Angeles County Emergency Medical Services Agency (EMSA). EMSA had obtained 2000 masks and 10,000 vacuum-packed filter canisters packaged in original, unopened boxes (dated 1984). The masks were given to EMSA Emergency Response teams for use in early 1997. The purpose of this study was to evaluate, after 13 years in storage, the amount of protection the masks would provide, as well as their physiological effectiveness, including their visual capability and breathing proficiency during heavy workloads. Acoustic capability was not addressed because the mask does not cover the ears and would therefore have no effect.

The three Mark V respirators evaluated in this study had a molded medallion under the forehead strap tabs marked February 1984. It was not known whether the masks were new or reconditioned after manufacturing due to slight scuff marks found on the face pieces and lenses. It was originally assumed that the masks had been reconditioned after their manufacturing. In 1984, the Navy explored the possibility of adding a nosecup to this mask but no nosecups were present in the masks used in this study. A report (Chambers, 1984) surveying the effects of age with shipboard storage indicated that the Mark V lenses, at least 17 years old, turned yellow to orange in color. The older masks also had a tendency to take the compression set of both the face piece and lens because they were folded during storage. Because the three masks supplied for testing did not outwardly show these characteristics during their known 13 years in storage, this supported the assumption that the masks were new.

Figure 1 shows the Mark V nuclear, biological, and chemical (NBC) protective respirator. It is mounted on the head with a five-strap harness and buckle system with only the bottom two straps being adjustable while wearing the mask. A seal is formed around the face by a hollow tube, internally molded within the perimeter of the mask. There is a single lens made of a clear plastic material. The mask lacks a nosecup, but there is an exhalation valve directly in front of the mouth with inhalation valves on both sides within the metal filter canister mounting disks. Each filter canister has a 0.5-in-wide rubber mounting/sealing toroidal gasket fastened to the outer edge of its posterior surface that stretches over a large metal mounting plate to attach the canister to the mask. The internal edge of the rubber gasket is loose.

2. Methodology

The volunteers used as test subjects in this evaluation were well-conditioned 19-year-old males weighing ~80 kg and were 1.85 m in height. The tests were conducted in an air-conditioned laboratory where the temperature was maintained at 21 °C. The testing was conducted in compliance with an approved human-use protocol.

Figure 1. The Mark V protective respirator.

2.1 Physiological Testing

The physiological portion of the procedure consisted, in part, of a series of standard tests used to evaluate mask performance and to determine if any visual degradation was caused by wearing the mask (North Atlantic Treaty Organization [NATO] Army Armaments Group, 1977). Two tests were conducted to determine if the lens of the Mark V respirator had any effect on the color acuity of the wearer due to either aging or construction. Color acuity was evaluated by the Farnsworth-Munsell Dichotomous Test for Color Blindness, which uses a series of 15 colored caps that the subject must arrange in the correct color sequence (Lakowski, 1969; Whitcomb and Benson, 1996; The Psychological Corporation, 1947) and by Ishihara's Test for Color Blindness (Kanehara and Company, 1920), which consists of a book of plates displaying a number that the subject must discern within a specific color pattern. The Howard-Dolman Test (Armstrong, 1943; Howard, 1919) was used to determine the effect that the distortion or material degradation of the lens might have on depth perception by having the subject attempt to align two movable arrows from a distance of 6 m. While wearing the mask, static visual acuity was determined by having the subject read the standard Snellen charts (Westheimer, 1981; Snellen, 1862) which are commonly used in clinical visual testing. Any deviation from the unmasked baseline measurement of the subject would be an indication of visual distortion caused by the lens. Glare from light hitting the lens could also present a problem; therefore, the subjects' contrast sensitivity was also tested while wearing the mask using the Pelli-Robson chart (Metropia Ltd., 1989).

Finally, the visual field and Esterman field were measured with the Marco Perimeter, a hemisphere around which a small moveable light can trace a subject's visual limits (NATO Army Armaments Group, 1977). Separate measurements were taken for each eye, except for the Esterman field, which was done with binocular vision. The visual field test determines the extent to which the mask reduces the total visual field, both peripheral and binocular. The

Esterman Field test measured the visual ability across the full visual field. Values were calculated as percentages of the normal fields when the subject did not wear a mask. Figure 2 shows the various measurements that were taken. The peripheral field is the overall field of view while the binocular field is the overlapping intersection of the fields of view for both the left and right eye. The lateral, inferior, and medial efficiency indexes (Weiss, 1991; NATO Armaments Group, 1977) were measured for the right eye from 70 to 135°, from 135 to 180°, and from 250 to 310°, respectively. The specific visual efficiency indices were calculated as a percent of the normal field for the same degree wedges.

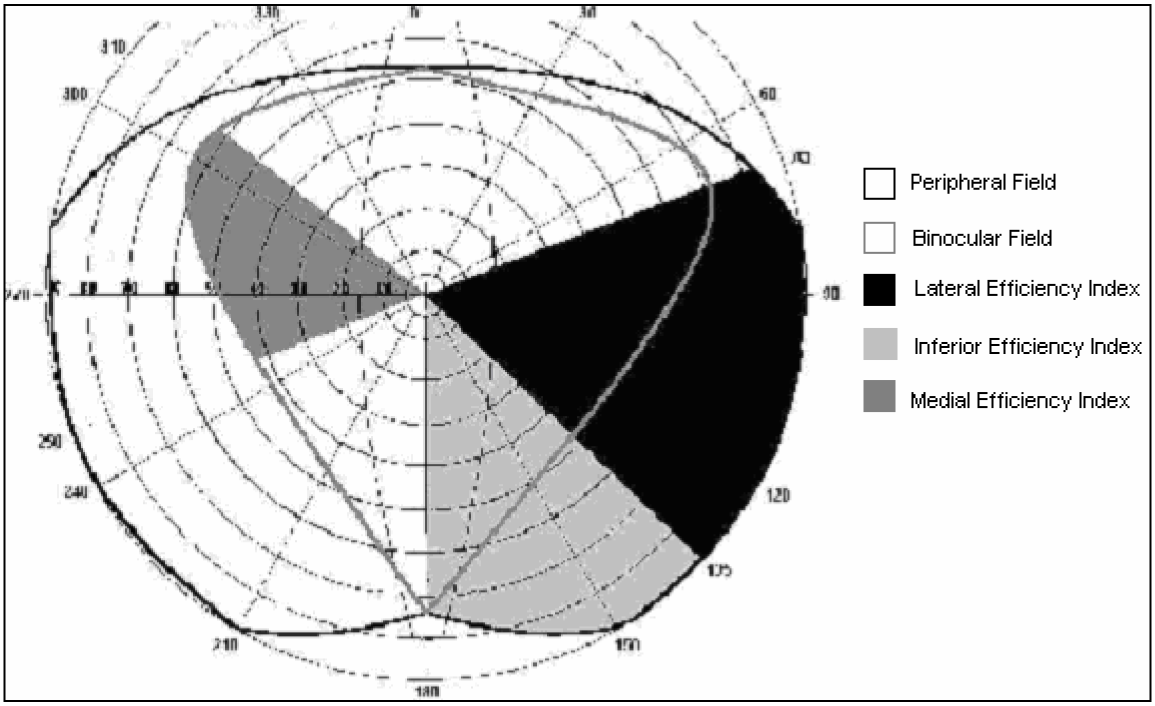

Figure 2. Diagram of visual field measurements in a standard binocular field.

A second physiological evaluation was performed to measure the potential build-up of carbon dioxide (CO_2) within the mask during exercise. While wearing a mask, the subject would pedal a Monark stationary bicycle for 10 min with a braking resistance of 1.0 kilopond (kp) and another 10 min at a braking resistance of 2.0 kp. A mask internal air sample was continually extracted through a hollow plug inserted in the lens of the mask and directed through an Ametek Model CD3A gas analyzer to determine CO_2 concentration. The percentage of CO_2 was averaged and recorded every minute.

2.2 Fit Factor

This test determined if the mask was leaking by comparing the concentration of a mineral oil aerosol within the mask to its concentration outside the mask in the surrounding ambient air environment. This ratio of inside concentration to outside concentration is known as a “fit or leakage” factor because it makes no judgment of the toxicity of the material being measured. If the toxicity of the aerosol and its physiological threshold concentration were known, it would be a protection factor.

Testing used to determine the fit factor of the masks was done using the TDA-99D Mask Leakage Detector made by Air Techniques, Inc., Owings Mills, MD. Leakage tests were conducted both statically and dynamically using Emory 3004 aerosol with the Mark V respirator placed both on a face-form (static method) and on a human subject (dynamic method). With the mask mounted on the face-form, a vacuum was created inside the face-form at the rate of 15 L/min. Using a wand emanating the aerosol, a narrow spray of Emory 3004 was directed around the peripheral edge of the mask and then over each component of the mask. Any mask penetration was pulled by a vacuum through a sensor and recorded by the detector. The narrow stream emitted from the wand made it possible to pinpoint locations of any leaks in the mask. The second test to determine the fit factor of the mask was performed under a hood into which the Emory 3004 aerosol was released. A human subject would then stand within the hood while wearing the Mark V respirator and perform the following series of exercises for 1 min each:

- Breathe normally.
- Breathe deeply.
- Move head from side to side.
- Move head up and down.
- Recite the "Rainbow Passage."
- Perform facial expressions.
- Look up and move head from side to side.
- Jog in place.
- Breathe normally.

Air samples were continually extracted by a vacuum through the same narrow plug in the lens of the mask. The percent penetration readings were recorded for each activity and later converted to determine fit factor.

3. Results

3.1 Physiological Testing

The results of the vision testing are presented in Table 1. The Farnsworth-Munsell Test and Ishihara Test were each passed without error by both subjects. Negligible differences were

Table 1. Results from vision testing of Mark V respirator.

Test	Subject A	Subject B
Farnsworth-Munsell	Pass	Pass
Ishihara	Pass	Pass
Depth perception	—	—
Trial 1	2 mm	5 mm
Trial 2	1 mm	0 mm
Trial 3	5 mm	6 mm
Average	2.7 mm (2.3 mm)	3.7 mm (2.3 mm)
Acuity	20/15 (20/15)	20/20 (20/20)
Contrast sensitivity	1.95 (1.95)	1.95 (1.95)
Visual field	—	—
Peripheral	61.4%	68.1%
Binocular	38.2%	39.4%
Lateral eff. index	88.6%	91.4%
Inferior eff. index	27.5%	23.9%
Medial eff. index	66.2%	52.5%
Esterman field	93.3%	90.5%

Note: Unmasked baseline measurements are shown in parentheses for comparison.

found between the baseline and masked conditions during the depth-perception testing. Visual acuity and contrast sensitivity were also unaffected by the mask. Reductions were discovered in the sizes of visual and Esterman fields of view. The visual field and Esterman field results are given as percentages of the normal, unmasked fields of view.

The CO_2 testing did show an accumulation of CO_2 in the mask during heavy exercise, as recorded in Table 2. Subject A voluntarily stopped the test after 6 min when the inhaled CO_2 level reached 2.65%. The CO_2 concentration for Subject B reached a high of 1.49% after 8 min of exercise, but it then appeared to drop, even though the workload was increased after the first 10 min.

Table 2. Results from CO_2 testing of Mark V respirator.

Subject A				Subject B			
Time (min)	CO_2 (%)	Time (min)	CO_2 (%)	Time (min)	CO_2 (%)	Time (min)	CO_2 (%)
1	1.83	11	—	1	0.62	11	0.74
2	2.12	12	—	2	1.17	12	0.81
3	2.45	13	—	3	1.01	13	1.10
4	2.55	14	—	4	1.03	14	0.99
5	2.65	15	—	5	1.32	15	0.85
6	2.12	16	—	6	1.05	16	0.55
7	Cancel	17	—	7	1.08	17	0.62
8	—	18	—	8	1.49	18	0.50
9	—	19	—	9	1.08	19	0.41
10	—	20	—	10	0.72	20	0.60

While no acoustic testing was done on the mask because the ears were not covered and the mask contained a voicemitter in front of the mouth, it was observed that a voicemitter in one of the masks tested contained at least three moderate wrinkles in its diaphragm. These wrinkles would impede clear communication as a result of the slackness in the diaphragm.

3.2 Fit Factor

Figure 3 illustrates the locations where leaks were found in three Mark V respirators using the face-form leakage detector. In mask no. 1, leaks were found at the top of the face seal, at the top of the lens where the lens meets the mask, at the bottom of the face seal, at the exhalation valve, and at various spots around the canister-mask connection. Mask nos. 2 and 3 also showed leaks at the exhalation valve and around the rubber mounting/sealing gasket of the filter canisters, and mask no. 3 showed an additional leak at the top of the lens.

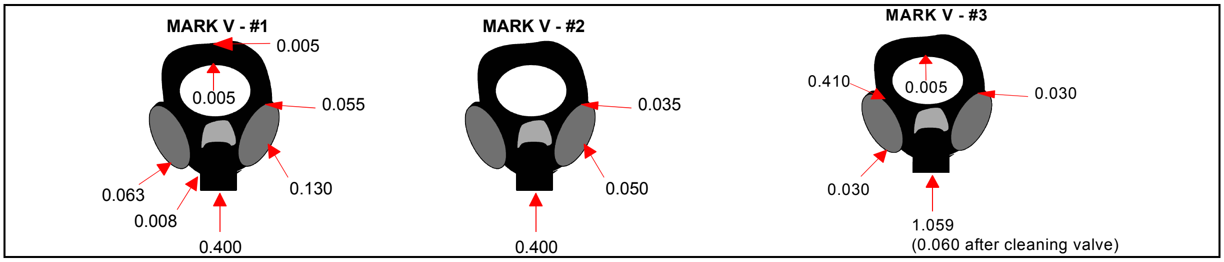

Figure 3. Leak locations and percent penetration in the Mark V respirators.

This part of the fit factor testing pinpointed where the problem areas of the mask were. The human testing conducted under the hood showed the cumulative effect of all the leaks in each mask. Table 3 compares the test results of each mask conducted on a single human subject. The fit factor numbers were converted from the raw concentrations of aerosol displayed by the TDA 99D. The averages shown in Table 3 represent the geometric mean of the values of the nine exercises when each mask was worn. Mask no. 2 had a geometric mean of 0 because exercises 4 and 6 had a reading of 0.

4. Discussion

The Mark V respirator has very little effect on the visual capability of the wearer. The most significant problem with regard to vision is the reduction in the size of the visual fields of view. While wearing the mask, the size of the overall visual field is reduced to <70% of the normal unmasked field. This is a significant decrease; however, it is not nearly as severe as some of the masks that are in use today. The most problematic aspects of the visual field are the binocular field and the inferior field, or downward-looking region. The filter canisters protrude into the

Table 3. Results of the human fit factor test.

Exercise	Minimum Fit Factor		
	Mask no. 1	Mask no. 2	Mask no. 3
Breathe normally	1020	690	250
Breathe deeply	330	450	170
Move head from side to side	180	420	220
Move head up and down	190	0	170
Recite "Rainbow Passage"	210	180	140
Perform various facial expressions	370	0	130
Look up, moving head side to side	800	310	220
Jog in place	540	500	340
Breathe normally	800	500	130
Geometric average	407	0	187

field of view, limiting sight below the nose line. Fogging did not present as much of a problem as would have been expected considering the lack of a nosecup. One subject complained of fogging during exhalation due to the high humidity of the exhaled air, but the mask immediately defogged in a cyclic manner once fresh, less humid air was inhaled.

The most critical physiological problem with the mask occurred during exercise when the level of CO_2 increased. Subject A exhibited breathing difficulty after the mask accumulated CO_2 levels of ~3%. Fogging also became an increasing problem due to the saturated warm exhaled air accumulating inside the mask causing condensation on the cooler lens. In this case, the test was stopped after only 6 min due to breathing difficulty. The second subject did not encounter as severe a problem with increased CO_2 levels, possibly because the mask did not have a tight seal. After reaching a high of 1.5% at ~8 min into the test, the CO_2 level actually began to subside. This is possibly due to an accumulation of sweat around the face seal, which facilitates the exchange of gases between the environments inside and outside the mask.

The physiological problems of the mask become irrelevant when one sees the results of the fit factor tests. According to these results, the wearer of this mask in a toxic environment would probably be incapacitated before he or she had to worry about vision or prolonged exercise. The current U.S. Army requirement is a fit factor of 1667 as a minimum standard for gas masks (King, 1983). The Mark V respirator did not meet this standard even during quiet breathing. The primary problem areas of the mask appear to be the exhalation valve and the canister connections. Rather than using threaded filter canisters, the Mark V respirator uses filter canisters that are held to a mounting plate by an attached rollable rubber mounting/sealing gasket. When these rubber gaskets are relatively new, they may provide adequate protection against leakage. However, as the gaskets get older, as seen by all three sets of filter canisters used in this evaluation, they could crack and leak. The problem with the exhalation valve could be due to one or more of several reasons: (a) loss of stiffness with age allowing the valve to prolapse, (b) turbulent backflow or, (c) a simple design flaw.

The face seal of the mask, by itself, appeared to be adequately functional when tested on the faceplate of the TDA 99D mask leakage detector, but this seal could very well have been broken by the various head movements performed during the dynamic human fit factor test. Low-level leakage at the top-center of the face piece, top center of the lens, and bottom center of the face piece in mask no. 1 suggested that a compression set had begun because it was folded during storage. When the three masks evaluated were removed from their original packaging at the beginning of this study, they were mounted on a stiff cardboard three-dimensional (3-D) frame in their carrier bags to prevent compression set during storage. This storage frame had a wide, flat central surface to preclude the mask folding in the center and thus should inhibit the compression set. There was no visual indication of the compression set in any of the masks during our initial inspection. The onset of compression set was only suggested in one of the three masks when a leakage test was performed. When the U.S. Navy conducted a survey on Mark V respirators aboard 10 ships (Chambers, 1984), they found 52.2% of the 78 masks surveyed had slight to severe permanent compression set in masks 1–27 years old. Unfortunately, the data presented in Chamber's report did not indicate the ages of the masks showing a compression set, nor did they indicate if they were mounted on the 3-D frame in their carrier.

Before testing was even begun on the Mark V respirator, another problem was found with the filter canisters. After being sealed in a vacuum for so long (13 years), the rubber attachment gasket of one of the canisters split radially as soon as it was stretched over the mounting plate on the mask. Furthermore, the buckles on the straps used to hold the mask in place make it very uncomfortable to wear as well as being relatively difficult to tighten in comparison to other masks.

5. Conclusions

Overall, the results of this study indicate that the Mark V respirator does not provide sufficient fit factor protection to the user against toxic materials after 13 years in storage; the masks should be discarded or possibly used solely for training purposes when such compromised mask use is appropriate and acceptable. Because the Mark V respirator was designed without a nosecup, CO_2 has a tendency to rapidly accumulate within the mask. This dramatically affects the breathing capability of the wearer and limits his or her ability to work. Visual capability when wearing the mask appears acceptable except that the lower visual field of view is reduced.

6. References

Armstrong, H. *Principles and Practice of Aviation Medicine*, 2nd ed.; Williams and Wilkens: Baltimore, MD, 1943; p 82.

Chambers, G. L. Initial Survey for Evaluation of Navy Mark V Protective Mask. PE S0410-SL, Task No. IP3S, August 1984.

Howard, H. J. A Test for the Judgment of Distance. *American Journal of Ophthalmology* **1919**, *2*, 656.

Kanehara and Company. Ishihara's Series of Plates Designed as a Test for Color Blindness. Tokyo, 1920.

King, Kenneth J. Revised Joint Service Operational Requirement (JSOR) for the Protective Mask. USATRADOC ACN 11954, April 1983.

Lakowski, R. Theory and Practice of Color Vision Testing: A Review, Part II. *British Journal of Industrial Medicine* **1969**, *26*, 265.

Metropia Ltd. Pelli-Robson Chart. Instructions Version 6/89, 1989.

North Atlantic Treaty Organization (NATO) Army Armaments Group. Combined Operational Characteristics, Technical Specifications and Evaluation Criteria for the Protective Mask: Unclassified Version. Publication D-103, NBC Defence Panel, January 1977.

Snellen, H. *Optotypes: Scala tipografica per mesurare il visus*; P. W. Vander Weijer: Utrecht, Netherlands, 1862.

The Psychological Corporation, *Farnsworth Dichotomous Test for Color Blindness. Panel D-15*; The Psychological Corporation: New York, NY, 1947.

Weiss, R. A. Concept of a Unit Circle and Unit Sphere as a Method of Expressing Respirator Physiology Function and Degradation—I: Vision. *Journal of the International Society for Respiratory Protection* **1991**.

Westheimer, G. Visual Acuity. *In Adler's Physiology of the Eye*, 7th ed.; Moses, R. A., Mosby Company: St. Louis, MO, 1981; p 530.

Whitcomb, M. A.; Benson, W., Eds. *Armed Forces Committee on Vision*; National Academy of Sciences, National Research Council: Washington, DC, October 1996.

INTENTIONALLY LEFT BLANK.

NO. OF
COPIES ORGANIZATION

2 DEFENSE TECHNICAL
INFORMATION CENTER
DTIC OCA
8725 JOHN J KINGMAN RD
STE 0944
FT BELVOIR VA 22060-6218

1 COMMANDING GENERAL
US ARMY MATERIEL CMD
AMCRDA TF
5001 EISENHOWER AVE
ALEXANDRIA VA 22333-0001

1 INST FOR ADVNCD TCHNLGY
THE UNIV OF TEXAS AT AUSTIN
3925 W BRAKER LN STE 400
AUSTIN TX 78759-5316

1 US MILITARY ACADEMY
MATH SCI CTR EXCELLENCE
MADN MATH
THAYER HALL
WEST POINT NY 10996-1786

1 DIRECTOR
US ARMY RESEARCH LAB
AMSRL D
DR D SMITH
2800 POWDER MILL RD
ADELPHI MD 20783-1197

1 DIRECTOR
US ARMY RESEARCH LAB
AMSRL CS IS R
2800 POWDER MILL RD
ADELPHI MD 20783-1197

3 DIRECTOR
US ARMY RESEARCH LAB
AMSRL CI OK TL
2800 POWDER MILL RD
ADELPHI MD 20783-1197

3 DIRECTOR
US ARMY RESEARCH LAB
AMSRL CS IS T
2800 POWDER MILL RD
ADELPHI MD 20783-1197

NO. OF
COPIES ORGANIZATION

ABERDEEN PROVING GROUND

2 DIR USARL
AMSRL CI LP (BLDG 305)
AMSRL CI OK TP (BLDG 4600)

NO. OF COPIES	ORGANIZATION
1	USARL AMSRL SL M J PALOMO WSMR NM 88002-5513
1	USARL AMSRL SL EA R FLORES WSMR NM 88002-5513
1	USARL AMSRL SL EI J NOWAK FT MONMOUTH NJ 07703-5601

ABERDEEN PROVING GROUND

NO. OF COPIES	ORGANIZATION
1	US ARMY DEV TEST COM CSTE DTC TT T APG MD 21005-5055
1	US ARMY EVALUATION CTR CSTE AEC SVE S R POLIMADEI 4120 SUSQUEHANNA AVE APG MD 21005-3013
1	US ARMY EVALUATION CTR CSTE AEC SV L R LAUGHMAN 4120 SUSQUEHANNA AVE APG MD 21005-3013
33	DIR USARL AMSRL SL DR WADE J BEILFUSS AMSRL SL B P TANENBAUM J FRANZ J MORRISSEY AMSRL SL BB M RITONDO S JUARASCIO D FARENWALD AMSRL SL BD R GROTE AMSRL SL BE E DAVIS (10 CPS) L ROACH R WEISS (10 CPS) AMSRL SL E M STARKS AMSRL SL EC J FEENEY E PANUSKA