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This document provides a plan for the independent assessment and evaluation of the ~~Live Fire~~ vulnerabilities of the USMC's LAV-25. It will be conducted for the LFT office of OSD when the test is conducted by the USMC in 1989. The plan comments on the planned shots, and the issues they should address.

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INDEPENDENT ASSESSMENT PLAN: LAV-25

A. INTRODUCTION

1. Objective:

The primary objective of these tests is to assess the vulnerabilities of the LAV-25 to selected threats, both from direct damage (penetration, fragments, blast) and indirect damage caused by on-board ordnance and combustibles. The tests will address the vulnerability to the threats of the vital components of the LAV-25 vehicle (including crew and troop personnel) that are related to the mission accomplishment (mobility, firepower and communications).

2. Background. (to p. A)

a. Description of LAV-25: The LAV-25 is an 8 x 8 wheel, diesel-powered, lightly-armored vehicle that combines speed, mobility and firepower to fulfill a variety of missions for the U.S. Marine Corps. In addition to operating on or off highways, the LAV-25 is also capable of swimming and can be helicopter transported. The vehicle carries a crew of three (driver, gunner and commander) with a four-man infantry squad positioned in the rear of the vehicle. The armament of the LAV-25 consists of an automatic 25 mm chain gun (M242) mounted in a two-man turret, a coaxially mounted 7.62 mm machine gun (M240), and a commander's pintle-mounted 7.62 mm machine gun (M60). An ancillary smoke grenade launcher (M257) is mounted on each side of the turret. Depending on the organizational element of the Marine Corps and the mission, the four-man squad at the rear is equipped with both anti-personnel and anti-armor weapons. Table 1 summarizes the major characteristics of the LAV-25.

Table 1. Principal Characteristics of the LAV-25.

Maximum weight, combat loaded	28,400 lb.
Length	252.6 inches
Width	98.4 inches
Height	100.9 inches
Propulsion:	
Engine type	diesel, two-stroke turbocharged
Rated output	275 hp
Maximum speed	62 mph
Transmission	5-speed automatic
Fuel capacity	71 gal
Armament:	
Main gun	25 mm/210 HE/AP ready, 420 stowed
Machine gun	7.62 mm/400 ready, 1200 stowed
Smoke grenades	40 mm/8 ready, 8 stowed
M16 rifles	5.56 mm/4050 stowed

b. <u>Description of Joint Live Fire Test (JLFT) of LAV-25:</u> The testing of the LAV-25 is planned as a two phase program. Phase I will characterize the vulnerability of the basic system and Phase II will demonstrate solutions. A total of 108 shots are planned for three Phase I tests. In the first, 32 will be fired into an instrumented ballistic hull to determine whether stowed or carry-on ammunition can be initiated by each threat. In the second, an additional 60 shots will be fired into an inert loaded LAV-25 to determine the vulnerability of personnel and selected critical components. In the third, the remaining 16 shots will be fired at the LAV-25, live loaded, to determine if ready ammunition can be initiated by the prescribed threats. From the total of 108 shots, 88 shotlines were selected through the random selection process of the Board on Army Science and Technology (BAST) methodology to address critical issues. The balance of 20 pre-selected shots are geared to either fill gaps not covered by random shots or to focus on specific critical components. The threat munitions chosen for these tests against the LAV-25 are the 7.62 mm, 14.5 mm, 30 mm kinetic energy rounds and the RPG-18 shaped charge, rocket propelled grenade. The three tests are described in the following three matrices, which categorize the shots by direction of attack, compartment attacked and component at risk (Figures 1-3).

		7.62 mm	14.5 mm	30 mm	RPG-18	Totals
Azimuth	Front					0
	Side	R-1 R-2 R-3 R-6 R-7 R-8	Y-1 Y-2 Y-3 Y-5 Y-7	B-1 B-3 B-5 B-7 B-8	G-1 G-4 G-6 G-8	20
	Rear	R-4 R-5	Y-4 Y-6 Y-8	B-2 B-4 B-6	G-2 G-3 G-5 G-7	12
Compartment	Driver					0
	TC	R-3 R-8	Y-1 Y-2 Y-3 Y-5 Y-7	B-1 (?) B-3	G-1	10
	Gunner	R-1 R-2 R-6 R-7		B-8		5
	Fire Team	R-4 R-5	Y-4 Y-6 Y-8	B-2 B-4 B-5 B-6 B-7	G-2 G-3 G-5 G-6 G-7 G-8	16
Component	25mm HE	R-1 R-2 R-6 R-7	Y-1 Y-2	B-1 B-2 B-8	G-1 G-2	11
	SMAW	R-3 R-4	Y-3 (?) Y-4	B-3 B-4	G-2 G-4 G-5 G-8	10
	LAW/AT-4	R-5	Y-5 Y-6	B-6	G-5	5
	Pop-up Flares	R-8	Y-7 Y-8	B-5	G-6 G-7	6
	Mines (Fire Team Carry-on)			B-7	G-3	2
	Frag Grenades	R-4	Y-8		G-2	3
	Fuel Cell			B-1 B-2	G-1 G-2	4
	40mm Grenades					0

Figure 1. Ballistic Hull - Stowed (Live) Ammo Tests (Test 1).

		7.62 mm	14.5 mm	30 mm	RPG-18	Totals
Azimuth	Front		Y-10 Y-13 Y-14	B-12 B-14 B-15 B-18 B-20	G-12 G-14 G-18	11
	Side	R-9 R-10 R-11 R-12 R-13 R-14 R-15 R-21 R-22 R-23 R-24 R-25 R-26 R-27	Y-9 Y-11 Y-12 Y-15 Y-16 Y-21 Y-22 Y-23 Y-24 Y-25 Y-26 Y-27	B-9 B-10 B-11 B-13 B-16 B-17 B-19 B-25 B-26 B-27	G-9 G-10 G-11 G-13 G-15 G-17 G-19 G-20 G-25 G-26 G-27	47
	Rear	R-16			G-16	2
Compartment	Driver	R-10 R-23	Y-10 Y-13 Y-23	B-12 B-15 B-27	G-14 G-18 G-27	11
	TC	R-9 R-12 R-14 R-25	Y-11 Y-25	B-10 B-11 B-17 B-25	G-9 G-13 G-25	13
	Gunner	R-11 R-15 R-22	Y-16 Y-22	B-18	G-15 G-17 G-19 G-20	10
	Fire Team	R-16 R-21 R-24	Y-21 Y-24		G-16	6
Component	Halon Bottles	R-24	Y-24			2
	Hydraulic Reservoir	R-12 R-13 R-26	Y-15 Y-26	B-9 B-16 B-26	G-26	9
	Transmission	R-27	Y-14 Y-27	B-27	G-10 G-27	6
	Turret	R-22 R-25	Y-16 Y-22 Y-25	B-18 B-25	G-19 G-25	9
	25 mm (Inert)		Y-9	B-10 B-13	G-9 G-15 G-17 G-20	7
	SMAW (Inert)	R-21	Y-21		G-16	3
	5.56 mm ammo	R-14				1
	Engine			B-14 B-20	G-12	3
	M43A1 Chemical Detector	R-26	Y-26	B-26		4
	M42 Remote Alarm		Y-24			1
	M18 Gas Filters	R-21	Y-21 Y-24			3
	M1A1-19 Precleaner - Particulate Filter	R-21	Y-21			2
	NBC Control Box	R-23 R-27	Y-10 Y-23 Y-27	B-26 B-27	G-14 G-26 G-27	10
	M3 Heater	R-23 R-24 R-26 R-27	Y-9 Y-23 Y24 Y26	B-10 B-13 B-27	G-17 G-20 G-27	13
	M25A1 Mask/ Hose Assembly	R-16 R-23 R-24 R-26	Y-9 Y-23 Y-24 Y-26	B-13	G-17 G-20 G-2 G-27	13

Figure 2. Loaded LAV - Inert (Test 2).

		7.62 mm	14.5 mm	30 mm	RPG-18	Totals
Azimuth	Front					0
	Side	All (4)	All (4)	All (4)	All (4)	16
	Rear					0
Compartment	Driver					0
	TC	R-17 R-18 R-19 R-20	Y-19 Y-20	B-21 B-22 B-24	G-23	10
	Gunner		Y-17 Y-18	B-23	G-21 G-22 G-24	6
	Fire Team					0
Component	25 mm Ready Ammo	R-17 R-18	Y-17 Y-18	B-21 B-22	G-21 G-22	8
	25 mm Feed Chute	R-19 R-20	Y-19 Y-20	B-23 B-24	G-23 G-24	8
	M3 Heater			B-21 B-22		2
	M25A1 Mask/ Hose Assembly	R-18	Y-18	B-21		3

Figure 3. Live Loaded LAV (Test 3).

B. ISSUES ADDRESSED IN THE JOINT LIVE FIRE TEST AND EVALUATION

1. What are the effects of the threats on the combat utility of the LAV-25?

a. Sub-issues: Listed below are statements of the issues to be tested:

1) Mobility: What is the vulnerability of the LAV-25 to mobility kill through loss of critical component functions?

2) Firepower: What is the vulnerability of the LAV-25 to firepower kill through loss of critical component functions?

3) Communications: What is the vulnerability of the LAV-25 to communications kill through loss of critical component functions?

4) What are the effects of threats (both direct and indirect) on personnel in the LAV-25 as revealed by the following:?

Direct Effects on Personnel

a) What is the vulnerability of personnel to direct hits or behind armor debris and secondary fragments caused by penetration of the threats or overpressure caused by the impact of the 30 mm APDS and RPG-18 threats?

Indirect Effects on Personnel

b) What is the vulnerability of personnel to debris and/or overpressure caused by the initiation of on-board high explosive and combustible ordnance (stowed munitions)?

c) What is the vulnerability of personnel to toxic fumes from the initiation of stowed munitions or fires (fuel/other) initiated by the threats?

d) What is the vulnerability of personnel to intense heat/suffocation from fires (fuel/other) initiated by the threats?

e) What is the vulnerability of personnel to debris from a halon bottle ruptured by the threats?

f) What is the vulnerability of personnel to NBC effects resulting from damage to on-board NBC defense systems?

b. Criteria: Vulnerability of the LAV-25 to the effects of the threats on combat utility can be measured in terms of probability of kill, P_k*. Vulnerability of personnel can be measured in terms of probability of incapacitation (PI_h) for each person involved (crew or fire team member).

* More correctly, $P_{k/h}$ (probability of kill, given a hit). This is the correct terminology for each P_k listed below.

c. Analytic Approach:

1) Sub-issues. The following table tabulates the sub-issues, indicating the test and shots applying to that sub-issue and the instrumentation used to evaluate the effect of the shot.

Table 2. Sub-Issues Addressed.

Issue	Test*	Shot No.	Instrumentation
Mobility	2	6 on transmission, 3 on engine, 9 on hydraulic reservoir	Temperature, plus actual damage to components
Firepower	2, 3	2: 9 on turret, 9 on hydraulic reservoir; 3: 16 on ready ammo	Temperature, plus actual damage to components
Communications	2	R-25, Y-25, B-25, G-25	Actual damage to components
Penetration	1, 2, 3	All	Mannequins, actual damage
BAD, spall, frags	1, 2, 3	All	Mannequins, actual damage
Overpressure	1, 3	All	Overpressure each shot
Debris from stowed munitions	1, 3	All	Mannequins, actual damage
Overpressure from stowed munitions	1, 3	All	Overpressure each shot
Toxic fumes from stowed munitions	1, 3	All	1: 1/2 on B and G only; 3: B-22 and G-22 only
Toxic fumes from from fires	1, 3	All	1: 1/2 on B and G only; 3: B-22 and G-22 only
Heat/suffocation	1, 3	All	Temperature, skin patches
Halon bottles	2	R-24, Y-24	Mannequins plus temperature (no toxic fumes or over-pressure)
NBC Defense System	2, 3	2: 5 on detection, 49 on NBC filter; 3: 4 on NBC filter	Actual damage to components

* 1 = Stowed munitions in ballistic hull
2 = Inert test of LAV-25
3 = Live loaded LAV-25

2) Damage Assessment. After each shot/burst, damage is assessed by examination of the instrumentation readings and establishment of the necessary event time history. Components will be examined for damage and assessed as either operational or non-operational, based on a 10-minute rule (can be recovered to perform functionally within 10 minutes, being repaired by the crew on the battlefield). The effect of loss of operation of a component or group of components is determined by use of the Damage Assessment List (DAL), contained in the Detailed Test Plan (DTP). The list, developed by a panel of experts, relates the effects of specific loss or damage to specific components to the overall functioning of the LAV. A component assessed as non-operational translates to a rating in terms of $P_k(M)$, $P_k(F)$ and $P_k(K)$, corresponding to a mobility, firepower or catastrophic kill (K kill is assessed as either zero or one, and relates to those events where severe damage occurs by initiation of high explosives or munitions). Loss of the communication function translates to

$P_k(M)$ and $P_k(F)$ through the DAL. Likewise, probability of incapacitation (PI_h) of personnel translates to $P_k(M)$ and $P_k(F)$ through the DAL. In this way, $P_k(M)$ or $P_k(F)$ amounts to a degradation factor. A $P_k(M)$ of 1.00 is a total loss of mobility, that is, a mobility kill. A $P_k(F)$ of 0.70 is a 70% loss of firepower capability, that is, the LAV's firepower is reduced by 70%. In this way, the effect of a particular shot or threat can be accumulated in terms of firepower or mobility degradation. This approach appears to be a reasonable method of evaluating the effect of specific damage to the system. In terms of the sub-issues:

a) Mobility and Firepower. Since the Damage Assessment List (DAL) relates test damage, including personnel, to a loss in combat utility in terms of either mobility or firepower kill, these issues appear to be well characterized and straightforward. Catastrophic defeat, $P_k(K)$, also appears to be straightforward (since it is either 0 or 1).

b) Communications. This aspect of vulnerability is not emphasized in the tests adequately, especially in an NBC environment. When the DAL was developed, the committee felt that the crew could communicate adequately with each other verbally (because of their close proximity) even if the intercoms were lost. However, operation in an NBC environment prevents that since, when masked, loss of intercom results in loss of communicability. The DAL needs revision to reflect this possibility and to correctly value the impact of this vulnerability on $P_k(M)$ and $P_k(F)$.

c) Personnel. There appears to be sufficient emphasis on all the various mechanisms that can affect the crew and troop personnel within the LAV-25 with the exception of the NBC, which needs to be included. For personnel, test results are converted to probabilities of incapacitation PI_h, which further translates to $P_k(M)$ and $P_k(F)$ through the DAL.

d. Data Required: For each test shot/burst, the following data are required on each component:

- Shock or overpressure: Did the component receive sufficient shock (acceleration) or overpressure to render it inoperable?

- Fire/temperature/burns: Did the round cause fire, flash or temperatures high enough to damage components sufficiently to render them inoperative?

- Other damage mechanism: Did some unforseen damage mechanism render a component inoperable?

Direct Effects on Personnel

- Penetration/perforation: Was the mannequin penetrated by the round, jet, spall or other behind armor debris? Did the mannequin receive sufficient damage to indicate human incapacitation?

- o Overpressure: Did the mannequin receive sufficient overpressures to indicate human incapacitation?

Indirect Effects on Personnel

- o Penetration/perforation: Was the mannequin penetrated by debris caused by initiation of stowed/ready munitions/ordnance? Did the mannequin receive sufficient damage to indicate human incapacitation?
- o Overpressure: Did the mannequin receive sufficient overpressures to indicate human incapacitation?
- o Toxic fumes: Was there a concentration of toxic fumes sufficient to cause a person to become incapacitated?
- o Fire/temperature/burns: Did the shot cause fire, flash or temperatures high enough to incapacitate personnel?
- o NBC Effects: Did the shot cause the NBC defense system to become inoperable or reduce the protective capability?
- o Shortcomings: From a detailed evaluation of each shot described in the DTP, some shortcomings have been discovered on specific aspects tested. These are discussed in detail in Appendix A, along with recommendations to improve the adequacy of the tests. The greatest lack appears to be in testing all the likely ways that initiation of internally stowed munitions and combustibles can occur.

e. Data Sources and Formats: Data from the following sources, or in the following formats, are required to address this issue:

- o Live fire tests from Phase I.
- o Off-line behind armor debris tests.
- o Off-line ammunition sensitivity tests.
- o Damage Assessment List.

2. Issue: Accuracy of Computer Model Predictions:

a. Statement: Can the SQUASH model accurately predict the outcome of the live fire test shots?

b. Criteria: The U.S. Army Ballistic Research Laboratory has developed the Stochastic Quantitative Analysis of System Hierarchies (SQUASH) model which will be employed to develop predictions of individual shot results in this test. It is a point-burst model which incorporates stochastic variability in (1) warhead/target hit-point location (including yaw), (2) main penetrator performance, (3) behind armor debris distribution, and (4) component kill assessment. The stochastic features of the model expand its predictive capabilities beyond the estimation of mean values for the damage functions (P_k's, casualty estimates), to the estimation of the probabilities associated with damage to various combinations of damaged components. This aspect of the model is particularly well suited for applications involving Live Fire Tests where a range of outcomes might be expected for a repeated series of shots under the same test conditions. Model predictions will be compared to the actual test results in an effort to assess the model's predictive accuracy and to identify model improvements needed to provide confidence when the model is used to extrapolate to conditions not tested.

c. Analytic Approach: The potential methodologies for comparing observed results to model predictions vary with the nature of the available data. Any tested shotline provides quantifications of the following measures:

- o Vehicle/armor perforation.
- o Vehicle loss of function measures (M-, F-, K-kills and expected casualties).
- o Component damage vector (the list of damaged items).

At the simplest level, accuracy of the model estimates of mean values for the first two measures can be assessed with statistical tests oriented toward paired data such as the non-parametric Wilcoxon matched-pair sign ranked test. While providing useful information regarding systematic deviations of test results from predictions, this type of analysis does not lend itself to suggesting specific improvements to the model nor does it take advantage of the full range of data produced by the SQUASH model in the course of making a shot prediction.

More significant insights into model performance can be derived from comparing the test results directly with the stochastically generated distributions of possible outcomes. One method is to identify the model's predicted probability of occurrence for the shot result and, if the probability is below a certain threshold, to categorize the event as "rare." If, according to an appropriate statistic, too many shot results are judged to be "rare," the model is found unacceptable. This approach is sensitive only to the occurrence of rare component damage vectors and does not consider the specific predicted probabilities corresponding to test events which are not considered rare.

Three additional approaches are currently being developed to make maximal use of the test data and corresponding model predictions. The first involves the use of a statistic based on comparisons between test observations and average model predictions (over all shotlines) for each possible component damage vector. The second method involves the use of the model distribution itself to establish, on a per shotline basis, the statistical significance of the disparity between the outcome and the model prediction. The preceding methods can be sensitive to occasional differences (between model predictions and observed test outcomes) in a single or small number of components out of a large number of items comprising the component damage vector. A third method introduces the concept of a "distance" between the actual shot result and individual component damage vectors in the distribution of model predicted outcomes. An appropriate statistic is chosen to evaluate the average distance between model predictions and test results.

d. Data Required: The implementation of any but the simplest non-parametric test establishes the requirement for detailed data to correlate test results with model predictions, including identification of the specific predicted component damage vector corresponding to the assessed test result.

e. Data Sources and Formats: The specific loss of function measures (M-, F- and K-kill) and component damage vector distributions from SQUASH computer runs and the corresponding test results for each shot are the data for this analysis.

C. EVALUATION

The foregoing describes how the test results can be translated by analysis to degradation of combat utility, P_k, in terms of mobility and firepower reduction. Whether such mission performance degradation is acceptable or not must be concluded by comparison with appropriate criteria statements from the USMC. It is our understanding that such statements do not exist in writing. In the absence of these, an alternative source of comparison criteria would be the mission profile which, we understand, was the source of the threats chosen for the Joint Live Fire Testing. However, these threats are all overmatching, deliberately chosen to reveal potential vulnerabiities of the LAV. Since the threats are overmatching, starting with one barely over the acceptance criteria and then increasing in severity, it would be reasonable to evaluate the vulnerabilities by threat type. The type of information expected to result will give insights on:

a) Adequacy of design criteria.
b) Unanticipated weaknesses/strengths.
c) Possible means to strengthen the system and reduce vulnerability further, where required.

Since the threats are overmatching, information about a) is unlikely. The other two results are likely, however, and are the meaningful information expected from these tests. Comparison of these results with the mission profile could dictate some changes in the anticipated employment/exposure of the LAV-25.

The results will form the basis of any necessary respose to the Congress on live fire vulnerability of the LAV-25.

APPENDIX A

1. DISCREPANCIES/SHORTFALLS IN CURRENT TEST PLAN.

a. Direct effects to personnel from threats (i.e., penetration, BAD/frags, and overpressure) appears to be reasonably well covered and traceable according to event timing. Indirect effects may be more difficult to trace. Vulnerability of ammunition and combustibles appears to be well tested in both test 1 and 3 and the information will be enriched by that from test 2, in spite of target being inert. However, there are areas of potential masking of events, one by another. For example, measuring the overpressure time history should be able to distinguish between penetration by the threat and initiation of on-board munitions or combustibles. However, it may not be possible to distinguish on the mannequins between BAD damage from the threat and explosive debris damage if on-board munitions or combustibles are initiated. Therefore, the data may need to be compared to the mannequin damage from the inert test 2 and other off-line BAD data in order to determine the damage attributable to each event, if the distinction is important.

b. The 30 mm APDS and RPG-18 shots in test 2 (inert test of LAV-25) are not instrumented for overpressure as a direct effect. This leaves the issue (overpressure direct effect) only partly covered.

c. Toxic fumes threat to on-board personnel are measured in only half of the 30 mm and RPG-18 events in test 1. These measurements should be taken for each event for which there is a possibility of initiation of on-board munitions or combustibles, i.e., all 30 mm and RPG-18 events and possibly the 7.62 mm and 14.5 mm events as well if there is the possibility of on-board initiation.

d. Since the fume sensors are able to measure halon in addition to the fumes created from possible fire events, the two test events specifically directed at halon bottle rupture (R-24 and Y-24) should be monitored by both fume sensors and overpressure (blast) sensors.

e. The carry-on munitions and ordnance used by the fire team and stored in the rear (troop compartment) needs to be better tested. One of the largest possible sources of on-board explosions are the mines, but it is not clear that any of the penetrating rounds are directed at the location indicated for this stowage. This is likewise true for the 12 bandoliers of 40 mm grenades, which contain a mix of HE and white phosphorus. These are definitely vulnerable to possible initiation. Also, the case of fragmentation grenades appears to be vulnerable to initiation and should be tested. However, it would appear that shot G-2 will do that. If not, then a shot should be planned to test their vulnerability as well.

f. It is not clear why the particular shots selected (G-9, G-16 and G-20) were chosen for shock measurement. They are described in the detailed test plan as shots to determine if any shock-induced damage results from the RPG shots. It states neither why they expect this from RPG but not from the other threats, nor why these particular three should be chosen from all the others. If RPG-induced shock is expected, then all the RPG shots should be instrumented for shock measurement.

g. The analysis does not consider the effect of LFT on LAV-25 operations in an NBC environment nor the effects of shots on the two components of the NBC defense system; chemical detection and warning and NBC filter subsystems. Twenty-six shots programmed during tests 2 and 3 have potential impact on crew survivability as a result of damage to on-board NBC defense systems. The reduction or loss of crew capability as a result of operating in an NBC environment further reduces Mobility, Firepower and Communication.

2. RECOMMENDATIONS TO IMPROVE TEST ADEQUACY.

a. Add overpressure sensors for all 30 mm and RPG-18 shots (test 2 - 30 shots).

b. All 30 mm and RPG-18 events in test 1 should be instrumented for toxic fumes (add 8 more).

c. Halon bottle rupture shots (R-24 and Y-24) should be instrumented for toxic fumes and overpressure.

d. Examine carefully those shotlines near the location of mines (troop carry-on, shown as location 5, page 1 of Enclosure 1 to stowage plan, Appendix F). If not intersected, add engineering shots to test this load. Likewise, examine 40 mm grenade stowage for shotlines (location 7 in stowage plan, page 1 of Enclosure 1) and add engineering shots if required.

e. Instrument all 15 RPG-18 shots for shock, if appropriate, rather than only three.

f. Examine shotlines in relation to communications capability. DTP currently has four turret shots (R-25, Y-25, B-25 and G-25) which may be near the communications sets. If they are not sufficient to examine communications kill, further engineering shots should be planned. Also, any communications capability within the hull (see page D-17, Figure 6, Hull Communications Equipment) should be tested by adding further engineering shots.

g. Include the assessment of LFT shots on the NBC defense system; damage to subsystem components and the effect of the loss of other critical damage to subsystem components which, in an NBC environment, impact on Mobility, Firepower and Communication (e.g., the loss of internal communications when crew is masked effectively stops voice communication between TC, Driver and even Gunner).