REPORT DOCUMEN

AD-A280 772

Form Approved
OMB No. 0704-0188

(1)

1. AGENCY USE ONLY (Leave blank)	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	October 1993	Technical Documentation

4. TITLE AND SUBTITLE
Effectiveness of Medical Defense Interventions Against Predicted Battlefield Levels of Bacillus Anthracis

5. FUNDING NUMBERS
Contract No.: F33615-91-D-0652
Delivery Order No. 0002

6. AUTHOR(S)
Richard E. McNally, Malcolm B. Morrison, M. Stark, J. Fisher, J. Bo'Berry, M. Sanzone, and J. Berndt

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Science Applications International Corporation
626 Towne Center Drive, Suite 205
Joppa, Maryland 21085

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
Director
Division of Neuropsychiatry
Walter Reed Army Institute of Research
Washington, DC 20397-5700
ATTN: COL Steven R. Hursh

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release, distribution unlimited.

12b. DISTRIBUTION CODE

13. ABSTRACT (Maximum 200 words)

B. anthracis, the causative organism for anthrax, continues to be a biological warfare threat to U.S. forces. Exposure through inhalation is deadly unless the cause of infection is identified and treated before serious respiratory symptoms present.

The objective of this study was to determine the levels of *B. anthracis* likely to be found on the battlefield and the potential impact of *B. anthracis* attacks on unit effectiveness. The levels of *B. anthracis* are critically dependent on the weapons, form of agent dissemination, weather conditions, and time-of-day of an attack. In assessing the effects on a military operational unit following a *B. anthracis* attack, various defensive measures were considered including the wearing of protective equipment, especially the protective mask, and the use of medical interventions such as vaccination and antibiotic therapy.

Modeling results predicted that the use of vaccine could ensure survivability and preserve unit effectiveness at levels in excess of 90 percent. The study also provides insights into potential operational limitations imposed on a commander whose troops depend solely on antibiotic therapy and protective equipment for survival. Further, the findings illuminate some of the implications for survivability and unit effectiveness in the absence of the capability to either rapidly detect the presence of *B. anthracis* in the atmosphere or to easily diagnose anthrax casualties prior to the onset of symptoms.

14. SUBJECT TERMS
Bacillus Anthracis
Medical Defense Interventions
Battlefield Levels of Bacillus Anthracis

15. NUMBER OF PAGES
215

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	None

GENERAL INSTRUCTIONS FOR COMPLETING SF 298

The Report Documentation Page (RDP) is used in announcing and cataloging reports. It is important that this information be consistent with the rest of the report, particularly the cover and title page. Instructions for filling in each block of the form follow. It is important to *stay within the lines* to meet *optical scanning requirements.*

Block 1. Agency Use Only *(Leave blank)*.

Block 2. Report Date. Full publication date including day, month, and year, if available (e.g. 1 Jan 88). Must cite at least the year.

Block 3. Type of Report and Dates Covered. State whether report is interim, final, etc. If applicable, enter inclusive report dates (e.g. 10 Jun 87 - 30 Jun 88).

Block 4. Title and Subtitle. A title is taken from the part of the report that provides the most meaningful and complete information. When a report is prepared in more than one volume, repeat the primary title, add volume number, and include subtitle for the specific volume. On classified documents enter the title classification in parentheses.

Block 5. Funding Numbers. To include contract and grant numbers; may include program element number(s), project number(s), task number(s), and work unit number(s). Use the following labels:

C	- Contract	PR	- Project
G	- Grant	TA	- Task
PE	- Program Element	WU	- Work Unit Accession No.

Block 6. Author(s). Name(s) of person(s) responsible for writing the report, performing the research, or credited with the content of the report. If editor or compiler, this should follow the name(s).

Block 7. Performing Organization Name(s) and Address(es). Self-explanatory.

Block 8. Performing Organization Report Number. Enter the unique alphanumeric report number(s) assigned by the organization performing the report.

Block 9. Sponsoring/Monitoring Agency Name(s) and Address(es). Self-explanatory.

Block 10. Sponsoring/Monitoring Agency Report Number. *(If known)*

Block 11. Supplementary Notes. Enter information not included elsewhere such as: Prepared in cooperation with...; Trans. of...; To be published in.... When a report is revised, include a statement whether the new report supersedes or supplements the older report.

Block 12a. Distribution/Availability Statement. Denotes public availability or limitations. Cite any availability to the public. Enter additional limitations or special markings in all capitals (e.g. NOFORN, REL, ITAR).

- DOD - See DoDD 5230.24, "Distribution Statements on Technical Documents."
- DOE - See authorities.
- NASA - See Handbook NHB 2200.2.
- NTIS - Leave blank.

Block 12b. Distribution Code.

- DOD - Leave blank.
- DOE - Enter DOE distribution categories from the Standard Distribution for Unclassified Scientific and Technical Reports.
- NASA - Leave blank.
- NTIS - Leave blank.

Block 13. Abstract. Include a brief *(Maximum 200 words)* factual summary of the most significant information contained in the report.

Block 14. Subject Terms. Keywords or phrases identifying major subjects in the report.

Block 15. Number of Pages. Enter the total number of pages.

Block 16. Price Code. Enter appropriate price code *(NTIS only)*.

Blocks 17. - 19. Security Classifications. Self-explanatory. Enter U.S. Security Classification in accordance with U.S. Security Regulations (i.e., UNCLASSIFIED). If form contains classified information, stamp classification on the top and bottom of the page.

Block 20. Limitation of Abstract. This block must be completed to assign a limitation to the abstract. Enter either UL (unlimited) or SAR (same as report). An entry in this block is necessary if the abstract is to be limited. If blank, the abstract is assumed to be unlimited.

Effectiveness of Medical Defense Interventions Against Predicted Battlefield Levels of *Bacillus Anthracis*

Contract No. F33615-91-D-0652,
Delivery Order No. 0002

October 1993

Science Applications International Corporation

An Employee-Owned Company

Prepared By

Richard E. McNally
Malcolm B. Morrison
Maureen Stark
Joan E. Fisher
John T. Bo'Berry
Margaret A. Sanzone
Jack E. Berndt

Science Applications International Coporation
626 Towne Center Drive, Suite 205
Joppa, Maryland 21085

Effectiveness of Medical Defense Interventions Against Predicted Battlefield Levels of *Bacillus Anthracis*

Contract No. F33615-91-D-0652,
Delivery Order No. 0002

October 1993

Prepared By

Richard E. McNally
Malcolm B. Morrison
Maureen Stark
Joan E. Fisher
John T. Bo'Berry
Margaret A. Sanzone
Jack E. Berndt

Science Applications International Coporation
626 Towne Center Drive, Suite 205
Joppa, Maryland 21085

TABLE OF CONTENTS

TABLE OF CONTENTS -- Continued

EXECUTIVE SUMMARY

The mission of the Medical Biological Defense Research Program (BDRP) is to develop medical countermeasures to deter, constrain and defeat the use of biological agents against U.S. forces. This study evaluates the contribution of the fielded vaccine Michigan Department of Public Health-Protective Antigen (MDPH-PA), and antibiotic therapy as countermeasures to a *Bacillus anthracis* threat and the associated disease anthrax. The Medical Biological Defense Research Program addresses three principal defense capability issues:

1. Capability to operate in NBC conditions.
2. Capability to provide treatment for NBC-related injuries.
3. Capability to diagnose threat agent casualties.

This study helps to shed light on the capability of U.S. forces to survive and maintain unit operational effectiveness in a biological warfare environment. The results show that the use of vaccine can ensure survivability and preserve unit effectiveness at levels in excess of 90 percent. The study also provides insights into potential operational limitations imposed on a commander whose troops depend solely on antibiotic therapy and protective equipment for survival. Further, the findings illuminate some of the implications for survivability and unit effectiveness in the absence of the capability to either rapidly detect the presence of *B. anthracis* in the atmosphere or to easily diagnose anthrax casualties prior to the onset of symptoms.

The methodology in this study is based on computer simulations of a range of attack scenarios and world-wide climates. Weapon systems simulated include artillery, multiple rocket launchers (MRL), tactical ballistic missiles (TBM), and Intercontinental Ballistic Missiles (ICBM) with submunitions, spray releases from an aircraft, and man-portable terrorist devices. This choice of weapon systems encompassed a range of total agent mass simulations from 5 kg for a terrorist device to a total of 1,560 kg delivered by an ICBM armed with 40,000 submunitions. With these systems and agent fills, the effects of both direct and indirect attacks were portrayed with dosage-hazard footprints, bar charts reflecting post attack unit effectiveness, figures depicting spore concentration/area coverage, and bar charts illustrating casualty/area coverage. Each attack scenario was simulated in climates representing South Korea, Southeast Asia, Southwest Asia, and Central Europe at 0500, 1200, and 1900 hours. Results for the different times and climates demonstrate the effects that atmospheric stability, wind speed, and sunlight have on agent transport, diffusion, and viability.

Sensitivity analyses were conducted on:

1. Toxicity and decay estimates.
2. Survivability versus unit effectiveness outcomes.
3. Organizational unit types (the differences in impact of identical attacks on the effectiveness of units with different military functions).

An assessment was made of the sensitivity of unit effectiveness for variations in lethal dose between 8,000 and 10,000 spores per soldier; an LD_{50} value of 8,689 spores was chosen as the baseline toxicity level for the study. The impact of two sets of decay rates, a "high" and a "low" set, on hazard area coverage and unit effectiveness was also examined. The "high" decay rates ranged from 0.5 at night to 2.5 percent/minute in noonday sun compared to the "low" rates of from 0.1 to 1 percent/minute. The low rates were provided by U.S. Army Medical Research and Development Command (USAMRDC) and were used to produce maximum impact on unit effectiveness.

Unit effectiveness was the principal measure of merit used for this study and was based on calculations of the probability of surviving an attack given the exposure levels that would be experienced at four positions within a typical hazard footprint.

The final sensitivity analysis was a comparative assessment of the relative resiliency of five different types of military units to identical attacks by a terrorist device. The artillery unit, used as the base case organizational unit throughout the study, was compared with an ammunition supply point, a headquarters unit, an anti-armor infantry unit, and an attack helicopter unit.

The study findings were as follows:

- A unit protected by vaccine would have the capability to operate in an environment contaminated with levels of *B. anthracis* as high as 500 times the LD_{50}.

- The vaccine significantly reduces the need for treatment and diagnosis by precluding any appreciable level of infection among troops subjected to the range of attacks simulated in this study.

- Predeployment vaccination with the fielded vaccine would preserve unit effectiveness at or above 99 percent in all attack scenarios and climates with the exception of the simulated MRL attack in winter climatic conditions which would degrade unit effectiveness to 90 percent. The efficacy of the fielded vaccine is such that, for the attack scenarios simulated, protective equipment would only be required in the event of a *direct* MRL attack (exceeding 240 rounds or 240 kg of agent). Although only a mask would be needed to maintain unit effectiveness at 99 percent for *B. anthracis* attacks. However, MOPP 4 rather than masking alone would likely be the operational response until it could be confirmed that the attack was not chemical in nature.

- One of the important attributes of predeployment vaccine is that it provides an outstanding level of protection passively. It is neither dependent upon detection of attack nor timely diagnosis of infection, as antibiotic therapy would be, thus providing capability to counter a covert attack.

- For protection *downwind* of a target area, the vaccine is sufficiently robust to protect against the full range of dosages predicted in this study. The implication is that vaccine

protected personnel would not require the use of MOPP 4 (with its attendant degradation in unit effectiveness to 63 percent in the case of an artillery unit) if they are downwind of a *B. anthracis* attack.

- Sole dependency on antibiotic therapy against a *B. anthracis* attack would place unnecessary burdens on field medical staff, facilities, and medical logistics. Unit effectiveness and mobility would be unnecessarily impaired; and, more importantly, there would be loss of life that could have been avoided.

- Unit effectiveness was shown to be unaffected for spore dose levels ranging from 8,000 to 10,000 -- the number of spores per man expected to elicit a lethal response in 50 percent of the exposed population.

- The high estimates of agent decay rates (1 to 2.5 percent/min) produced by UV light for a 1200 hours attack would produce significantly reduced downwind hazards but only cause approximately a 5 percent reduction in the overall hazard level for units under direct attack.

- Skillfully employed *B. anthracis* can achieve both strategic and tactical/ psychological objectives. As a weapon of mass destruction, strategic objectives might be achieved through the execution of a single spray release of 240 kg of agent at night during winter climatic conditions. Alternatively, tactical objectives might be achieved with essentially no collateral damage to the attacker by a release at noon in summer climatic conditions where high ultraviolet radiation would rapidly decay the agent and limit effects to the an area less than 30 km in diameter.

LIST OF TABLES

LIST OF FIGURES

Unit Sensitivity Analysis

TBM with Submunitions Scenarios

Terrorist Device Scenarios

Artillery Scenarios

1.0 INTRODUCTION

Anthrax has been a health problem throughout recorded history. It is thought to have been the Fifth Plague of Egypt. Casimir Davaine isolated the bacterium in 1850, and Louis Pasteur developed the first major anthrax vaccine in 1877.

In recent history, people began thinking of *B. anthracis* as a potential weapon. The Japanese investigated using it against China in the mid-1930s, initially against livestock and then against large populations. On the Allied side, it was developed as a type of pre-atomic doomsday weapon specifically for use against civilian populations. However, it was never used. Enormous amounts of war stocks were later destroyed following WWII, and by the 1950s the total reserve could be measured in ounces.

B. anthracis, especially in pseudospores, proved to be too persistent for its intended use as a weapon. In the West, it was released as a test on the island of Gruinard off the northern coast of Scotland (in the Hebrides). A single, mass exposure was made there in 1943, amounting to a pseudospore infestation that simulated battlefield concentrations. As of the late 1980s, Gruinard Island (nicknamed "Anthrax Island" by the locals) was still too heavily infested with the pseudospores to allow human occupation. This was in spite of having been firebombed and thoroughly burned at least once.

The objective of this study was to determine the levels of *B. anthracis* likely to be found on the battlefield and the potential impact of *B. anthracis* attacks on unit effectiveness. The levels of *B. anthracis* are critically dependent on the weapons, form of agent dissemination, weather conditions, and time-of-day of an attack. In assessing the effects on a military operational unit following a *B. anthracis* attack, various defensive measures were considered including the wearing of protective equipment, especially the protective mask, and the use of medical interventions such as vaccination and antibiotic therapy.

2.0 BACKGROUND

2.1 CHARACTERISTICS OF *BACILLUS ANTHRACIS*

Anthrax is a disease that attacks both human beings and animals. It is caused by the encapsulated, spore-forming, large gram-positive rod *Bacillus anthracis*. The bacteria grows vegetatively within the body tissues of the host; sporulation occurs when the vegetatively growing organism is exposed to the atmosphere. Virulent strains of *B. anthracis* produce a protective capsule composed of poly-D glutamic acid and an exotoxin. As a result, *B. anthracis* is found in soil (particularly dry soil) as a resistant spore that may persist for years. Spores vegetate in the soil when the pH and temperature conditions are favorable, and an organism-spore-organism cycle can be maintained for years.

The bacillus produces an exotoxin or exotoxins with at least three active fractions: edema factor, lethal factor, and protective antigen. Anthrax toxin and capsule production are associated with two separate plasmids, pX01 and pX02, respectively. In the host, the actions of a combination of these factors cause the destruction of phagocytic cells and capillary permeability, resulting in illness. One study has shown that phagocytosis by human neutrophils is inhibited in the presence of protective antigen and edema factor, potentially increasing the host's susceptibility to disease. Alum-precipitated antigenic material from culture filtrates containing protective antigen is used as the current anthrax vaccine for humans, while live spores of the avirulent, nonencapsulated Sterne strain are used as a veterinary vaccine.

B. anthracis is sensitive to damage by UV light, depending on whether the bacterium is a vegetative cell or a spore. More than 99 percent of the vegetative cells of Vollum 1B and Sterne were killed with 20 seconds of exposure to UV wavelengths between 280 and 300 nm at levels of 0.9 W/m^2, while 25 minutes of UV exposure was needed to kill the same amount of Sterne spores. In addition to being less sensitive to UV radiation, spores of *B. anthracis* are much more resistant to dryness and heat than vegetative cells.

2.2 EFFECT OF *BACILLUS ANTHRACIS* EXPOSURE ON THE POPULATION

B. anthracis can infect humans through a variety of routes resulting in different manifestations of the disease. In peacetime, the human exposure naturally found occurs from ingesting contaminated meats or by contact with the hides of infected animals.

Cutaneous anthrax is the most common naturally occurring form of the disease accounting for nearly 90 percent of all cases. It generally develops when a penetrating traumatic injury results in deposition of the spore under the skin. People who work with animal-origin products from anthrax-endemic areas are at risk of contracting the disease. Bites from flies may mechanically transmit *B. anthracis*, but reported cases are rare and sporadic, and this route of infection is not thought to play a role in epidemics.

A second common, naturally occurring form of the disease is caused by the inhalation of spores from contaminated dust, wool, or hair, especially when handled in confined space. After inhalation, the spores localize in the mediastinal lymph nodes. A septicemic phase follows, with concomitant pulmonary involvement.

A third common, naturally occurring form of the disease is intestinal anthrax. Because spores can be found in meat from infected animals, ingestion of raw meat, blood, or inadequately cooked meat from such animals can result in infection. In industrialized nations, intestinal anthrax is less common than the cutaneous or pulmonary form of the disease; however, on a worldwide scale, intestinal anthrax is much more common than inhalation anthrax. The low prevalence in industrialized nations is presumably attributable to the stringent laws concerning animals allowed into the food chain. Human-to-human transmission is possible but unlikely.

The symptoms of anthrax vary depending upon the route of entry. Two (2) to five (5) days after inoculation of a spore into a wound (cutaneous route of entry), a reddened, papular lesion develops which is commonly mistaken for an insect bite. Later, there is vesiculation that becomes a depressed, black eschar (scab). Without treatment, septicemia and death may occur in up to 20 percent of affected patients. With treatment, death is rare.

Initially, inhalation anthrax is associated with signs of mild respiratory disease, i.e., mild fever, malaise, and a nonproductive cough. Within 7 days of onset of the symptoms, the disease becomes more severe, with progressive respiratory distress and cyanosis. Edema of the neck, thorax, and mediastinum signal the beginning of a rapidly fatal course. Treatment is rarely successful after onset of symptoms.

A less common, clinical form of the disease, intestinal anthrax, is characterized by gastroenteritis with emesis, bloody feces, and signs of septicemia. Death is the usual outcome. There is also an oropharyngeal form of anthrax in people. Those affected develop fever, edema, and cervical or submandibular lymphadenopathy.

In human beings, the diagnosis of anthrax is made on the basis of clinical signs as well as results of serologic testing, bacteriologic culture, and inoculation of laboratory animals. Vesicular fluid is the best source of *B. anthracis* for culture in people with cutaneous anthrax. One disadvantage of reliance upon culture for diagnosis is the rapid course of the disease after serious symptoms present. If anthrax is not in its advanced stages, antibiotic treatment is effective, with penicillin or ampicillin considered the drugs of choice in eliminating the bacteria. Results of bacteriologic cultures of wound and blood specimens will usually be negative for *B. anthracis* if antibiotics have been administered, although this negative reading does not necessarily signify that anthrax has been defeated. Current therapy would consist of administration of both oral and IV antibiotics plus vaccine.

2.3 PREVALENCE AND COURSE OF THE DISEASE ANTHRAX

There are areas of the world where anthrax is endemic (prevalent) in animals. This results in chronic environmental contamination with resulting human and animal disease. *B. anthracis* is found most commonly in areas with neutral to mildly alkaline soil (pH 6 to 8.5), and periods of drought and flooding. Flooding allows the bacteria to accumulate at the ground surface in low-lying areas. Subsequent drought affords conditions for exposure of the spores. Anthrax has been reported in the Middle East, Africa, Central and South America, as well as other areas of the world.

Pulmonary or inhalation anthrax, the form of the disease most likely to be propagated through weaponization of *B. anthracis*, begins after an incubation period which varies from 1-6 days, presumably dependent upon the dose of inhaled organisms. Onset is gradual and nonspecific, with fever, malaise, and fatigue, sometimes in association with a nonproductive cough and mild chest discomfort. In some cases, there may be a short period of improvement. The initial symptoms are followed in 2-3 days by the abrupt development of severe respiratory distress with dypsnea, diaphoresis, stridor, and cyanosis. Physical findings may include evidence of dramatically widened mediastinum, often with pleural effusions, but typically without infiltrates. Shock and death usually follow within 24-36 hours of the onset of respiratory distress.

2.4 DIAGNOSIS AND TREATMENT OF ANTHRAX

Routine laboratory examinations of hosts reveal a neutrophilic leukocytosis. When pleural effusions or evidence of meningitis are present, pleural and cerebrospinal fluids may be hemorrhagic. The differential diagnosis of an epidemic of inhalation anthrax while still in its early stages of nonspecific symptoms could be impeded by similarities to a wide variety of viral, bacterial, and fungal infectious diseases. Progression of the disease over 2-3 days with the sudden development of severe respiratory distress followed by shock and death in 24-36 hours in essentially all untreated cases eliminates any diagnosis other than inhalation anthrax. The presence of a widened mediastinum on chest X-ray, in particular, should alert one to the diagnosis. Other suggestive findings include chest-wall edema, hemorrhagic pleural effusions, and hemorrhagic meningitis.

Other diagnoses of symptoms similar to anthrax include aerosol exposure to Staphylococcus Enterotoxin B (SEB); but in this case, onset would be more rapid after exposure (if known), and no prodrome would be evident prior to onset of severe respiratory symptoms. Mediastinal widening on chest X-ray will also be absent. Patients with plague pneumonia will have pulmonary infiltrates and clinical signs of pneumonia (usually absent in anthrax). *B. anthracis* will be readily detectable by blood culture with routine media. Smears and cultures of pleural fluid and abnormal cerebrospinal fluid may also be positive. Impression smears of mediastinal lymph nodes and spleen from fatal cases should be positive. Toxemia is sufficient to permit anthrax toxin detection in blood by immunoassays, and such assays will be available in field-deployed laboratories. The obvious disadvantage of serologic

and culture diagnostic techniques is the time required for results compared to the rapid and fatal course of the disease without treatment.

Almost all cases of inhalation anthrax where treatment was begun after patients were symptomatic have been fatal, regardless of treatment. Historically, penicillin has been regarded as the treatment of choice, with 2 million units given intravenously every 2 hours. Tetracycline and erythromycin have been recommended in penicillin-sensitive patients. The vast majority of *B. anthracis* strains are sensitive *in vitro* to penicillin, although penicillin-resistant strains exist naturally. Moreover, it is not difficult to induce resistance to both penicillin and tetracycline through laboratory manipulation of organisms. All strains tested to date have been sensitive to erythromycin, chloramphenicol, gentamicin, and ciprofloxacin. In the current setting, treatment should be instituted at the earliest signs of disease with oral ciprofloxacin (1000 mg initially, followed by 750 mg po bid) or intravenous doxycycline (200 mg initially, followed by 100 mg q 12 hours). Supportive therapy for shock, fluid volume deficit, and adequacy of airway may all be needed.

2.5 DEFENSE AGAINST *B. ANTHRACIS* AS A BIOLOGICAL WEAPON

A licensed, alum-precipitated, preparation of purified *B. anthracis* protective antigen (PA) has been shown to be an effective vaccine in preventing or significantly reducing the incidence of inhalation anthrax. Limited human data suggest that after completion of the first three doses of the recommended six-dose primary series (0, 2, 4 weeks, then 6, 12, 18 months), protection against both cutaneous and inhalation anthrax is afforded. Studies in rhesus monkeys indicated that good protection is afforded after two doses (1-16 days apart) for up to 2 years. It is likely that two doses in humans is protective as well, but there is too little information to draw firm conclusions. As with all vaccines, the degree of protection depends upon the magnitude of the challenge dose; vaccine-induced protection is undoubtedly overwhelmed by extremely high spore challenge.

In the present setting, three doses of the vaccine (at 0, 2, and 4 weeks) are recommended for prophylaxis against inhalation anthrax. Given projected stocks, two doses, 0.5 ml each, administered subcutaneously on days 0 and 14, are recommended initially. A third dose should be given two or more weeks after the second dose as additional vaccine becomes available. Contraindications for use are sensitivity to vaccine components (formalin, alum, benzethonium chloride) and/or history of clinical anthrax. Reactogenicity (likelihood of producing side effects) is mild to moderate: up to 6 percent of recipients will experience mild discomfort at the inoculation site for up to 72 hours (tenderness, erythema, edema, pruritus), while a smaller proportion (< 1 percent) will experience more severe local reactions (potentially limiting use of the extremity for 1-2 days); modest systemic reactions (myalgia, malaise, low-grade fever) are uncommon, and severe systemic reactions (anaphylaxis, which precludes additional vaccination) are rare. The vaccine should be stored at refrigerator temperature (not frozen).

Choice of antibiotics for prophylaxis is guided by the same principles as that for treatment; i.e., it is relatively easy to produce a penicillin- or tetracycline-resistant organism in the laboratory. Therefore, if there is information indicating that a biological weapon attack is imminent, prophylaxis with ciprofloxacin (500 mg po bid), or doxycycline (100 mg po bid) should begin. If unvaccinated, a single 0.5 ml dose of vaccine should also be given subcutaneously. Should the attack be confirmed as anthrax, antibiotics should be given for at least four weeks to all exposed. In addition, two 0.5 ml doses of vaccine should be given two weeks apart to the unvaccinated; those previously vaccinated with fewer than three doses should receive a single 0.5 ml booster, while vaccination probably is not necessary for those who have received the entire three-dose primary series. Upon discontinuation of antibiotics, patients should be closely observed; if clinical signs of anthrax occur, patients should be treated as indicated above. If the vaccine is not available, antibiotics should be continued beyond four weeks until the patient can be closely observed until discontinuation of therapy. Vaccine use may be of additional benefit even after exposure, along with antibiotics.

The use of the protective mask can dramatically reduce the exposure to inhaled *B. anthracis* spores. Tests using salt fog have determined that the median protective ratio of the M17A1 mask is 1.67×10^3. The protective value of the mask is critically dependent on the fit. If fit improperly, the protection afforded by the mask has been measured as low as 10, which would not provide an effective barrier to *B. anthracis* spores. Wearing a mask [Mission Oriented Protective Posture (MOPP) 3 and 4 or special situations where mask only is specified] at the time of a potential attack is complicated by the difficulty of detecting an aerosol attack with *B. anthracis*. In the case of many of the possible delivery methods, it would be difficult to detect a biological release if it occurred well upwind of friendly forces. Further, it may also be difficult to differentiate a biological release from conventional munitions, especially if a conventional attack is used to conceal a biological release.

3.0 METHODOLOGY

3.1 DATA SOURCES AND APPROACH

Data were extracted from a review of available literature starting with a bibliographic search of the Chemical/Biological Information Analysis Center (CBIAC) and the database maintained at the U.S. Army Medical Research Institute of Infectious Diseases (USAMRIID). See Appendix A for a summary of values provided by USAMRIID. Basic values were extracted from these sources to represent:

- The potential weaponization of *B. anthracis*.
- The physical characteristics of *B. anthracis* released as an aerosol.
- The toxicology of *B. anthracis* without medical intervention, with antibiotic therapy, or with an effective vaccine.

Potential weaponization concepts developed are shown in Table 1. A preliminary study was conducted to identify sensitivity to a number of key parameters for the study. These parameters included the median infective dose for *B. anthracis* spores, the protective ratios for antibiotic therapy and vaccination, unit effectiveness levels for military operational units placed at different locations within a hazard footprint, the effects of different climates, the consequences of releases at different times of day, and finally, the sensitivity to uncertainty about the biological decay rate. After a preliminary review of the available data with personnel from USAMRIID, the final parameters of the study required to characterize the weapons, the environmental conditions, the aerosol potential of *B. anthracis*, and the toxicology parameters were established. These parameters were then used to complete the final production simulations for quantifying estimates of the coverage and consequence of *B. anthracis* use on the battlefield.

Table 1. Weapons Characteristics for Dry *B. anthracis* Dissemination

Weapon System	Total Agent Mass (kg)	Rounds/ Submunitions (#)	Line Length (km)	Dissemination Efficiency (%)
TBM	78	2,000		5
Terror Device	5	1		1
Spray	1,200		100	60
Artillery	24	24		2.5
MRL	240	240		2.5
ICBM	1,560	40,000		5

3.2 SIMULATION MODELS

Three models were used in conducting the simulations used in this effort. The first model was PLUME, Version 2.6, updated February 28, 1991. PLUME was a model developed by Mr. Roger Gibbs of the U.S. Naval Surface Warfare Center at Dahlgren, VA. PLUME was originally adapted by Mr. Gibbs for use during the Persian Gulf War as a part of the Automated Nuclear, Biological, and Chemical Information System (ANBACIS) II program conducted at the Operations Center at the Defense Nuclear Agency. PLUME was used to generate footprints of biological attacks which were either precomputed and stored in the database system for near real-time response or computed based on the projected and estimated weather patterns. The model results were used to directly prepare the spore-area coverage charts and the footprint contours indicating the levels of hazard that would be generated by each attack scenario. The hazard levels at each grid location produced by PLUME were then used by the CASUALTY model to calculate the expected levels of casualties with and without medical and physical protection. The CASUALTY model was developed by Mr. Richard McNally of Science Applications International Corporation. The casualty results were then used to estimate changes in unit effectiveness for units located at different locations on the battlefield using the Army Unit Resiliency Analysis Model (AURA) developed by Dr. Terrence Klopcic at the U.S. Army Research Laboratory (formerly the U.S. Army Ballistic Research Laboratory).

3.3 LIMITATIONS AND ASSUMPTIONS

Limitations and assumptions frame any simulation project, and certainly this effort was no exception. The limitation and assumptions can be attributed to the nature and confidence of the data and the modeling tools used for the study.

The data used for this study includes environments, weaponization, agent characteristics, and unit effectiveness relationships. Unit effectiveness data elements have been carefully developed by the staff of the U.S. Army Research Laboratory over a number of years and have been found to generate adequate representations of the actual units. Unit effectiveness results were modeled based on soldiers either in MOPP 0 or MOPP 4 in advance of the attack. No change in MOPP level after the attack was modeled. It was assumed that the attack had been detected in time to begin antibiotic therapy starting within 24 hours after exposure and continuing for 30 days. The predeployment vaccination with Michigan Department of Public Health-Protective Antigen (MDPH-PA), completed well before the attack, would have consisted of three doses administered at 0, 2, and 4 weeks.

Agent characteristics deserve special attention for this effort. Toxicity estimates were extrapolated from animal studies. The quantitative estimates on the benefit of medical intervention were also based on animal data. The median infective dose estimates of 8,000 to 10,000 spores per man reflect a 20 percent relative difference range. If analogy with chemical data is relevant, a 50 percent uncertainty in median lethal dose is common. Sensitivity analysis on this 20 percent range in median lethal doses was conducted and results were found

to be insensitive, a finding which is discussed later in this report. One possible factor leading to this insensitivity is the low probit slope for infective dose. Low probit slopes result in small changes of population response for large changes in dose.

It should be noted that the protective value of the vaccine was based on a finding of no lethalities in monkeys exposed to 500 times the median infective dose of spores (Appendix A). A protective value was estimated from this data, but the actual protective value may be higher for monkeys.

One caution should be noted regarding the toxicity data. Literature could be cited that presents relatively simple methods for increasing the infectivity of *B. anthracis* by as many as two orders of magnitude. If such techniques were used, the resulting hazard may be severe enough in some cases to overwhelm protection by the vaccine. Appendix C provides the results of simulations using a 100-fold increase in toxicity. No submunition attacks were capable of overwhelming the vaccine. Spray attacks achieved some limited success, but even at the worst, never achieved more than 15 percent degradation in unit effectiveness in a very limited area.

Other agent characteristics used in this study include the density of the agent, the effectiveness of dissemination of inhalable particles (less than 5 microns in diameter), and the sensitivity of the agent to UV radiation. The density of the agent and the effectiveness of dissemination are key factors in the functional capability of the weapon systems that employ the agent. The variety of weapon systems represented in this study covers a considerable range, and there exist well-characterized data from U.S. programs (undertaken prior to 1969). The sensitivity to UV radiation is an area of higher concern. The values observed in the literature are from chamber trials where chamber characteristics confound the estimation of UV exposure with the physical characteristics of the chambers. Two estimates of decay rate were examined to identify the sensitivity to this factor and will be discussed below. The two ranges studied bound the values found in the literature.

Data on weaponization of *B. anthracis* by potential enemies is not available. The choice of weapons used in this study and the fireplans used for the artillery and multiple rocket launcher cases provide a spectrum of potential agent area coverage possibilities. Since there were no threat systems to directly use as data elements, representative weapons volumes and fill weights were used to estimate the mass of agent that might be weaponized in the various systems and warhead designs. One system deserves special note. The spray system represents the largest estimate of the potential fill weights for such a device and may be one to two orders of magnitude as large as a U.S. designer might have used prior to 1969. This system capability was maximized in order to identify the impact of an extreme level of threat on available protection systems. Although the representation of any single weaponization scheme might be off by some unknown margin from some yet-to-be identified threat, the results should generally prove to be accurate to within an order of magnitude in spore area coverage. Since the spore area coverage results are nearly constant over a large range of spore levels-of-interest for medically unprotected personnel, the level of uncertainty is not viewed to be very significant.

The environmental factors important for the battlefield levels of *B. anthracis* are the amount of sunlight, wind direction, wind speed, atmospheric stability, and surface terrain A listing of the hourly values used in this study can be found in Appendix B; Table 2 provides a synopsis of environmental conditions modeled. It should be noted that the comparatively lower casualty results for Southeast Asia reflect the impact of the forest terrain which reduces the number of spores reaching troops.

Table 2. Synopsis of Environmental Conditions Modeled

Region	Central Europe	Southwest Asia	Southeast Asia	South Korea
Wind Speed (km/hr)	9-14	7-16	6-9	3-12
Surface Type	Barren	Sand	Forest	Barren
Agent Decay Rate (%/min)	0.1 to 1	0.1 to 1	0.1 to 1	0.1 to 1

Sunlight exposure increases agent decay as a result of UV radiation. There are two levels of uncertainty regarding UV radiation and decay rates. First, there is some uncertainty as to the levels of UV radiation in the atmosphere depending on meteorological conditions throughout the day for each location. Second, there is uncertainty attributable to the response of the agent to various UV radiation exposures. This uncertainty in agent decay rate would result in more variation than would estimates of differences in UV radiation variations.

Wind direction changes over time can have dramatic effects in the shape of the footprints from any attack, but no wind direction changes were portrayed in this study because they are critically dependent upon synoptic wind patterns and topographic influences which were not represented in this analysis. However, the casualty and unit effectiveness estimates would not be expected to differ significantly as a result of simulating wind direction changes over time since the spore area coverage results would be nearly the same.

Wind speed is known to vary considerably over small time scales. Available data for the climatic regions studied in this effort were represented at hourly intervals. The changes in wind speed over the course of the diurnal cycle should provide reasonable representative values. Long-term tracer studies have had considerable success in validating the modeling of wind speed variations.

The changes in atmospheric stability when combined with wind speed variations over the 24 hours of a day can dramatically change the hazard footprint. Data on the precise time when stability changes occur are not recorded by weather authorities. The stylized Pasquill-based stability values used in modeling the transport and diffusion of biological agent must be correctly represented to generate an accurate footprint for agent releases that transition through periods of night, dawn/dusk, and strong sunlight. Appendix B documents the stability values used in this study on an hourly basis. Release times of 0500 hours and 1900 hours were chosen to encompass multiple environmental periods while the 1200 hours release was chosen

to remain in the sunlight period. The choice of release times would minimize the impact of the uncertainty of the exact time of the change in stability.

In addition to the limitation of toxicology data on the analysis and reliability of the results, the modeling tools make assumptions and place further limitations on the study. The PLUME model is a flat-terrain, tri-variant gaussian transport and diffusion model. It has been modified to represent changes in wind speed, wind direction, atmospheric stability, and agent decay rate on an hourly basis. NO validation of the model has been published. Because of the large grid necessary to accommodate successful releases of *B. anthracis* (several hundred km downwind travel), grid artifacts can sometimes be generated. For instance, the circular pattern formed by the submunition impacts of ballistic missiles generally cannot be seen in the hazard footprints. Hot spots with very high contamination levels may not be depicted due to the absence of a grid point at the hot spot.

4.0 SENSITIVITY ANALYSIS

Four key issues for the study of the effective levels of *B. anthracis* spores were outlined: the effective number of spores that can be released with particle sizes appropriate for retention within the respiratory system; the population response to spores/vegetative cells of *B. anthracis*; the impact of a protective mask or medical intervention using pre- or post-exposure antibiotic therapy and/or vaccination; and the consequences on unit effectiveness from the casualties created during the attacks.

4.1 EFFECTIVE NUMBER AND SIZE OF *BACILLUS ANTHRACIS* PARTICLES

A wide range of potential delivery systems was studied in the United States before 1969. These systems examined the release of dry spores as well as wet releases. Essentially, the release of *B. anthracis* spores can be accomplished by small devices using explosives, generators which use either explosives or compressed air, or spray devices using either single- or double-nozzle systems. The efficiency of release varies considerably with different release mechanisms (Table 1). The efficiency of release combines several factors. The first of two principal factors includes the ability to release sufficient quantities of viable agent to successfully infect a person if inhaled, ingested, or introduced into wounded or intact skin. The second principal factor includes the ability to generate aerosols with particles of the appropriate size.

The ability of particulates to attach on a surface depends on the surface characteristics of both the surface and the particulate in addition to the size of the particulate. The surface characteristics of particulate and surface can only be determined after specific testing. The tendency of particulates to be attracted to either hydrophobic or hydrophilic surfaces can be generically determined. The size of particulates has been established to be of primary importance in determining the region of the respiratory tree where deposition might occur and the level of deposition expected in that region. Particulates or droplets greater than 100 microns tend to be retained in the nasopharynx. Particulates or droplets between 0.1 and 5 microns in size tend to be nearly completely retained in the lowest levels of the respiratory tree, especially the terminal bronchioles and the alveoli.

The number of *B. anthracis* spores of size less than 5 microns in diameter required to provide a lethal dose to 50 percent of the population (expressed as LD_{50}) has been estimated to be between 8,000 and 10,000. The LD_{50} for rhesus monkeys has been determined to be 8,689 spores. Population response sensitivity to the range of 8,000 to 10,000 spores became the first issue to be addressed in this study.

The concentration of spores in dry agent has been found to be between 0.9×10^{12} and 1.02×10^{12} spores/g while the concentration of wet agent was approximately 2×10^{10}

spores/ml. The packing density of dry agent is 0.15 g/cm^3 while wet agent would have a density approaching 1 g/cm^3. A dry agent was used in this study.

4.2 SENSITIVITY TO ESTIMATES OF MEDIAN INFECTIVE DOSES

Two issues related to the estimate of median infective dose must be addressed. The first issue is the representation of the effectiveness of antibiotic therapy and/or vaccine. If antibiotic therapy is going to be effective, numerous sources cite that the therapy must be initiated before the onset of symptoms. After symptoms start, little success has been found in preventing death from pulmonary anthrax. Based on studies of available data, the U.S. Army Medical Research Institute of Infections Diseases (USAMRIID) has determined that antibiotic therapy is effective in reducing the lethality of *B. anthracis* pseudospore exposure if therapy is initiated in the first days after exposure and before the onset of symptoms. The use of antibiotic therapy was found to constitute approximately an LD_{10} at 10 times the untreated LD_{50}. Probit analysis techniques were used to develop a protective ratio of 670 for antibiotic therapy.

To illustrate this analysis, Figure 1 shows the classic relationship between population response and probits. A probit is one standard deviation of population response and a probit level of 5 is assigned to the 50 percent response level.

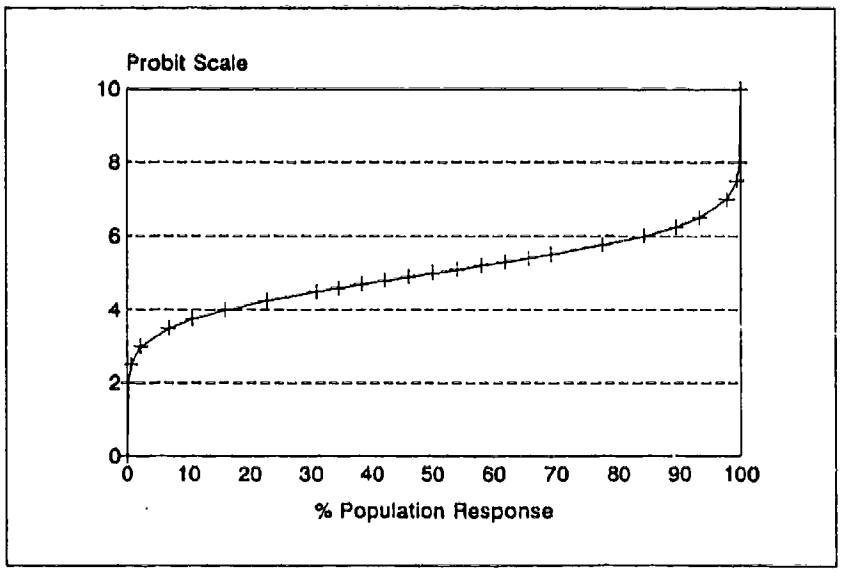

Figure 1. Probit Score vs. Population Response

Figure 2 demonstrates the use of the probit relationship as applied to the problem of estimating median infective doses for antibiotic and vaccine. Antibiotic therapy using doxycycline was protective against 10 inhaled LD_{50}s in 9 of 10 rhesus monkeys (Appendix A). Figure 2 shows that a factor of 10 times the untreated median infective LD_{50} dose (10 x 8689

spores) moves the untreated response line to the right such that the line intercepts a point representing a 10 percent population response (3.7 on the probit scale) on the vertical axis, and $\log_{[10 \times 8689 \text{ (spores)}]}$ or 4.94 on the horizontal axis. The protective value of antibiotic therapy is based on the assumption that the probit slope does not change with medical intervention.

A similar procedure is followed in the case of vaccination. USAMRIID has found that a dose 500 times the untreated infective dose for a 50 percent population response did not result in a single infection for vaccinated populations. [The results were specific to MDPH-PA efficacy, i.e., the currently fielded vaccine. In these experiments, ten adult rhesus monkeys were immunized with MDPH-PA at 0 and 2 weeks. At 8 weeks, the animals were challenged with 506 aerosol LD_{50}s of B. anthracis Ames spores. All monkeys survived. Five control monkeys given saline rather than MDPH-PA died following challenge with 439 aerosol LD_{50}s of Ames spores. In a longer term experiment, three monkeys received MDPH-PA at 0 and 2 weeks. At 38 weeks (8.5 months) the monkeys were challenged with 203 aerosol LD_{50}s of Ames spores. All three monkeys survived.][1] Graphically from Figure 2, shifting the untreated response line to the right 500 times the untreated LD_{50} dose (or 2.7 log units), the vaccine dose response line must intersect the treated dose response surface at a population response level representing 0 percent on the Y-axis. Zero (0) percent was conservatively estimated using a probit value of 2 which represents three standard deviations below the median value. The protective ratio for the vaccine is thus determined to be 9,390,000, a considerable level of protection.

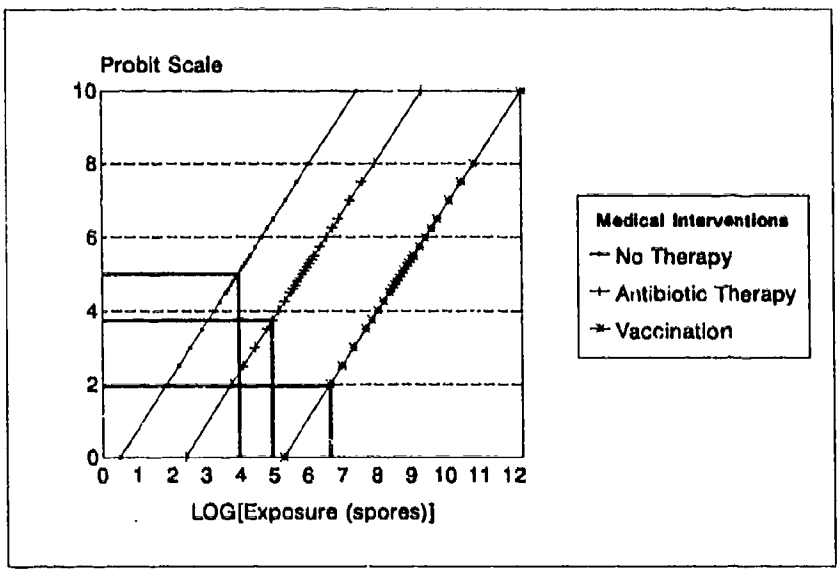

Figure 2. Medical Intervention Population Response

The footprints in Figures 3 and 5 show the consequences of varying the median infective dose between 8,000 and 10,000 spores. Contours are based on the *B. anthracis*

[1]From a memo by COL David Franz, Headquarters USAMRIID, Ft. Detrick, MD, dated 7/30/93.

The footprints in Figures 3 and 5 show the consequences of varying the median infective dose between 8,000 and 10,000 spores. Contours are based on the *B. anthracis* dosage that results in 5 percent and 50 percent population response (deaths) with no medical intervention, 50 percent population response with antibiotic therapy started in the first day of exposure, and contours representing 50 percent population response with vaccinated personnel. While the range in number of spores represents a 25 percent increase in the median toxicological values, it can be seen that there was no appreciable increase in the LD_{50} area coverage without medical interventions. Further, as can be seen in the panels displaying unit effectiveness, there is no perceptible difference across the three figures. Figure 4 shows an intermediate infective dose of 8689 spores which was based on monkey data and was the value used to represent the median infective dose in humans; it was used for the remainder of the study. (For additional assistance in interpreting footprint hazard graphs, see Appendix D.)

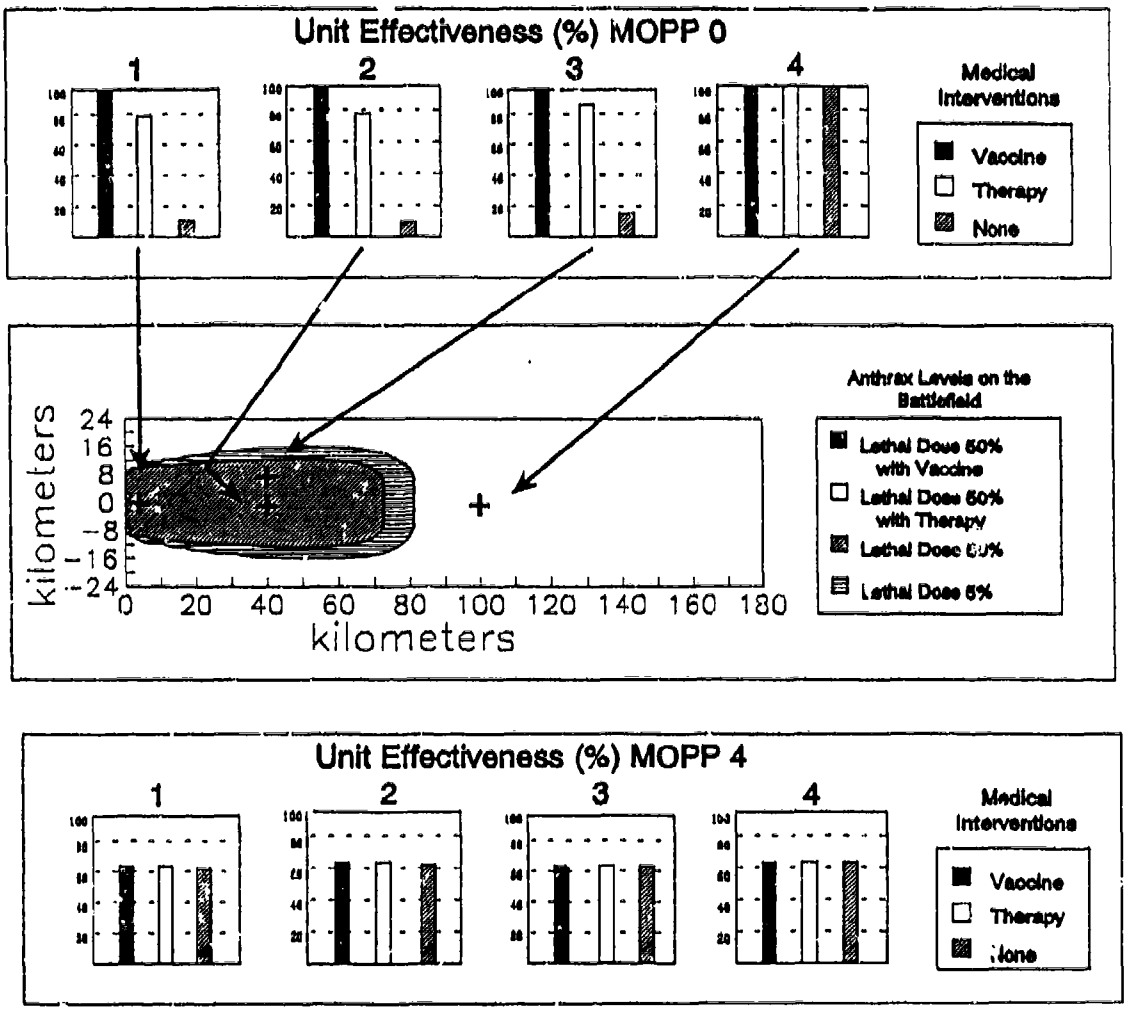

Figure 3. TBM with Submunitions in Central Europe at 1900 Hours: Artillery Unit Effectiveness with Medical Interventions (LD_{50} = 8,000 spores)

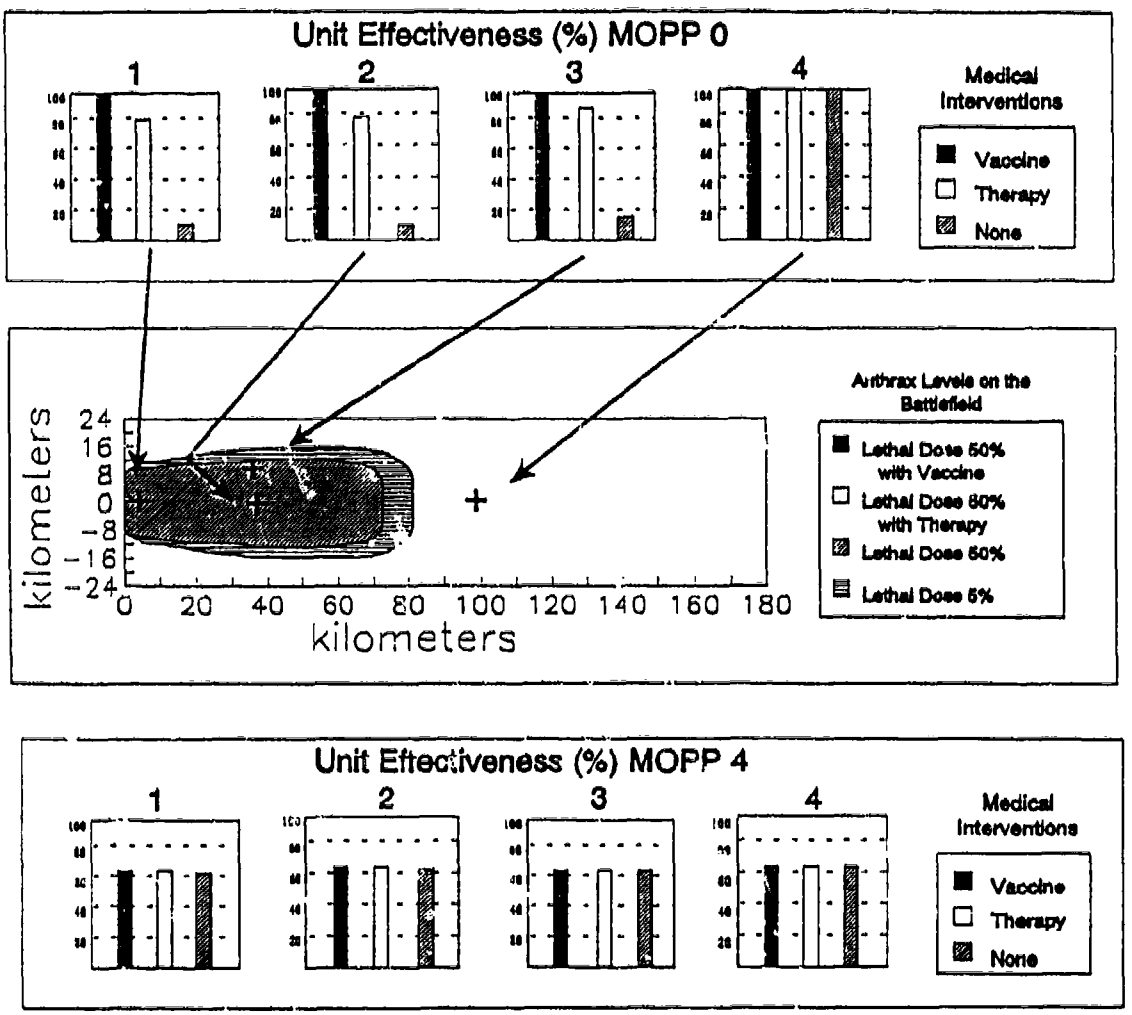

Figure 4. TBM with Submunitions in Central Europe at 1900 Hours: Artillery Unit Effectiveness with Medical Interventions (LD_{50} = 8,689 spores)

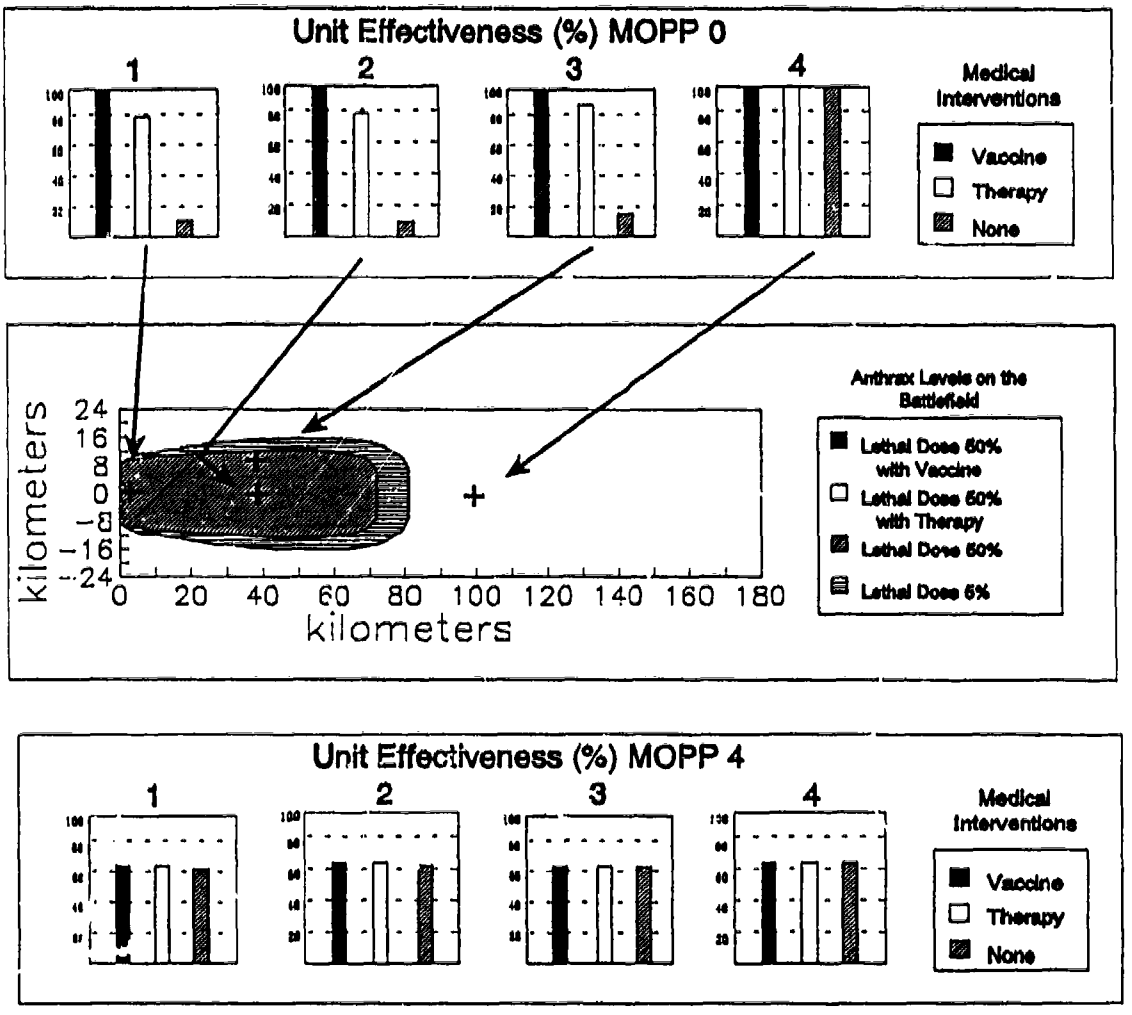

Figure 5. TBM with Submunitions in Central Europe at 1900 Hours: Artillery Unit Effectiveness Medical Interventions (LD_{50} = 10,000 spores)

4.3 SENSITIVITY TO AGENT DECAY AND TOXICITY ESTIMATES

Figures 6 and 7; 8 and 9; and 10 and 11 (pages 24-29) show comparisons of high and low ranges of decay rates for cases where attacks occurred at 0500, 1200, and 1900 hours respectively. For the three times of day modeled, the strongest decay effects were seen for the 1200 hours releases, where decay ratios were highest. The "low" range of decay rates (0.1 to 1 percent/minute) used as the baseline in this study was based on U.S. Army Medical Research and Development Command (USAMRDC) knowledge of the relationship between the chamber data and expectations for operations in the field. (See Appendix B for a listing of the hourly decay rates used as the standard for the simulations in this study.) The "high" range of decay rates (1 to 2.5 percent/minute) examined for comparison was based on data found in U.S. Army Chemical Research, Development and Engineering Center (CRDEC) sources[2]. The potential effects on the level and duration of hazard due to the uncertainty in decay rates can have an appreciable effect on the outcomes of model results.

As would be expected, the most pronounced effect of the "high" decay rates relative to the "low" would be the alteration of the extent of the downwind hazard. Figures 6-11 incorporate the effects of transport and diffusion, as do all the footprint maps in this study. However, if the effects of transport and diffusion are disregarded, the effect of differences in decay alone can be calculated. A decay rate of 0.5 percent/minute over a period of 10 hours would result in a loss of agent viability of 95 percent; a decay rate of 0.1 percent/minute would result in a loss in viability of only 45 percent.

Although transport and diffusion are the dominate phenomena affecting agent concentration for any given source strength, use of the "high" decay rate in an analysis can appreciably lower the estimate of the level of threat. For example, the artillery unit modeled in this analysis would occupy a deployment area 600 meters by 400 meters or approximately 240,000 m^2. If the artillery unit were to experience a direct attack at midday with a wind speed of 5 km/hour, the airborne agent would be expected to clear the area occupied by the artillery unit in 10 minutes or less. Based on the "high" decay rate of 2.5 percent/minute, a loss of 22 percent in the viable agent mass would occur within the 10 minute time frame. Another way of looking at this effect is to say that the amount of mass released, or the source strength, would be reduced as a result of decay *on the average* by 11 percent as it was transported across the targeted artillery unit. Again, using the example of an attack on an artillery unit but substituting the "low" decay rates, a loss of viability of 10 percent of the agent mass would occur within the 10 minute time frame, resulting in, *on average*, a 5 percent decrease in source strength across the target. The implication is that for *direct* attacks, there would be an overall variation of about 6 percent in the total agent mass conserved when comparing the "high" and "low" ranges of decay rates examined.

The effects of variations in decay rates on downwind units is easier to visualize on the footprint maps. In the comparison maps, differences in decay rate estimates produce enough variations in the extent of the downwind hazard to exclude some units from the attack when

[2]Recently renamed Edgewood Research, Development, and Engineering Center (ERDEC).

using the high decay rates that would be included in the downwind hazard drift when using the low decay rates.

One of the operational implications of releases during periods of maximum decay is that the extent of the hazard area is much more controllable. For example, based on hypothetical validation of the "high" decay rates, an Iraqi attack against Kuwait could be timed so as to nearly totally decay (99 percent in three hours at 2.5 percent/minute) before an anticipated shift in the on-shore wind pattern that might otherwise threaten Iraq.

Undocumented sources have suggested that decay can be prevented for the first 2 hours following release and that *B. anthracis* may be 100 times more toxic than the levels determined by USAMRDC. Appendix C addresses these issues by providing examples of the results that would be achieved by following these assumptions. Based on the lower decay rates used in the current study, which range from 0.1 percent/minute in darkness to 1 percent/minute in bright sunlight, the effect of a two hour delay in decay would be to conserve between 12 and 30 percent of the agent total mass that would be expected to decay in the first 120 minutes after dissemination. However, on a target such as an airfield attacked at night, the agent would clear the associated 4 km diameter area in about one hour or less assuming winds ranging from 3 to 9 km per hour. In this airfield attack case, the absence of decay in the first hour would only conserve about 6 percent of the total agent mass. Therefore, since the current study is based on an assumption that decay does occur during the first two hours after release, the results simulated in this study would provide only a slightly lower estimate of the resulting hazard and, consequently, a slightly more robust estimate of unit effectiveness than the alternate supposition.

The issue of a 100-fold increase in agent toxicity presents a much more serious operational challenge. To assess the operational impact and potential resultant medical workload, the sensitivity of unit effectiveness of an artillery unit and the capability of the medical products vis-à-vis this challenge were modeled for TBM submunition and spray attacks in Central Europe and Southwest Asia. The general conclusion was that the protective capacity of the vaccine was robust enough to maintain unit effectiveness above 85 percent in all cases without the protection of the mask. However, antibiotic therapy could be decisively overwhelmed for areas as large as 15,000 square km for the simulated spray attack at 0500 in Central Europe. If the unit was in MOPP 4 at the time of the attack, antibiotic therapy would have been required to sustain unit effectiveness at 63 percent -- the normal level of degradation for MOPP 4. Without antibiotic therapy, the protective ability of MOPP would also have been overwhelmed. If one does indeed believe that the toxicity of *B. anthracis* is 100 times more toxic than the level estimated by USAMRDC, then there is an unequivocal case for a vaccine policy that immunizes personnel prior to deployment, or at least in-theater prior to exposure.

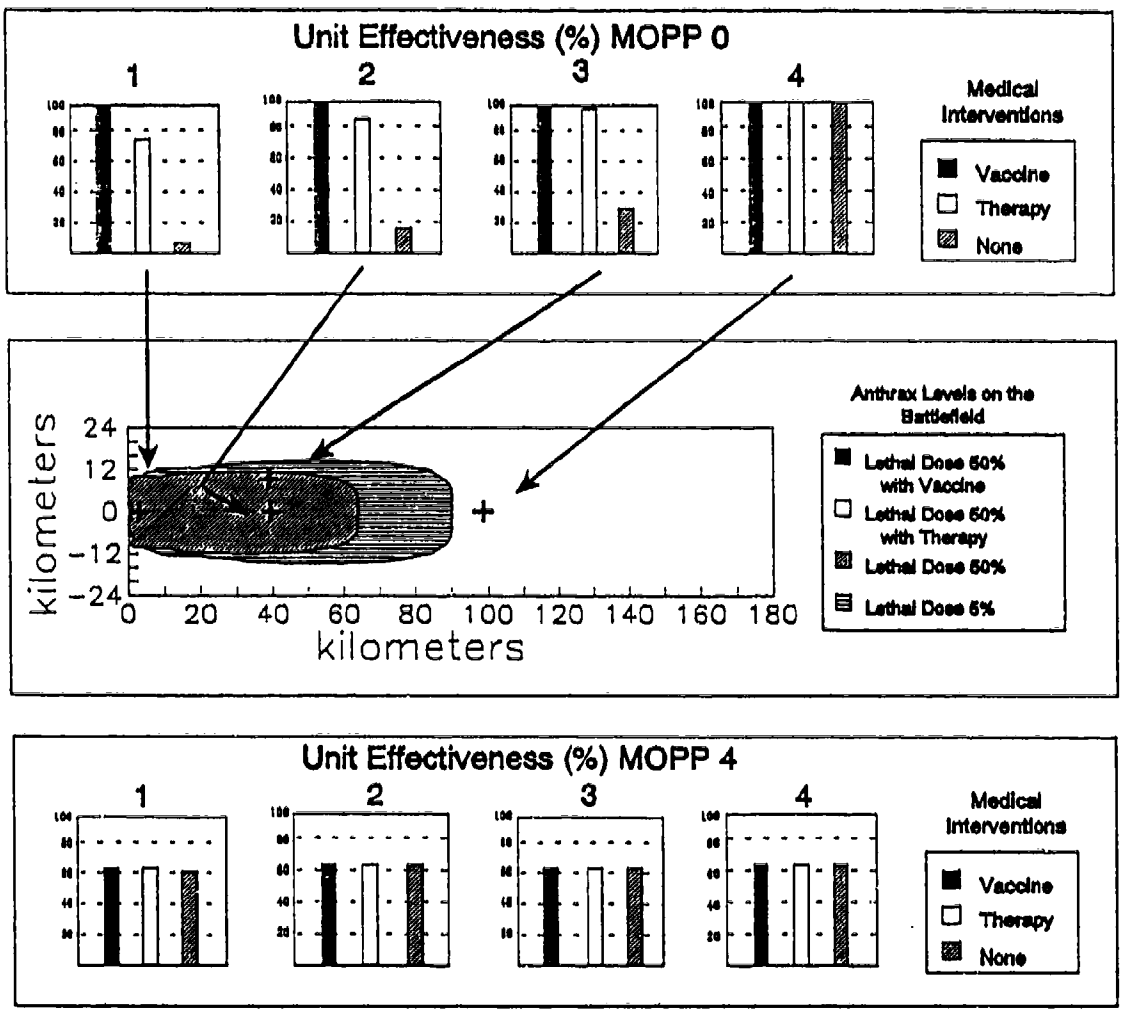

Figure 6. TBM with Submunitions in Central Europe at 0500 Hours: Artillery Unit Effectiveness with Medical Interventions (USACRDEC Decay Rates)

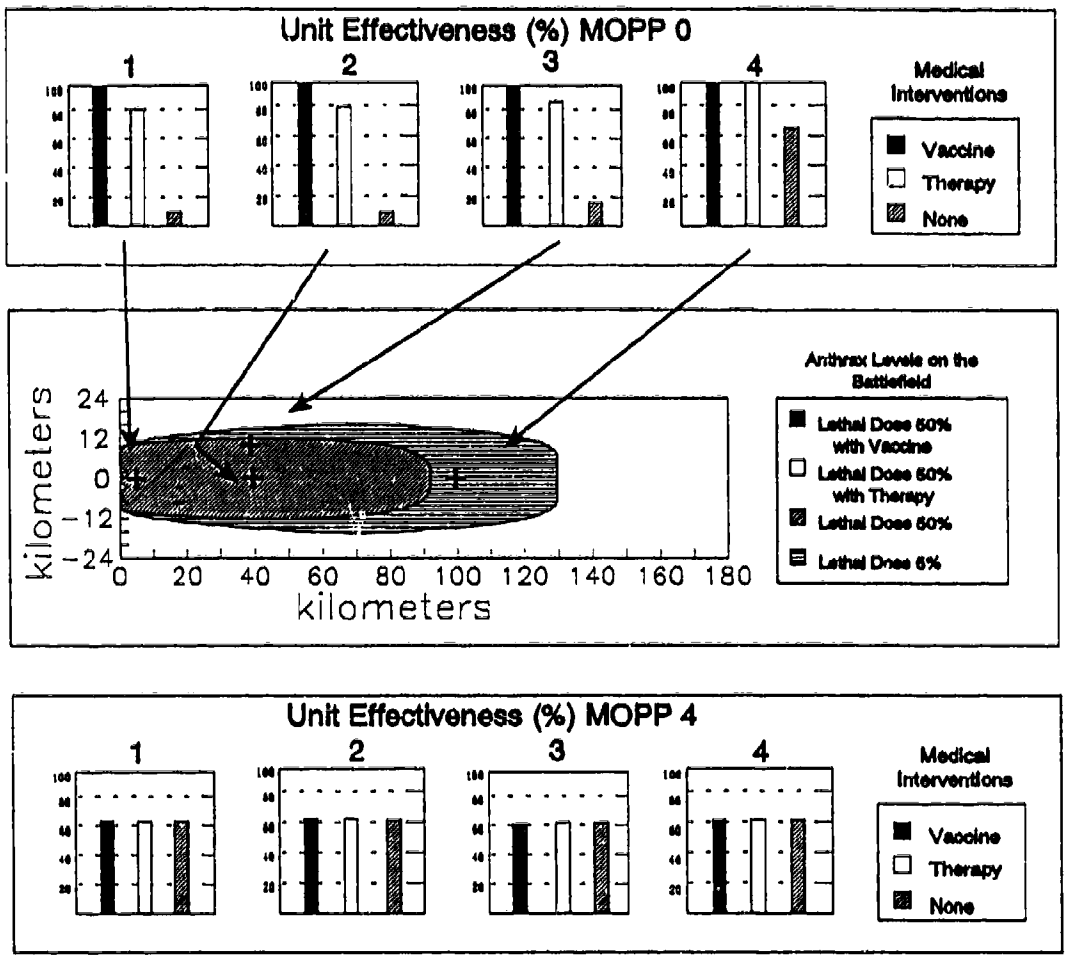

Figure 7. TBM with Submunitions in Central Europe at 0500 Hours: Artillery Unit Effectiveness with Medical Interventions (USAMRDC Decay Rates)

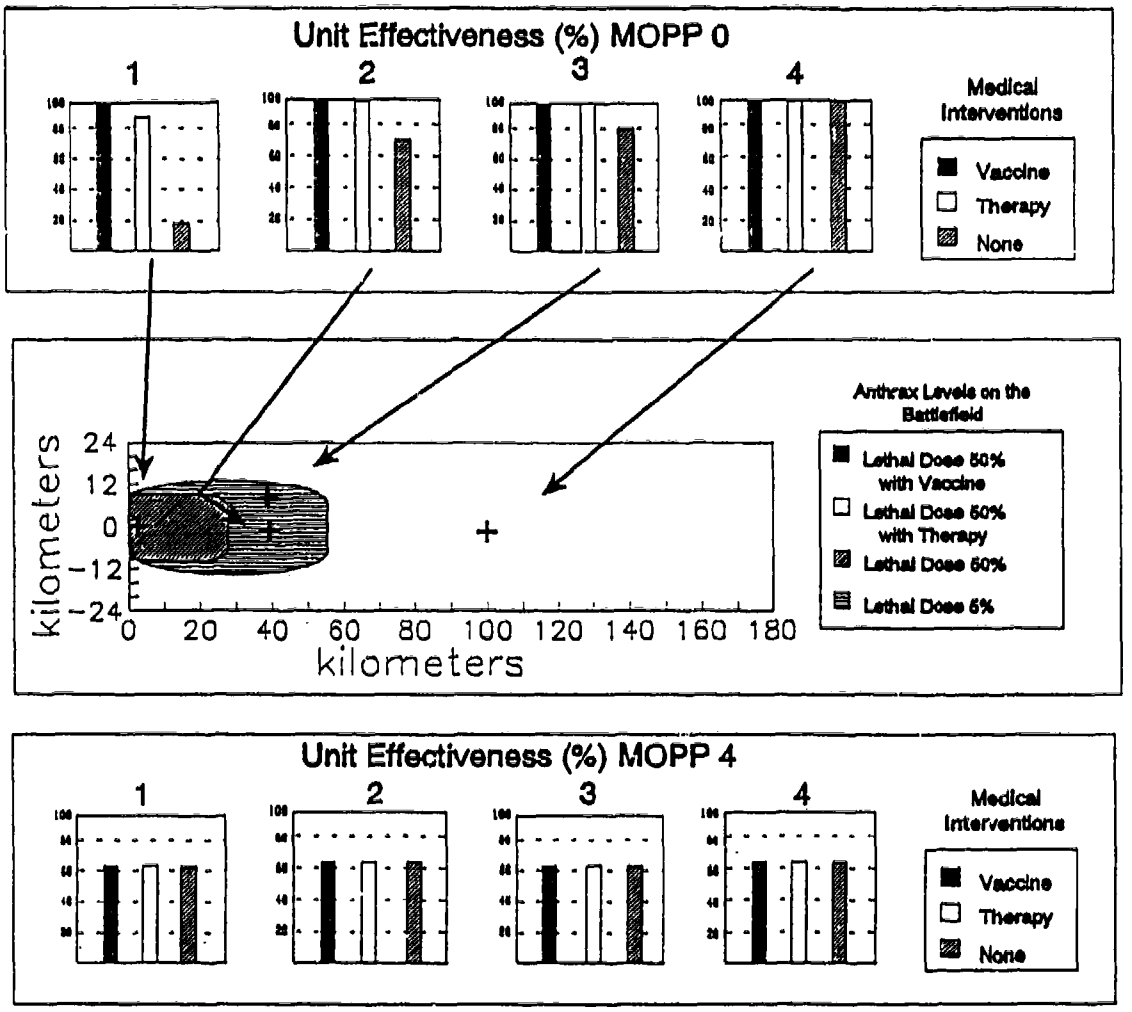

Figure 8. TBM with Submunitions in Central Europe at 1200 Hours: Artillery Unit Effectiveness with Medical Interventions (USACRDEC Decay Rates)

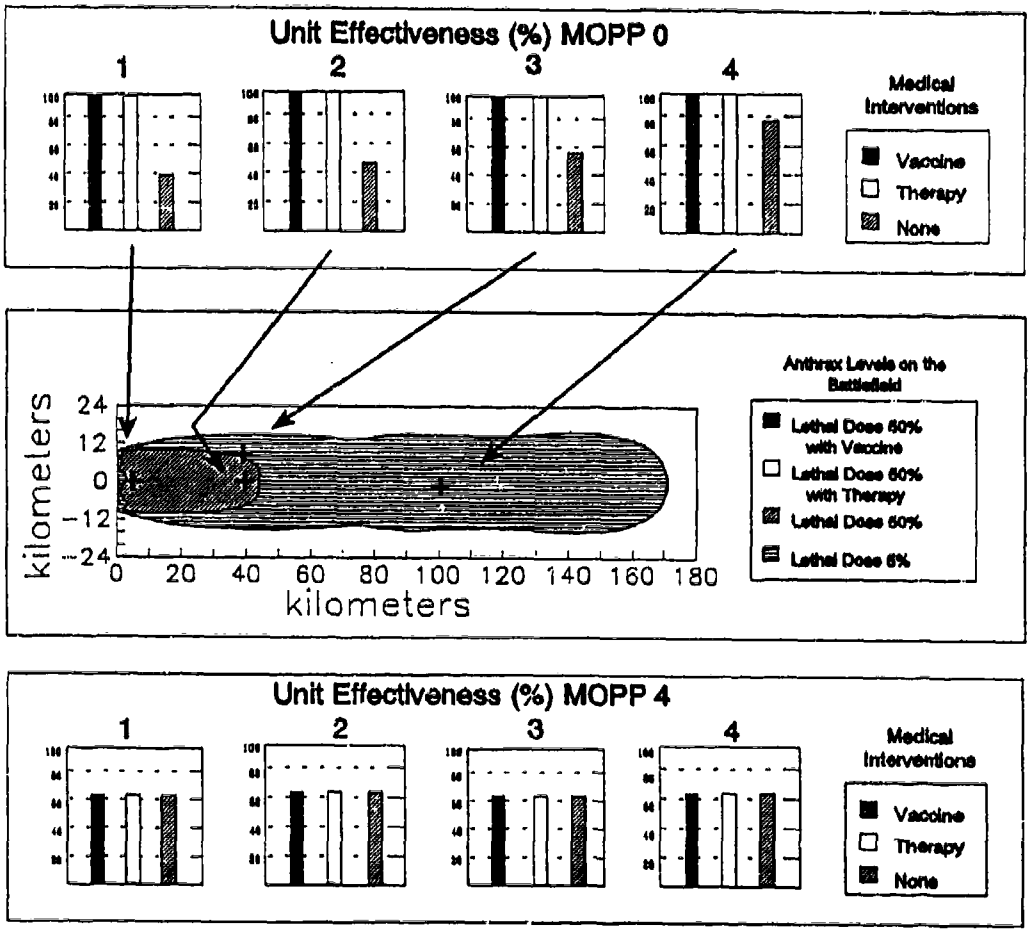

Figure 9. TBM with Submunitions in Central Europe at 1200 Hours: Artillery Unit Effectiveness with Medical Interventions (USAMRDC Decay Rates)

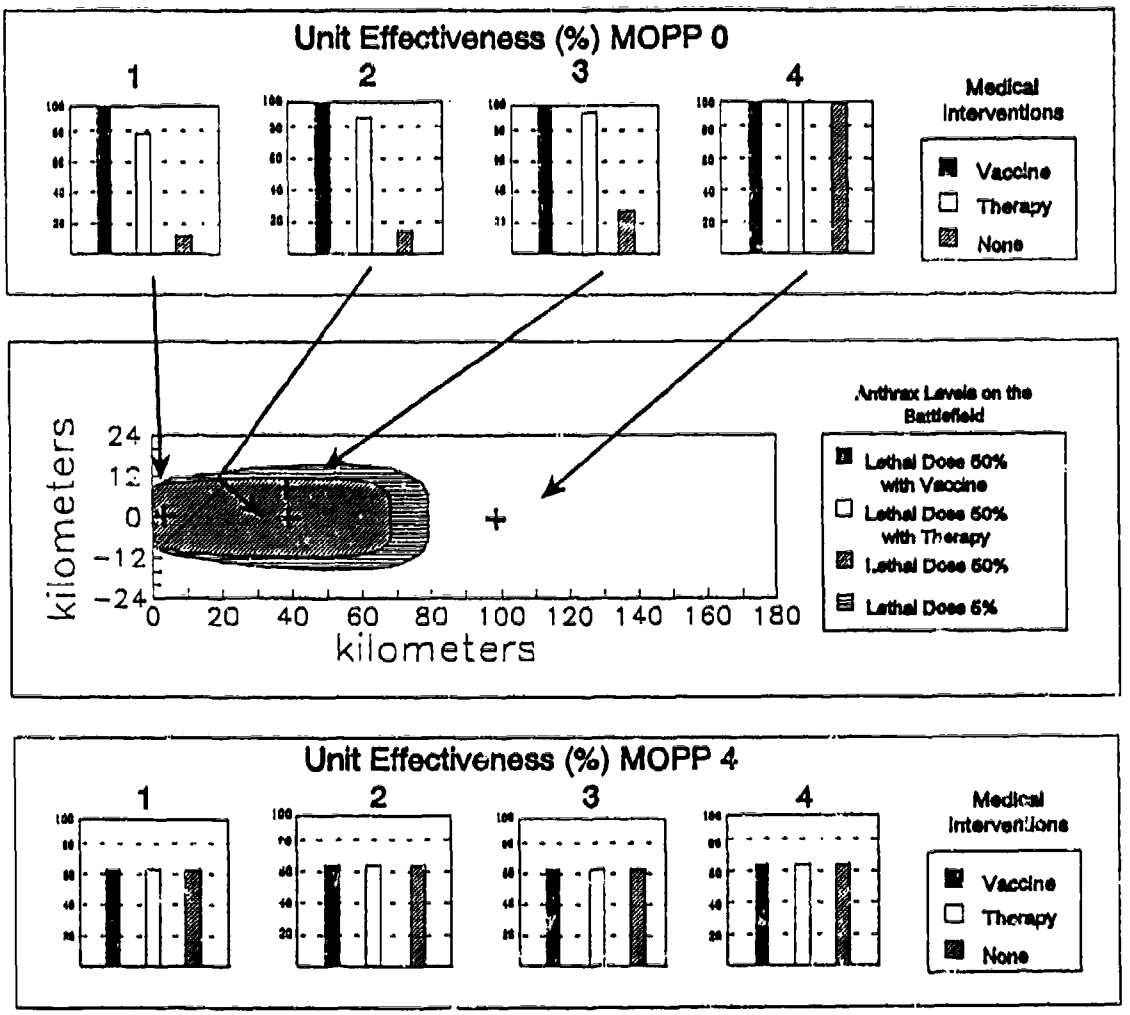

Figure 10. TBM with Submunitions in Central Europe at 1900 Hours: Artillery Unit Effectiveness with Medical Interventions (USACRDEC Decay Rates)

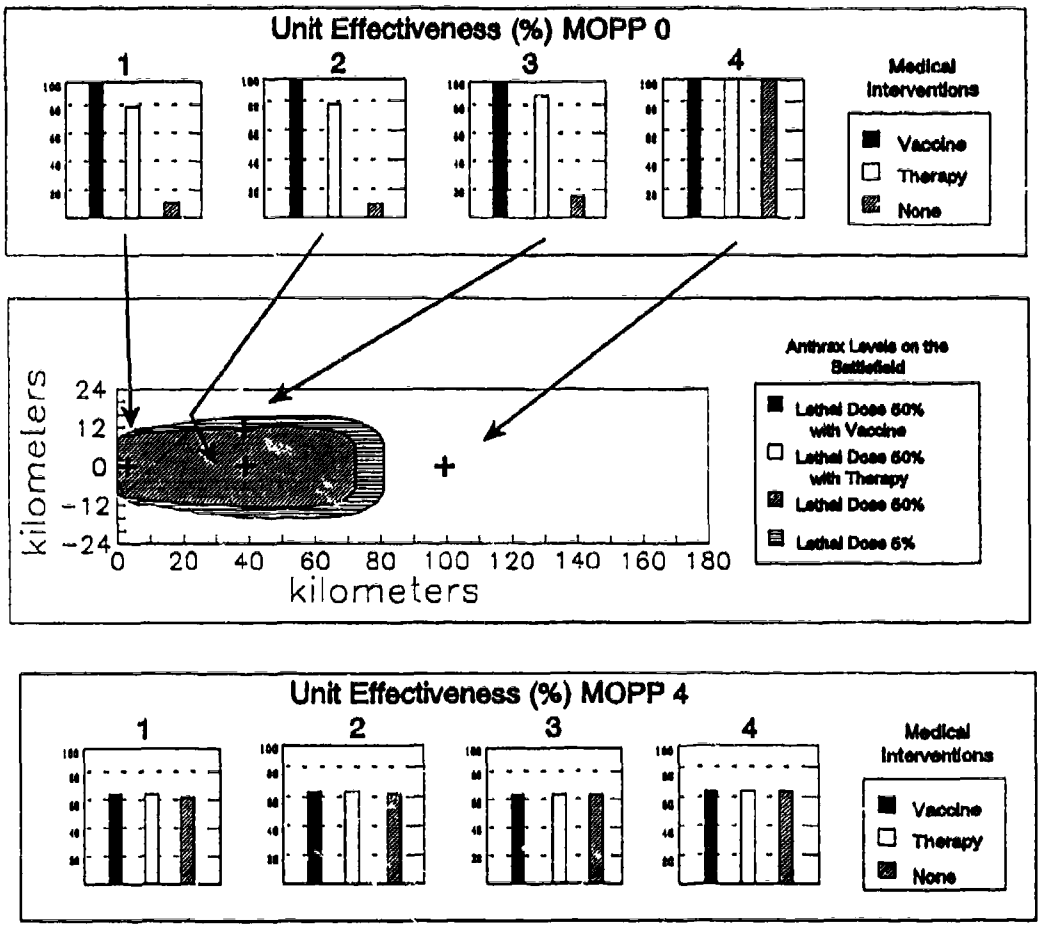

Figure 11. TBM with Submunitions in Central Europe at 1900 Hours: Artillery Unit Effectiveness with Medical Interventions (USAMRDC Decay Rates)

4.4 UNIT SENSITIVITY TO CASUALTIES FROM ANTHRAX

An artillery unit is used throughout the study as the target of attacks using six different weapon systems. In order to illustrate the unit sensitivity of various operational units, an attack with a terrorist device was also simulated against a headquarters unit, an ammunition supply point, an infantry anti-armor unit, and an attack helicopter unit for comparison.

A headquarters unit is most sensitive to casualties because the members of the unit have specialized tasks to perform; the loss of a few highly skilled workers is hard to absorb without a significant loss in unit effectiveness. Attack on an artillery unit, infantry anti-armor, or attack helicopter unit result in unit effectiveness degradation approximately proportional to the percentage of casualties suffered from an attack.

Figures 12-26 illustrate the relative resilience of these five units to personnel losses. Unit effectiveness is shown for a point in time after all casualties would be absorbed (mean time to death is approximately 7.5 days) but without any replacements. Above each hazard footprint, the unit effectiveness of a unit located at any of four locations on the battlefield relative to the attack is shown with results for Mission Oriented Protective Posture 0 (MOPP 0) with three alternatives of medical therapy: (1) vaccine protection, (2) antibiotic therapy begun on the day of the attack, and (3) no medical intervention. Below each footprint, the corresponding values for the same units are displayed but with MOPP 4 assumed before the attack and maintained until such time that it can be ascertained that there is no longer a threat of infection. This may take many days in the absence of a biological agent detector. As a point of reference, note that donning protective equipment causes a decline in unit effectiveness independent of casualties. The expected degradation attributable to MOPP 4 would result in 63 percent unit effectiveness for artillery, infantry, anti-armor, or attack helicopter units, 60 percent for headquarters units; and 25 percent for ammunition supply points, according to AURA calculations.

As a tool for comparison, a unit with an effectiveness level of 90 percent is considered to be fully functional while a unit with 70 percent unit effectiveness is considered to be incapable of normal operations. A level of 80 percent unit effectiveness may be looked upon as a reasonable goal for sustaining operations with a safe margin of error. By simply donning the protective equipment of MOPP 4, a unit is no longer capable of sustaining normal operations at a level equivalent to a non-nuclear, biological chemical environment.

Differences in unit sensitivity can be made by comparing units at the same positions on respective hazard footprints. For example, a unit located within the LD_{50} contour on the footprint would expect to experience 50 percent casualties if there is no medical intervention. Position 3 on the footprint is slightly within the contour; thus, units at that location would be expected to experience greater than 50 percent casualties. Note that the ammunition supply point at this position is expected to achieve about 55 percent unit effectiveness even though losses are greater than 50 percent. A headquarters unit at the same position, on the other hand, would be totally ineffective. The other three units would be expected to achieve only about 30 to 35 percent unit effectiveness at the same position. With vaccine, all units would

remain totally effective (headquarters unit would be at 98 percent), and the antibiotic therapy would preserve unit effectiveness at greater than 95 percent for all units with the exception of the headquarters unit (87 percent unit effectiveness).

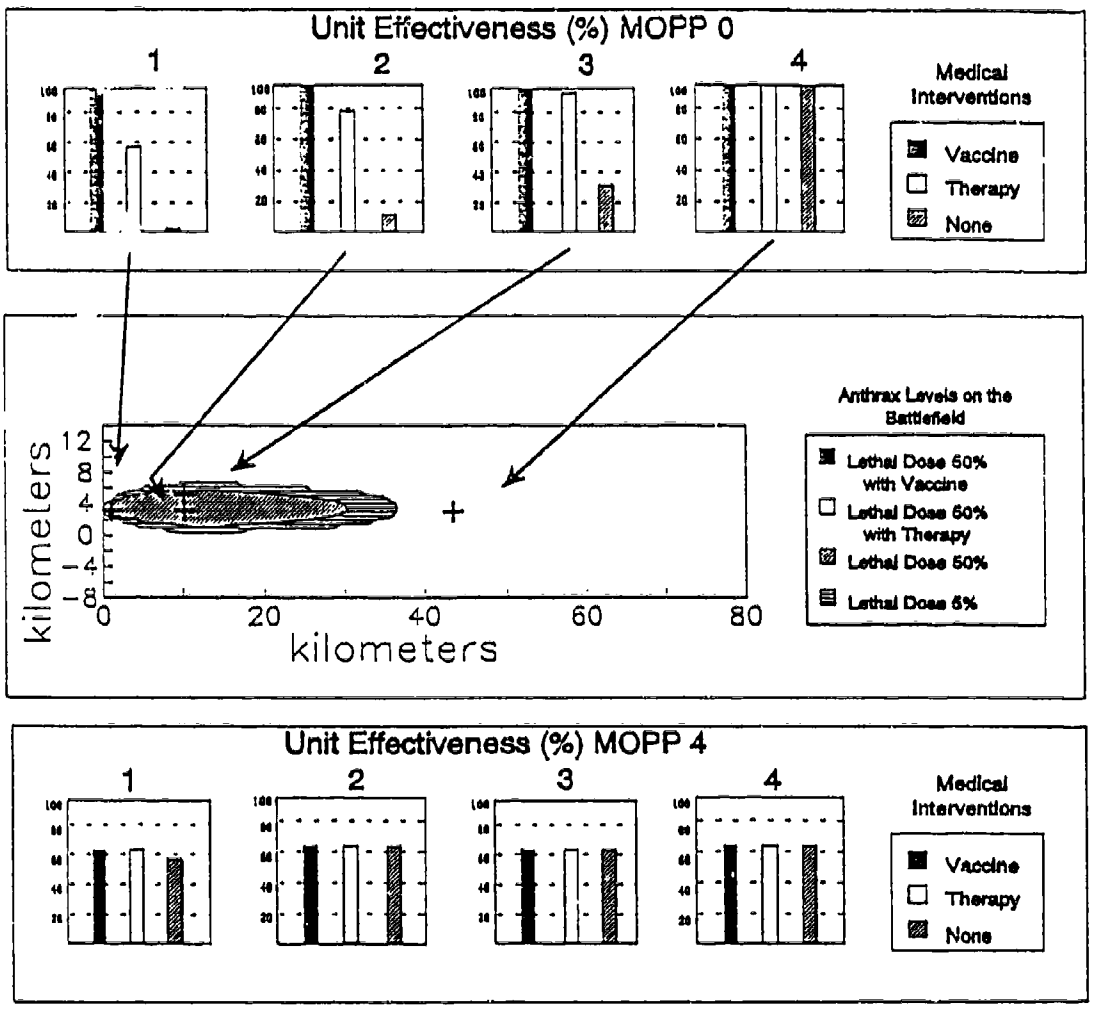

Figure 12. Terrorist Device in Southwest Asia at 0500 Hours: Artillery Unit Effectiveness with Medical Interventions

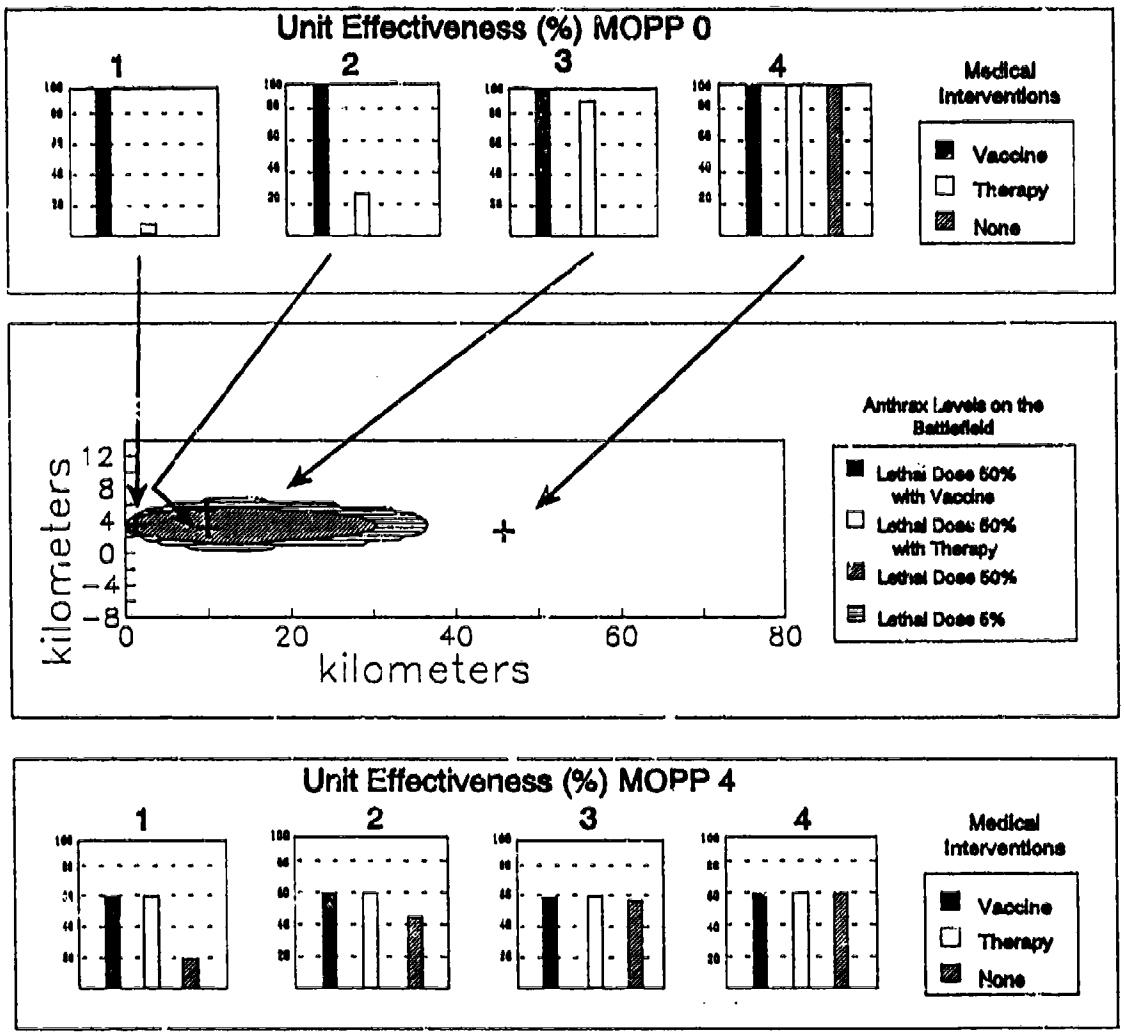

Figure 13. Terrorist Device in Southwest Asia at 0500 Hours: Headquarters Unit Effectiveness with Medical Interventions

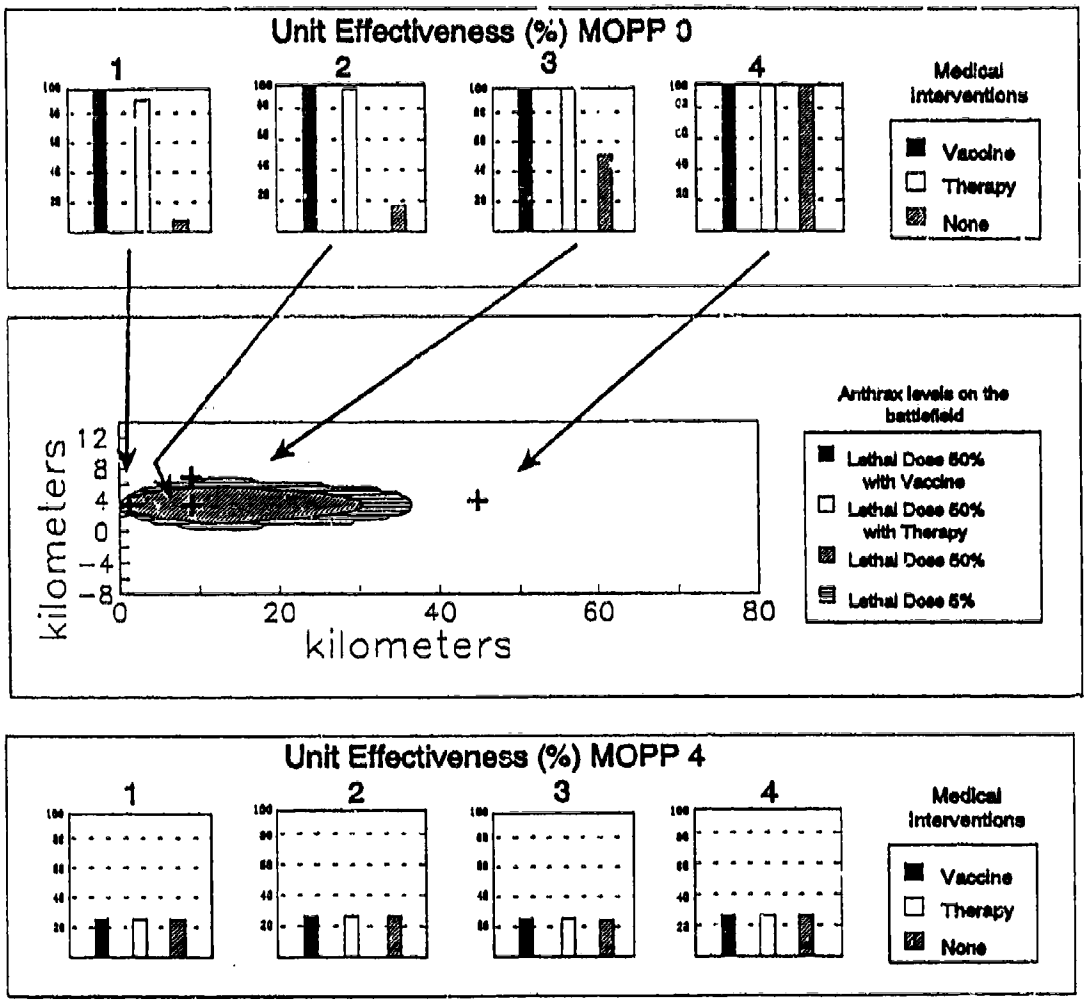

Figure 14. Terrorist Device in Southwest Asia at 0500 Hours: Ammunition Supply Point Unit Effectiveness with Medical Interventions

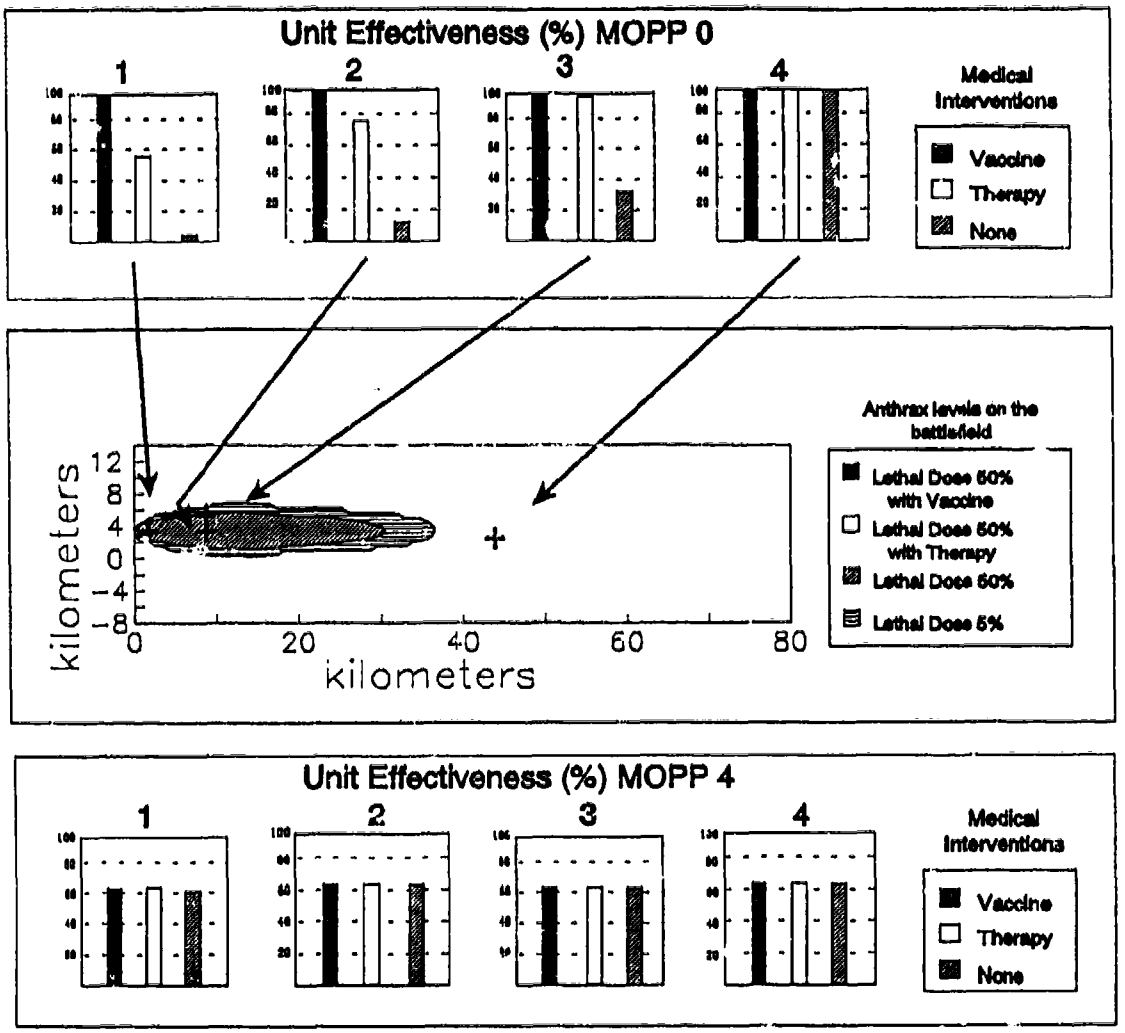

Figure 15. Terrorist Device in Southwest Asia at 0500 Hours: Infantry Anti-Armor Unit Effectiveness with Medical Interventions

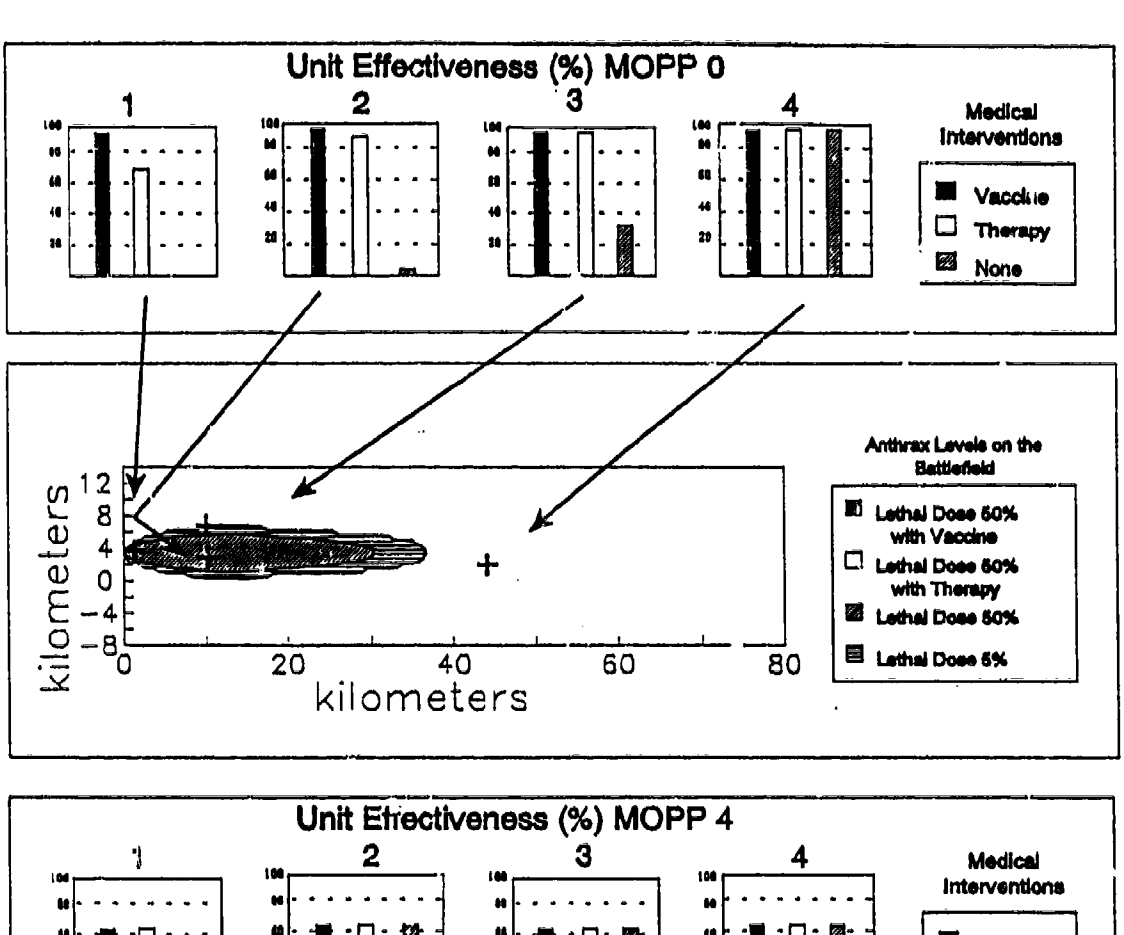

Figure 16. Terrorist Device in Southwest Asia at 0500 Hours: Attack Helicopter Unit Effectiveness with Medical Interventions

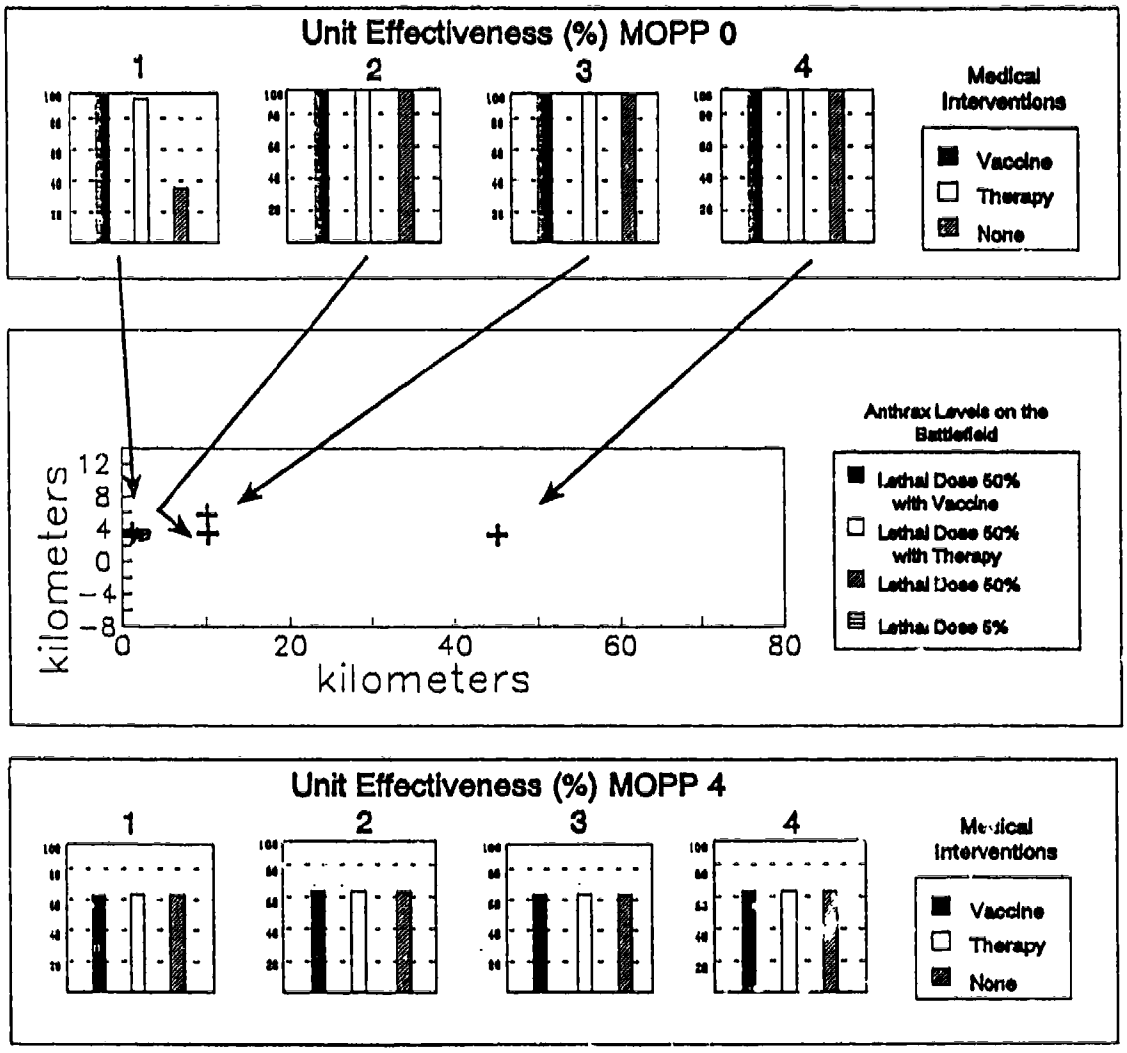

Figure 17. Terrorist Device in Southwest Asia at 1200 Hours: Artillery Unit Effectiveness with Medical Interventions

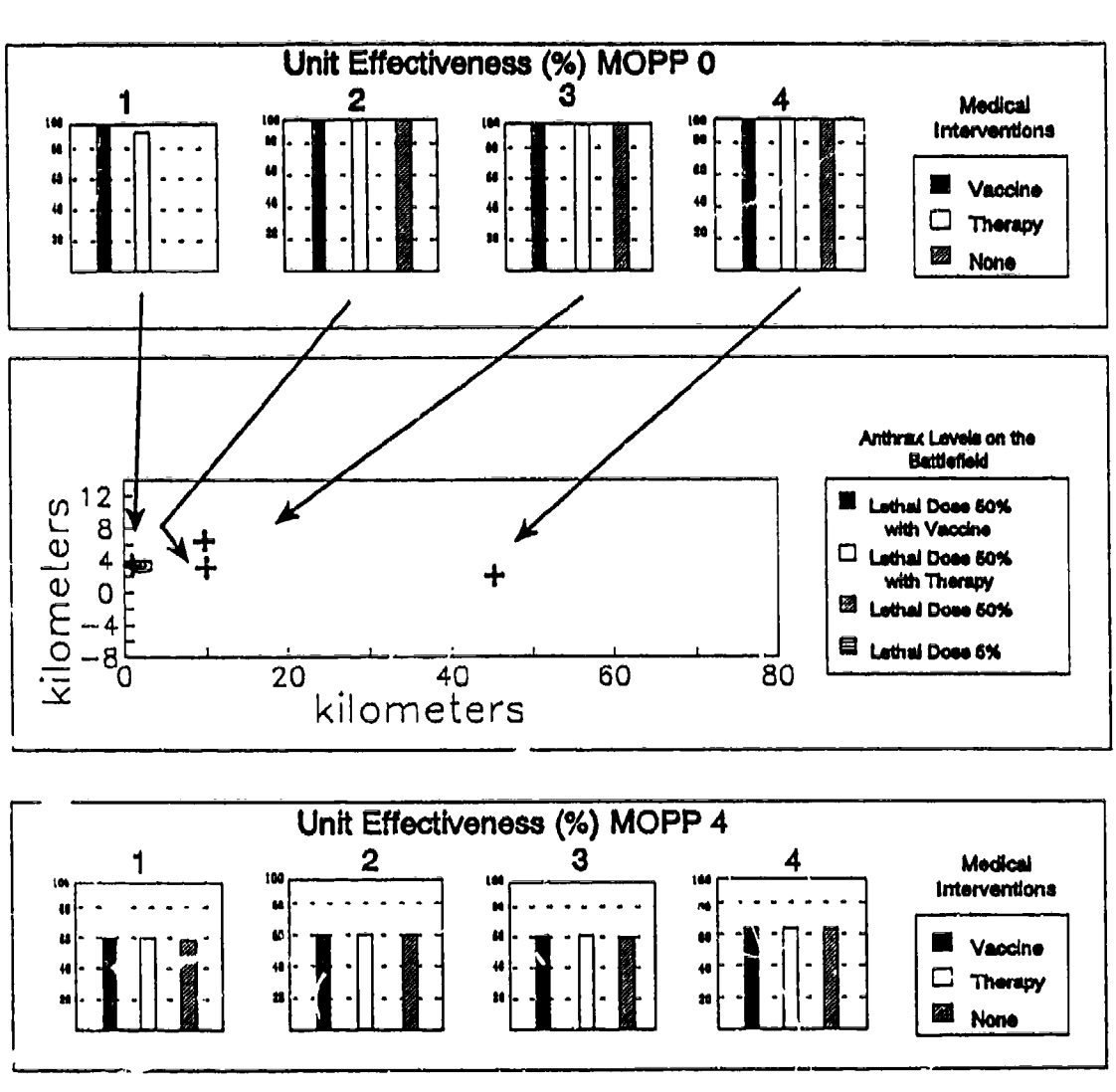

Figure 18. Terrorist Device in Southwest Asia at 1200 Hours: Headquarters Unit Effectiveness with Medical Interventions

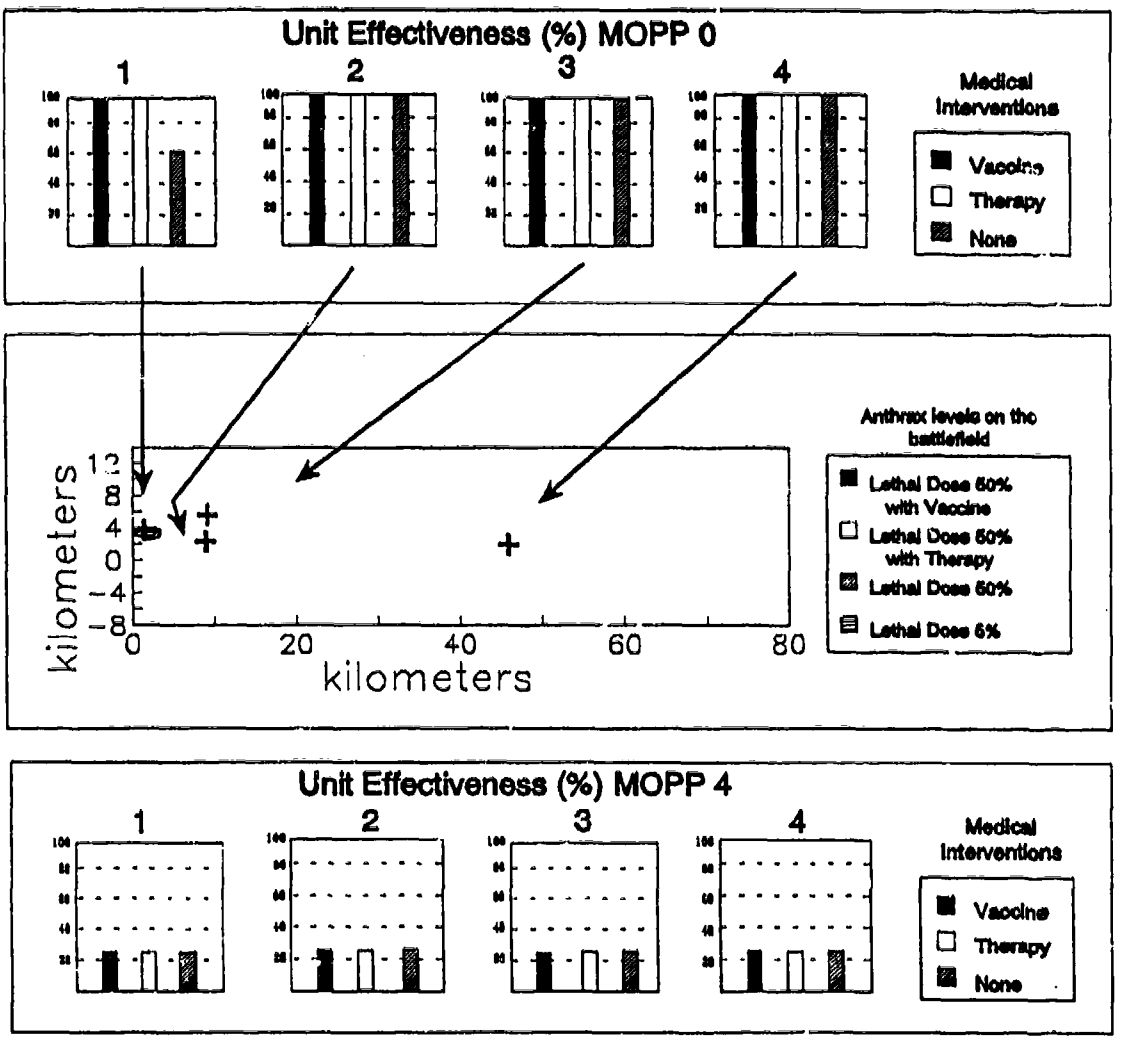

Figure 19. Terrorist Device in Southwest Asia at 1200 Hours: Ammunition Supply Point Unit Effectiveness with Medical Interventions

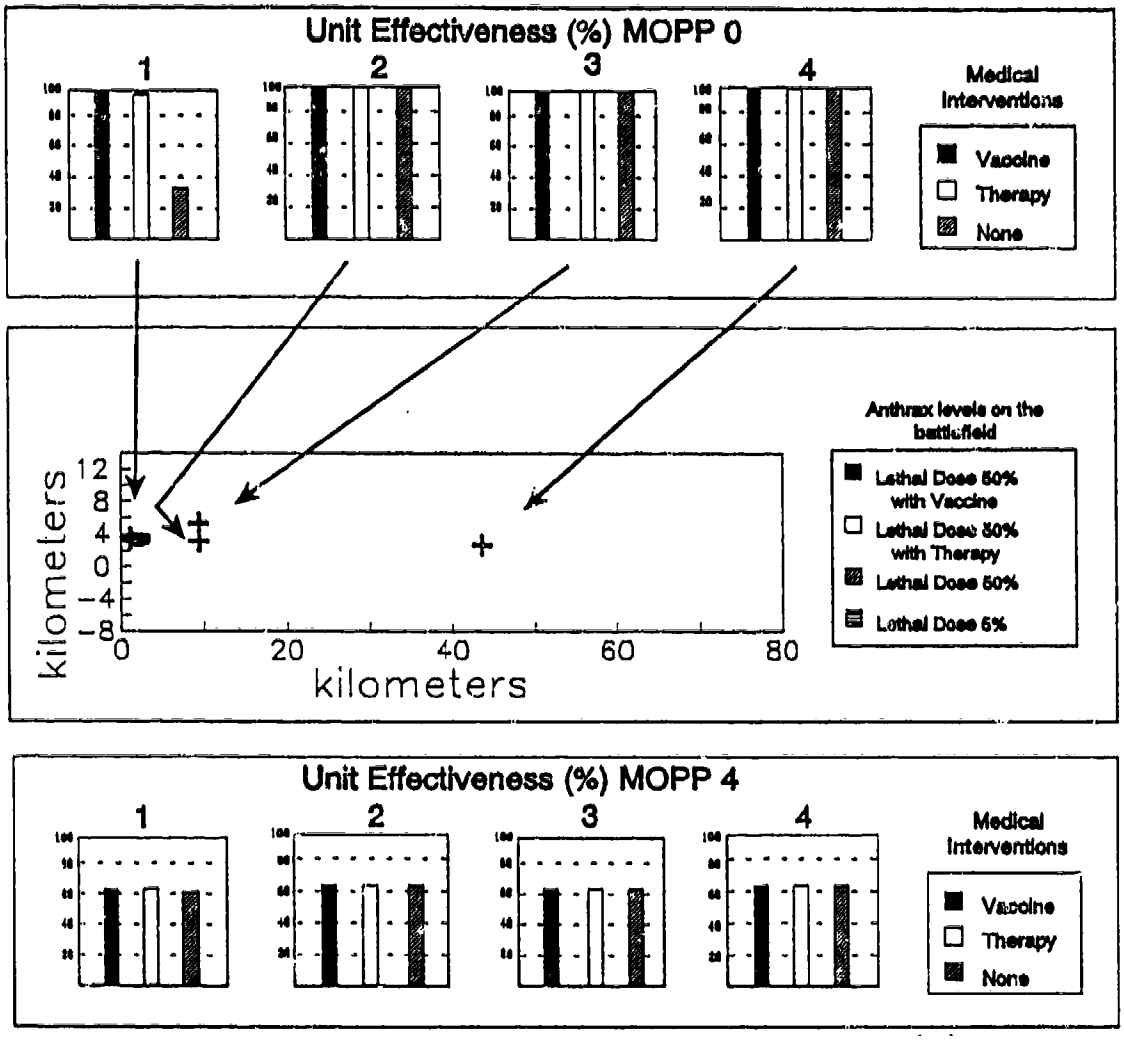

Figure 20. Terrorist Device in Southwest Asia at 1200 Hours: Infantry Anti-Armor Unit Effectiveness with Medical Interventions

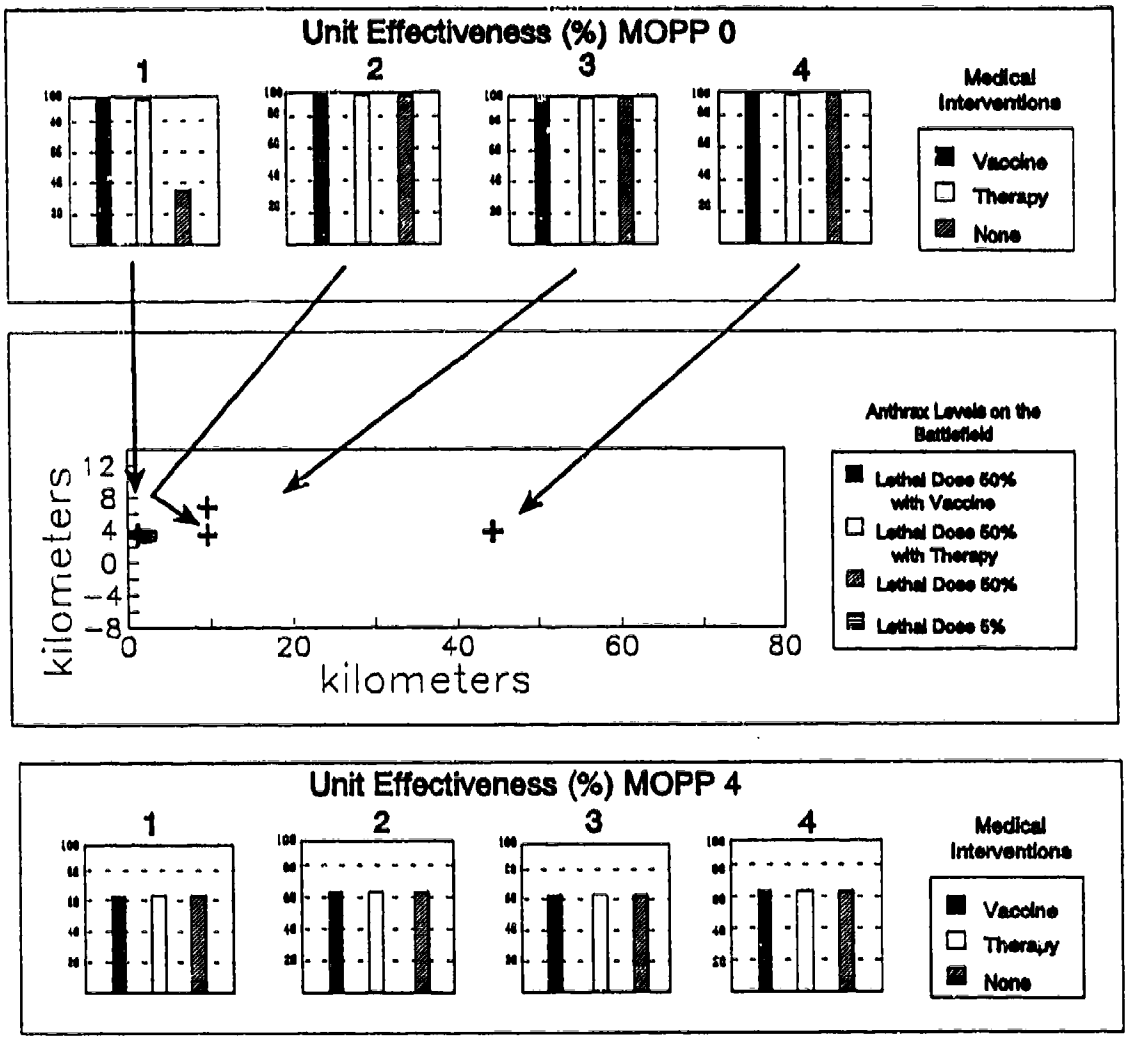

Figure 21. Terrorist Device in Southwest Asia at 1200 Hours: Attack Helicopter Unit Effectiveness with Medical Interventions

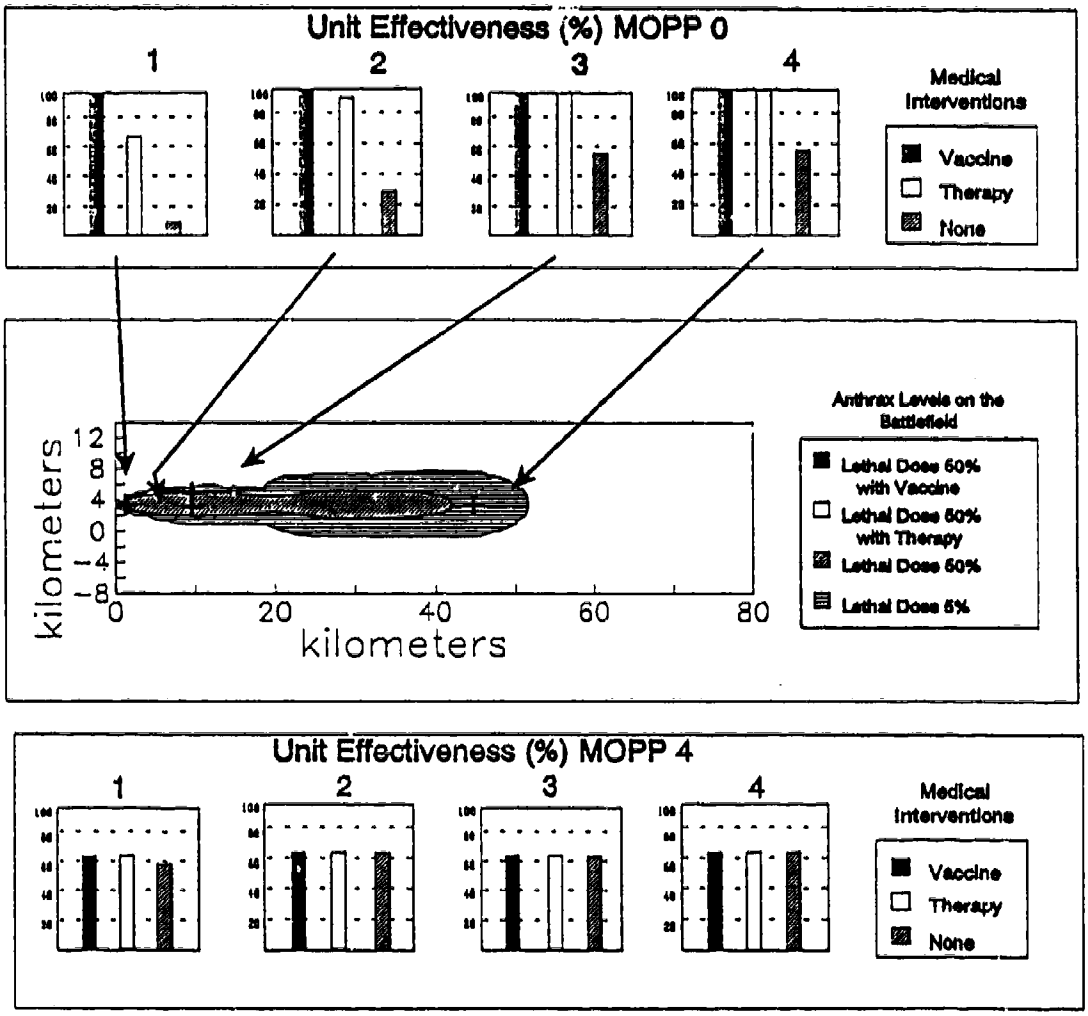

Figure 22. Terrorist Device in Southwest Asia at 1900 Hours: Artillery Unit Effectiveness with Medical Interventions

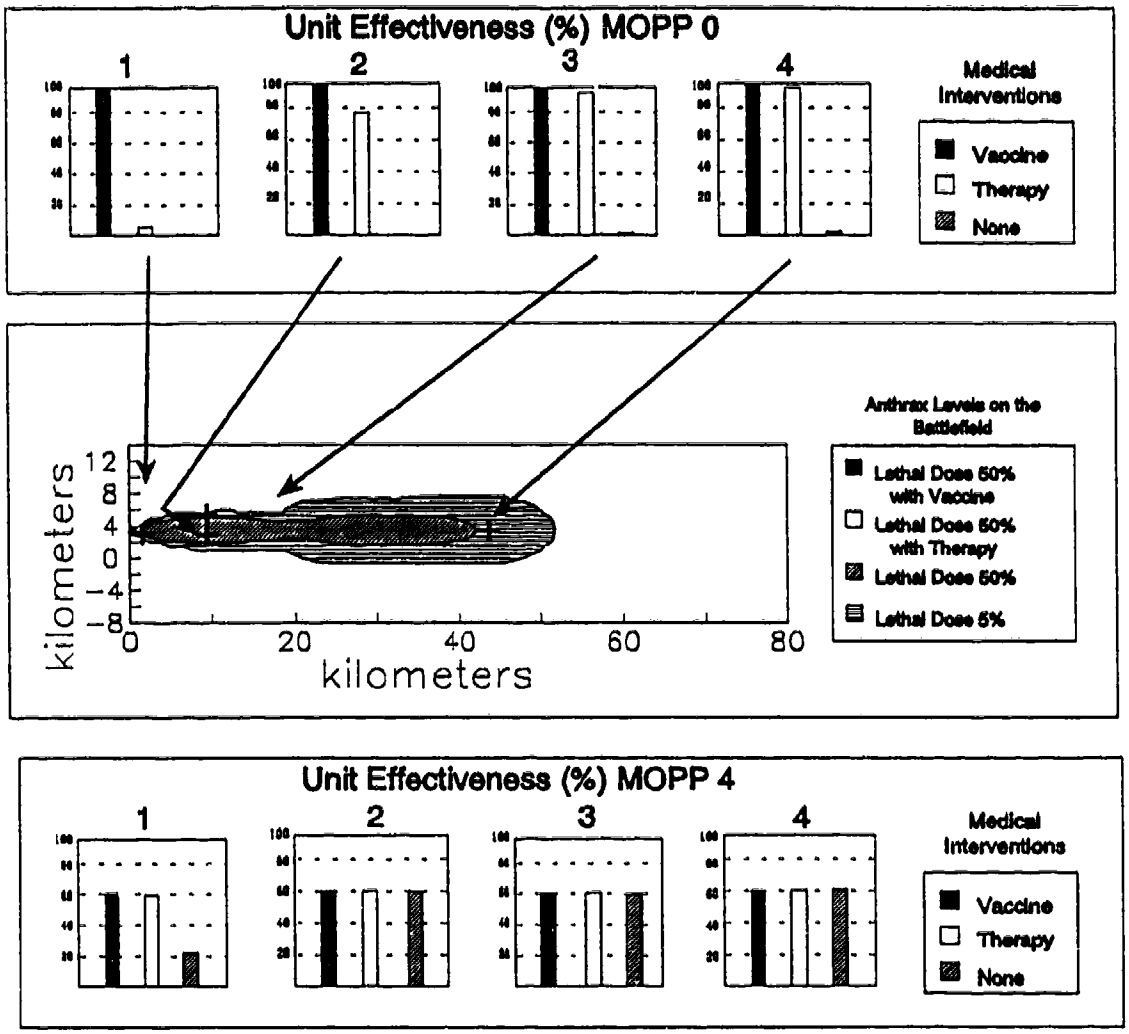

Figure 23. Terrorist Device in Southwest Asia at 1900 Hours: Headquarters Unit Effectiveness with Medical Interventions

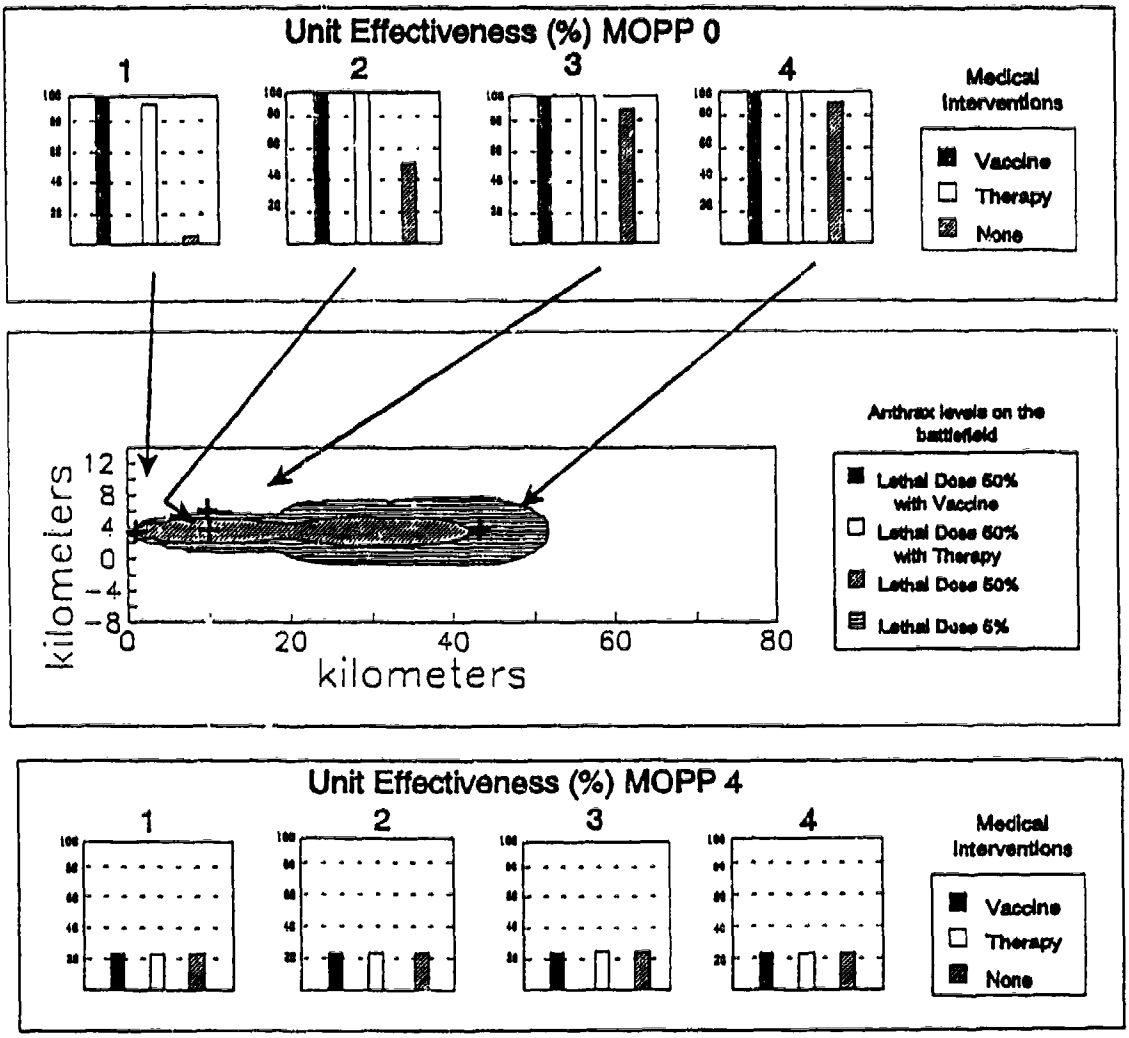

Figure 24. Terrorist Device in Southwest Asia at 1900 Hours: Ammunition Supply Point Unit Effectiveness with Medical Interventions

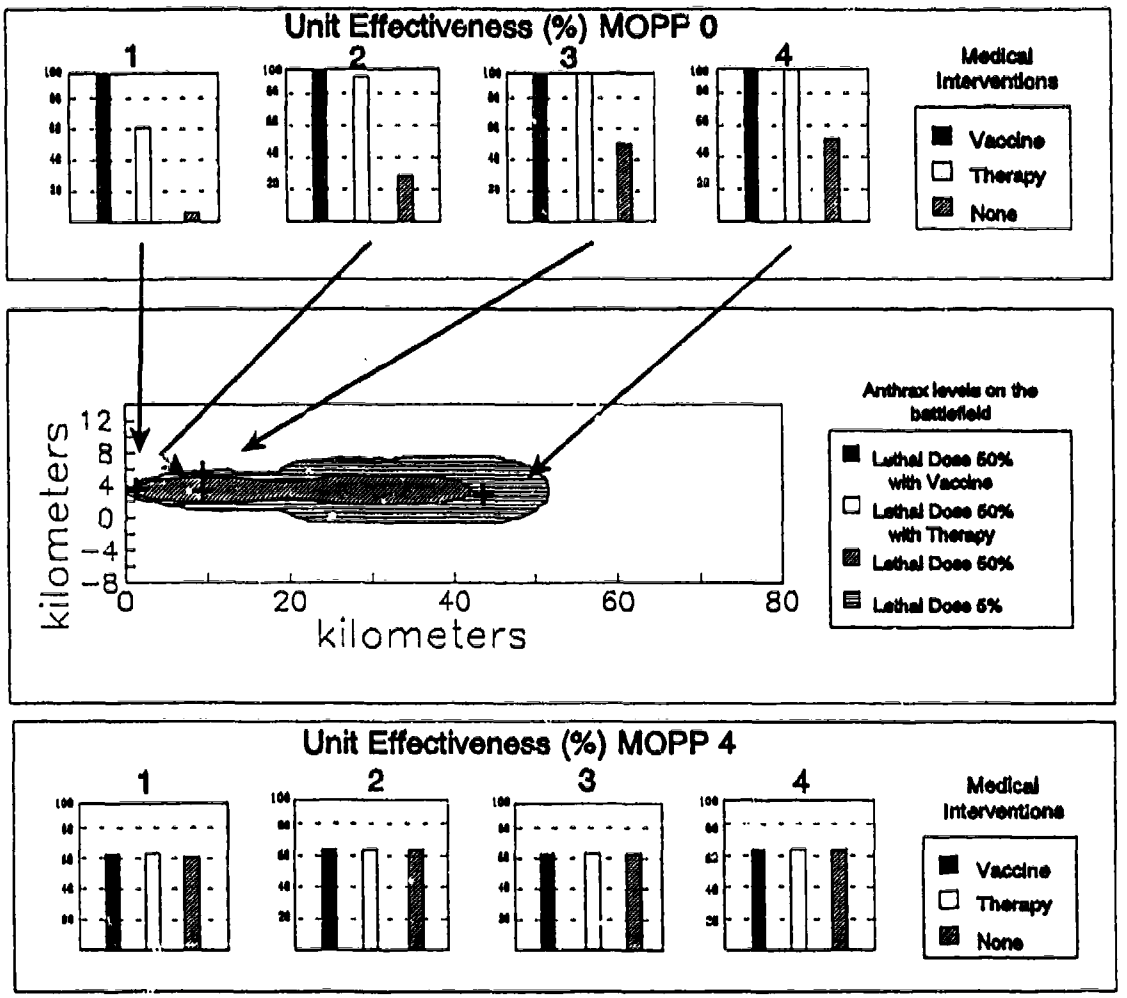

Figure 25. Terrorist Device in Southwest Asia at 1900 Hours: Infantry Anti-Armor Unit Effectiveness with Medical Interventions

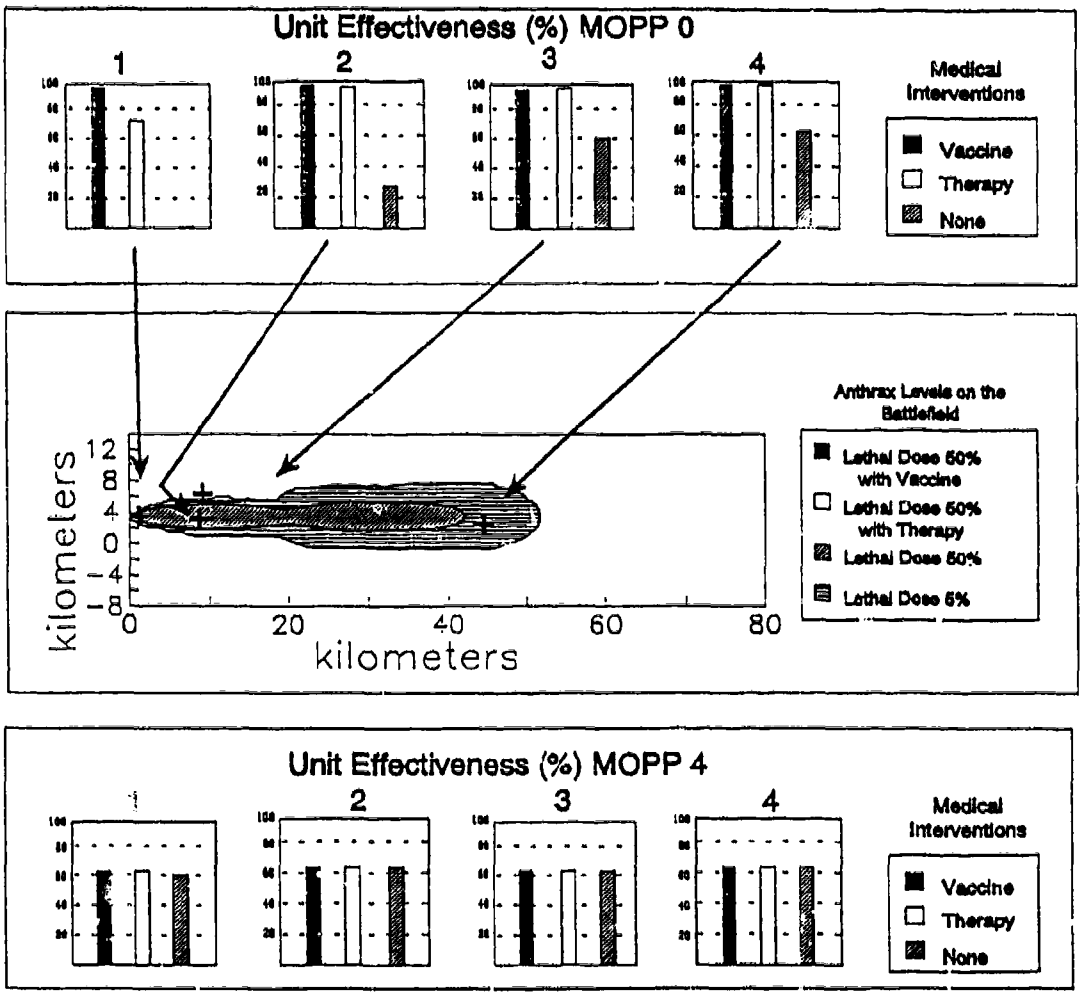

Figure 26. Terrorist Device in Southwest Asia at 1900 Hours: Attack Helicopter Unit Effectiveness with Medical Interventions

5.0 STUDY RESULTS

Study results are depicted using four graphical methods: hazard footprints, unit effectiveness bar charts, spore area coverage charts, and casualty area coverage charts. Each chart highlights important aspects of the study results.

Hazard Footprints

Hazard footprints, used in this section to display the severity of various *B. anthracis* attacks and the effect on units at various locations within the target area, provide a measure for quantifying the effectiveness of medical interventions and protective equipment. It is important to realize that deaths may still occur outside the footprinted area as the transport of spores continues beyond the LD_5 contour (5 percent expected fatalities). The hazard footprints for each weapon delivery system are supplemented with spore area coverage charts for each regional climate and a probability of casualty chart that compares the defensive capabilities of vaccine and antibiotic therapy across the theaters of operation.

Unit Effectiveness

Effects of the *B. anthracis* attacks were measured in terms of unit effectiveness rather than survivors for the purpose of quantifying the military significance of each scenario simulated. Nevertheless, it should be noted for baseline reference that casualty and unit effectiveness figures are not equivalent. For instance, while 50 percent of a unit may survive a biological attack, the unit would not necessarily maintain 50 percent effectiveness.

The difference between Survivor and Unit Effectiveness results is illustrated in three TBM attacks simulated for Southwest Asia (Figures 27-32), first with results shown for survivors, then the same results expressed as unit effectiveness. Note that unit effectiveness levels are generally lower than survival levels, as would be expected, for units operating in MOPP 0. However, while survival rates for units assuming MOPP 4 are high (near 100 percent), unit effectiveness levels hover around 63 percent, a result of performance degradation attributable to the bulkiness of the protective gear donned and the accompanying impairment of the field of vision. A 63 percent unit effectiveness in MOPP 4, then is equivalent to approximately 100 percent survival for personnel in an artillery unit. A dip *below* 63 percent effectiveness for MOPP 4 can therefore be interpreted to indicate a failing of the defensive measure with a resultant loss of lives. Units may have to remain in MOPP 4 for many days until such time that it can be confirmed that there is no longer a threat from *B. anthracis*.

The implication of analysis of the Survivor versus the Unit Effectiveness results is that protective gear, in particular a mask, would provide a high degree of protection against *B.anthracis* attack when used in combination with either vaccine or antibiotic therapy, but at a serious trade-off in unit effectiveness given an 80 percent rule of thumb for measuring operationality. The use of vaccine alone proved as effective as the use of vaccine plus

MOPP 4 in saving lives, except against the intense hazard created by a multi-rocket launcher attack simulated for 0500 and 1900 hours in South Korea (Figures 90 and 92). If only antibiotic therapy were available, the combination of protective equipment and antibiotic therapy could achieve a 63 percent unit effectiveness for all the scenarios simulated if soldiers remained in MOPP 4. MOPP 4 alone, without medical intervention, would still result in loss of life as well as a further loss of unit effectiveness for units exposed to the high levels of *B. anthracis* produced close to the site of impact of the simulated multi-rocket launcher, spray and artillery releases.

A further gleaning from the Survivor comparisons in Figures 27, 29 and 31 is that masking alone, compared to not masking, would provide individuals a much greater chance of survival following a *B. anthracis* attack in the absence of medical intervention. Since the main protection afforded by MOPP 4 against a *B. anthracis* attack is to prevent the inhalation of spores, the results for masking would be equivalent to results for units assuming either MOPP 3 or MOPP 4, since both postures include masking. The disadvantages of masking only as a defense against biological attacks are: (1) the risk of a poor fit, (2) the difficulty in detecting the nature of the attack and the routes of entry thus at risk, (3) delay in detection which can result in exposure through inhalation, and (4) the possibility of lack of detection until symptoms are observed, resulting in mass casualties.

Spore Area Coverage

Spore area coverage results show the peak levels of battlefield hazard in terms of the number of spores per square meter and the number of square meters of the target that contain at least that concentration of spores. The results represent total accumulation after the attack. The usefulness of such charts is in allowing a comparison of the differences in coverage by the time of day of the attack, and also in being able to quantify the extent of the hazard in a standardized way. Thus, attacks simulated for the various weapon delivery systems can more easily be compared for overall hazard potential and peak dosage levels, a task that would be difficult to accomplish simply by looking at the hazard footprints themselves since they are depicted in dosage ranges. In general, spore coverage resulting from 1200 hours releases presented a lesser hazard, both in overall extent of the coverage and peak concentrations, than the 0500 or 1900 hours releases, due in part to the greater instability of the atmosphere at this time of day and also to the effect of UV light in accelerating the decay rate.

Casualty Area Coverage

Finally, casualty area coverage charts were used to compare each weapon system across the theaters of operation for three medical intervention levels: (1) no therapy, (2) vaccine, and (3) antibiotic therapy. "Casualty area" is not a specific area of the target but a measure of probability over the entire target area. Probability of casualty percentages are different than footprint results because units occupy a finite fraction of the total footprint area used to calculate casualty area coverage. Results are shown for a unit with MOPP 0. Note that 1,000,000 m^2 is equal to 1 km^2 and that one order of magnitude reduction in casualty area coverage represents a 90 percent reduction in casualty probability.

The following specific results of the study are organized by weapon systems and attack scenarios.

5.1 TACTICAL BALLISTIC MISSILE WITH *B. ANTHRACIS* FILLED SUBMUNITIONS

A release of approximately 2,000 submunitions, each containing just under 39 grams of *B. anthracis,* was simulated for three times of day in four different climates. The submunitions release from the tactical ballistic missile (TBM) was executed at an altitude of approximately 15 km, impacting an area of about 3,000 meters in diameter.

The TBM attack scenarios (Figures 27-41) for the different climates and release times produced a hazard footprint ranging from 60 to 140 km downwind and a crosswind hazard extending out to approximately 25 km at the widest point. Transport time, or the time it would take for the hazard cloud to clear the target area, would vary from 7½-17½ hours, depending on the time of day.

Figures 28, 30, and 31 depict the percentage of unit effectiveness for four units following a TBM attack in Southwest Asia at 0500, 1200, and 1900 hours. In order to show the relationship between survivors and unit effectiveness, Figures 27, 29, and 31 depict the percentage of survivors for corresponding attack simulations. In each pair of figures, note how closely the percentage of survivors equates to unit effectiveness for an artillery unit in MOPP 0. Recall that artillery units have a somewhat linear relationship between personnel losses and unit effectiveness. The main conclusion here, however, is that while protective gear would be very successful in achieving survivability, it induces a degradation in unit effectiveness to 63 percent that could be avoided through the use of either predeployment vaccination or antibiotic therapy begun the first day of the attack. (Recall that the decline to 63 percent unit effectiveness is characteristic for an artillery unit, the target simulated throughout the footprints in the Study Results section.) Another factor to be considered for both individual survival and unit effectiveness is that without masking in advance of a biological attack, soldiers with no medical protection would be highly vulnerable, resulting in both large losses of life as well as a severe decline in military capability. Even soldiers with antibiotic therapy would be at risk in the event of a covert *B. anthracis* attack, since masking *plus* antibiotic therapy would be required to prevent casualties.

Across the four theaters of operation, the vaccine would be expected to maintain 100 percent unit effectiveness against the simulated TBM attack for MOPP 0. The antibiotic therapy would be less effective in several scenarios, notably the 0500 and 1900 hours releases in the South Korean climate (Figures 39 and 41) and the 0500 release time in the Southwest Asian and Central European climates (Figures 28 and 36). Here, a considerable fraction of the hazard footprint contained areas where the contamination levels could overwhelm the prompt use of antibiotic therapy, resulting in greater than 50 percent casualties. For all other climates and release times and in South Korea for the 1200 hours release, prompt administration of antibiotic therapy was shown to be highly effective in preserving life assuming, of course, that the *B. anthracis* attack would be detected within the first day of the attack so that antibiotic

therapy could be started in time to be effective. Note, however, that if a release of submunitions resulted in a smaller impact area either as a result of lower release altitude or a chance combination of environmental conditions, the increased intensity of the attack could overwhelm the protective factor afforded by the antibiotic therapy. In other words, the simulated TBM scenarios tested the limits of the protective ratio of antibiotic therapy so that any increase in the hazard level, such as that produced by time of day or meteorological conditions, could result in a large decrease in the beneficial effects of antibiotic therapy; in contrast, predeployment vaccine was not challenged by any of the scenarios and, therefore, presented a greater margin of safety for defensive capabilities against a TBM attack.

Note the generally lower concentration levels of agent in the footprints for the Southeast Asia scenarios (Figures 33-35) as evidenced by the narrow contours for the LD_{50} levels either with or without therapy. This can be attributed to the fact that the surface modeled in Southeast Asia was forested, and the treetops create a much rougher surface to air flow than sand or barren ground by approximately two orders of magnitude. This increased roughness decreases the relative stability of the atmosphere and reduces the effectiveness of the agent dissemination.

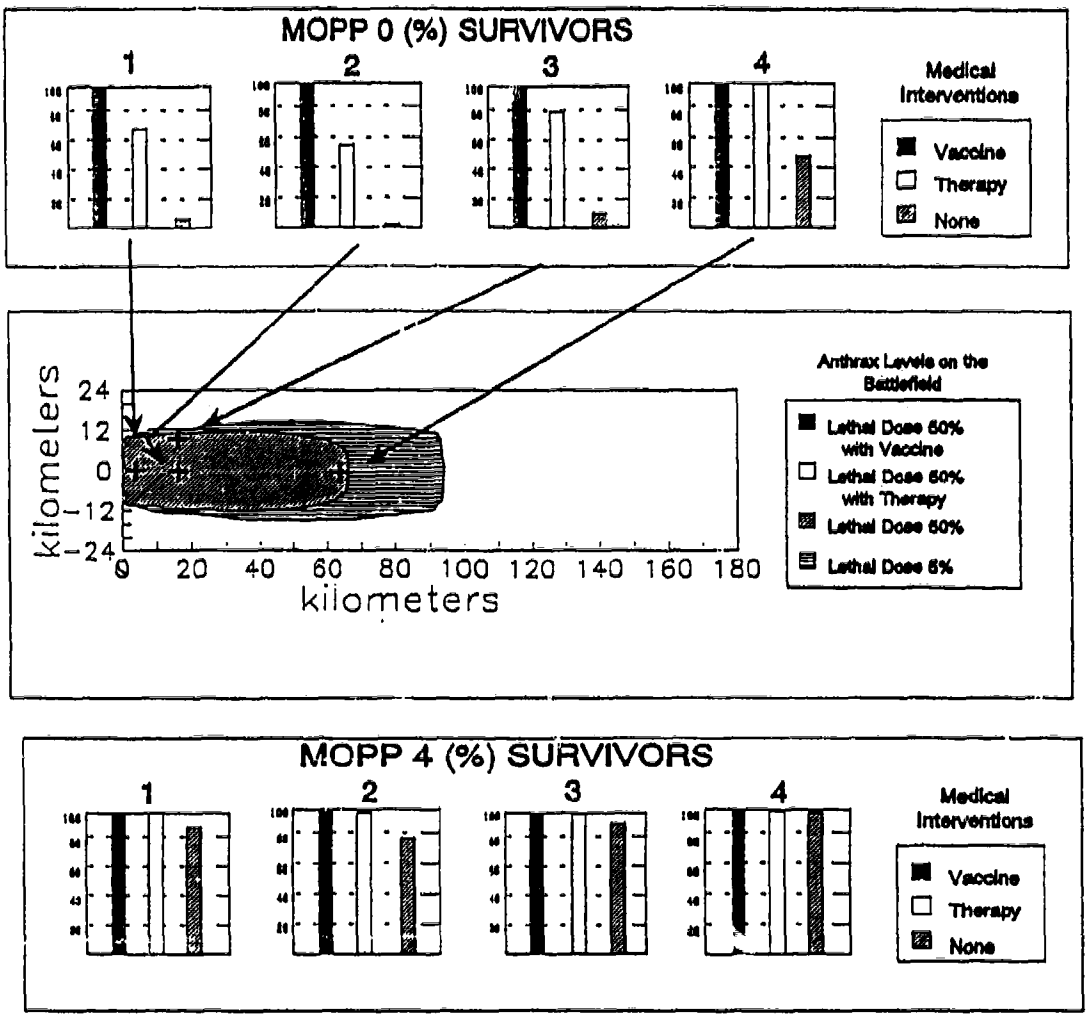

Figure 27. TBM with Submunitions in Southwest Asia at 0500 Hours: Artillery Unit % Survivors with Medical Interventions

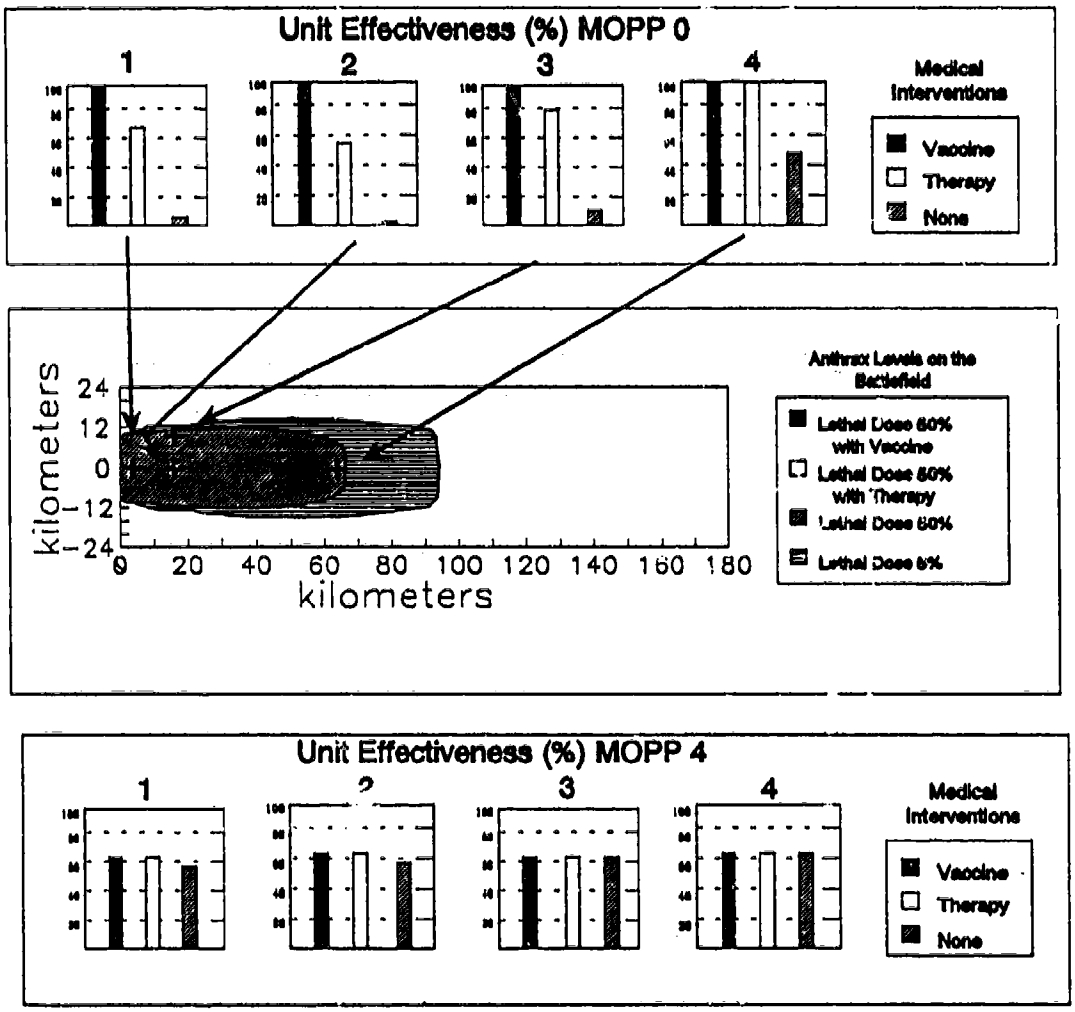

Figure 28. TBM with Submunitions in Southwest Asia at 0500 Hours: Artillery Unit Effectiveness with Medical Interventions

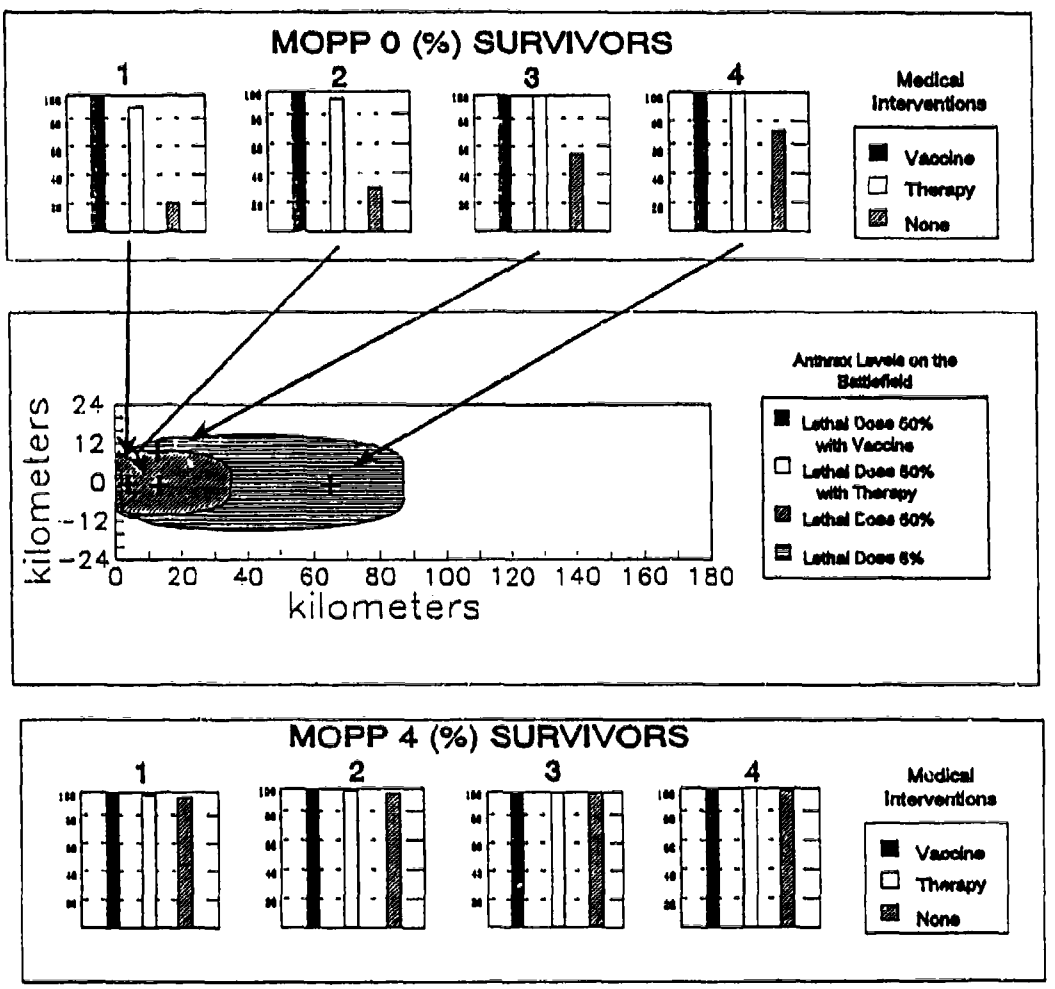

Figure 29. TBM with Submunitions in Southwest Asia at 1200 Hours: Artillery Unit % Survivors with Medical Interventions

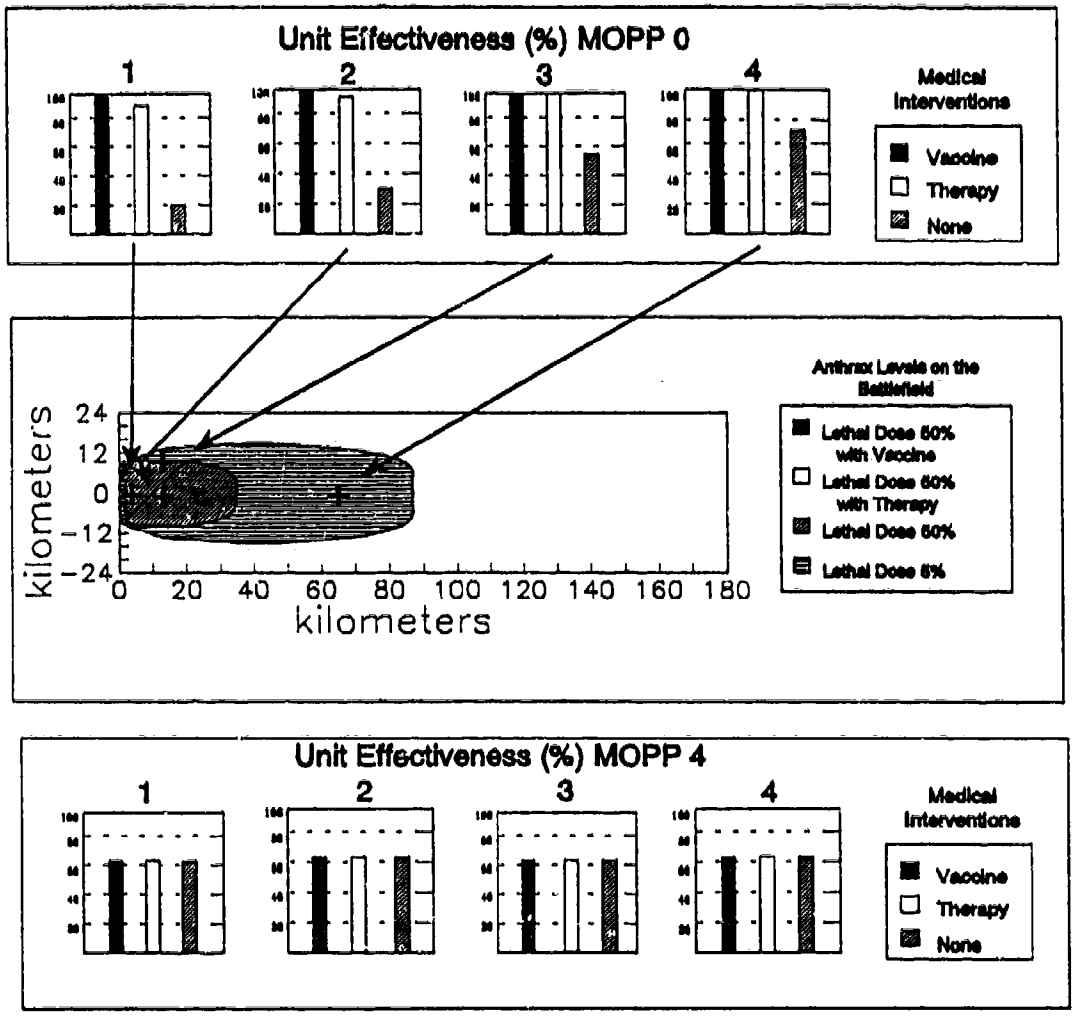

Figure 30. TBM with Submunitions in Southwest Asia at 1200 Hours: Artillery Unit Effectiveness with Medical Interventions

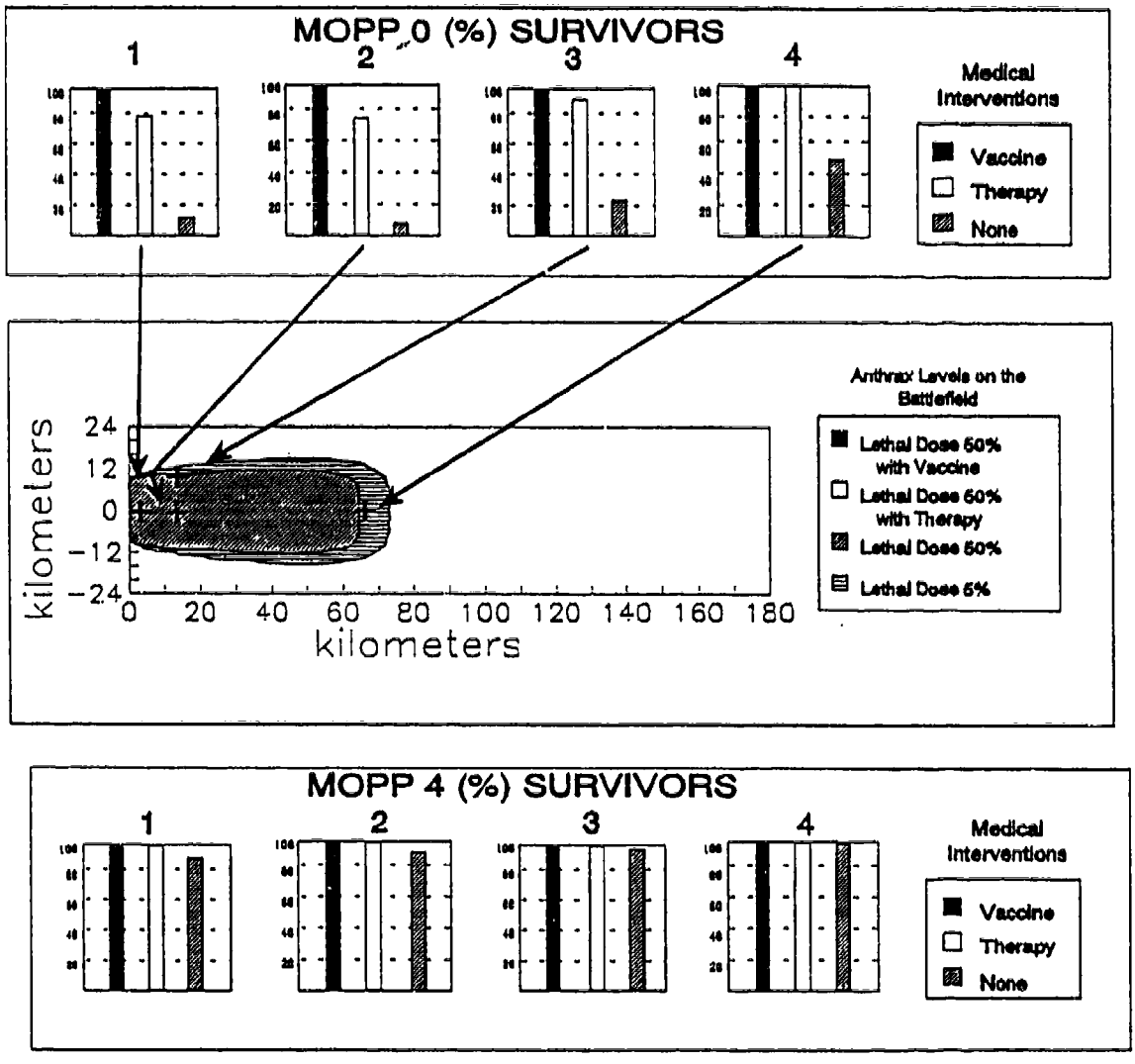

Figure 31. TBM with Submunitions in Southwest Asia at 1900 Hours: Artillery Unit % Survivors with Medical Interventions

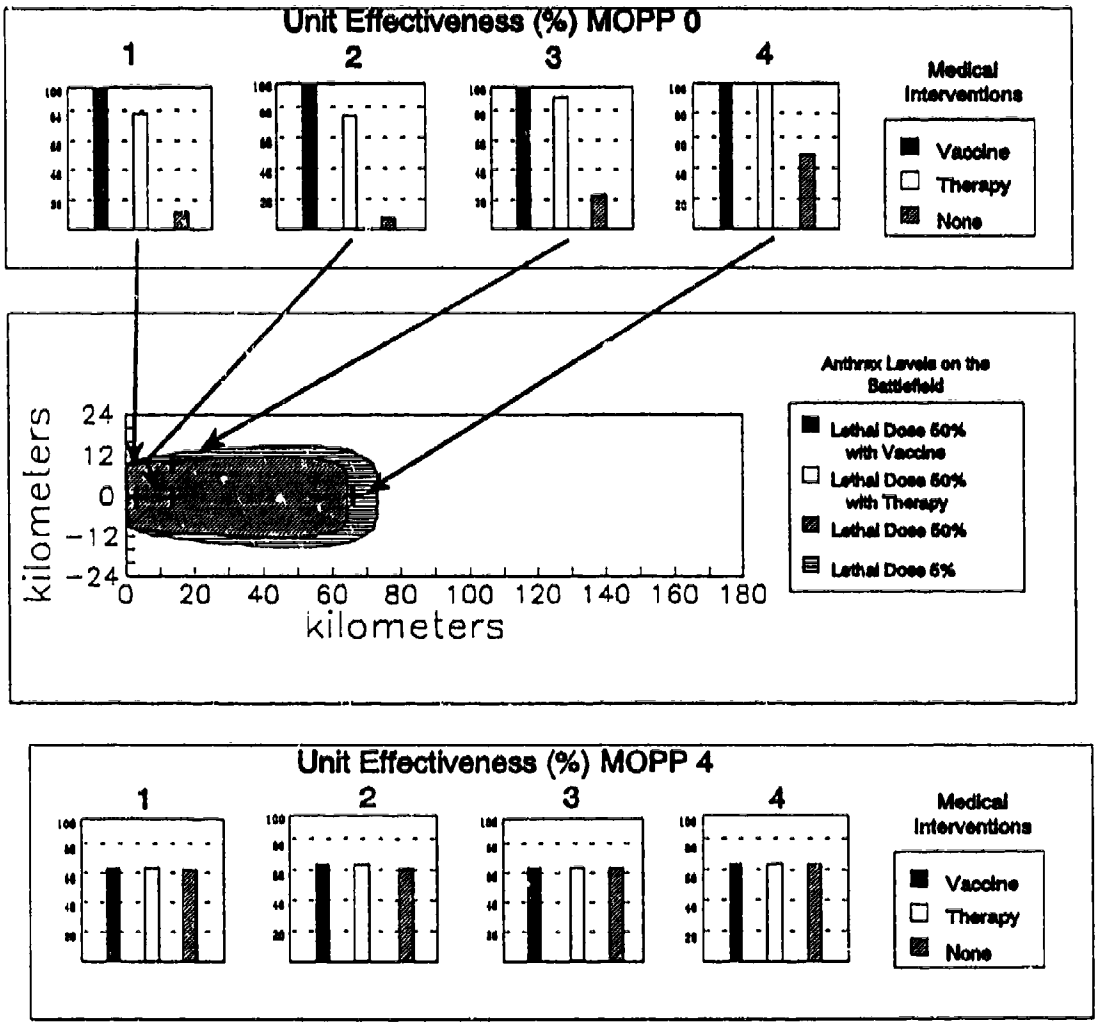

Figure 32. TBM with Submunitions in Southwest Asia at 1900 Hours: Artillery Unit Effectiveness with Medical Interventions

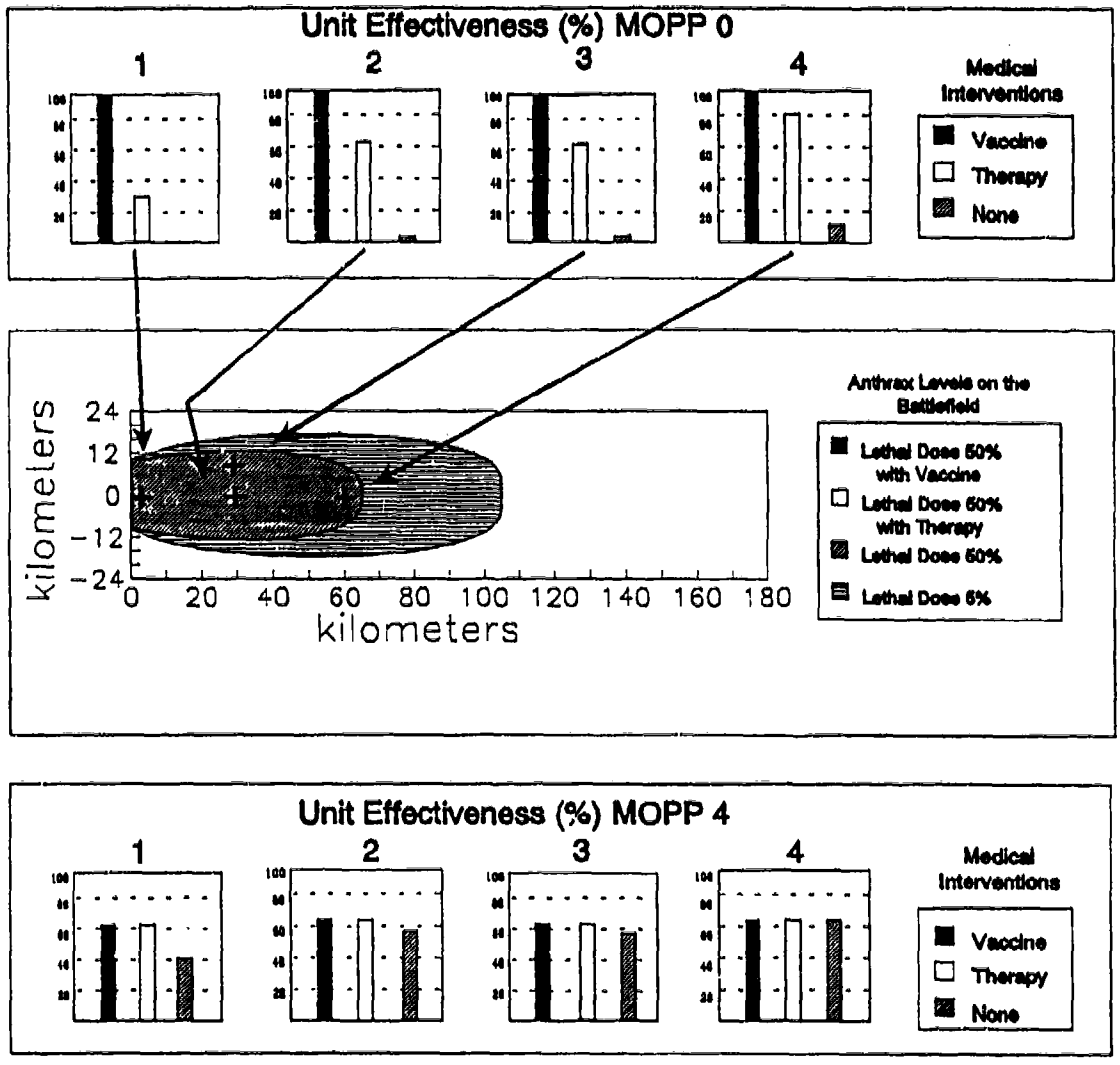

Figure 33. TBM with Submunitions in Southeast Asia at 0500 Hours: Artillery Unit Effectiveness with Medical Interventions

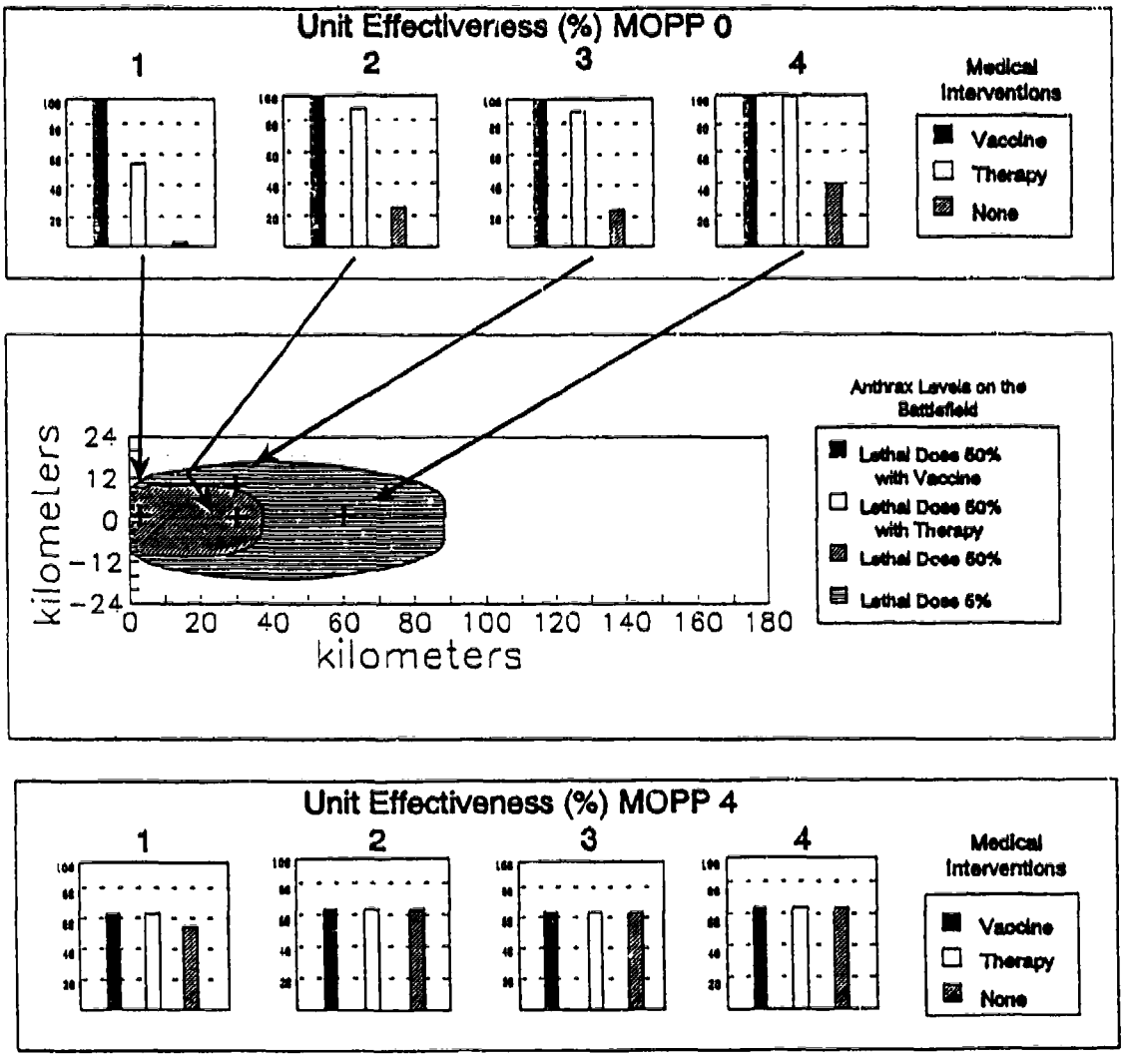

Figure 34. TBM with Submunitions in Southeast Asia at 1200 Hours: Artillery Unit Effectiveness with Medical Interventions

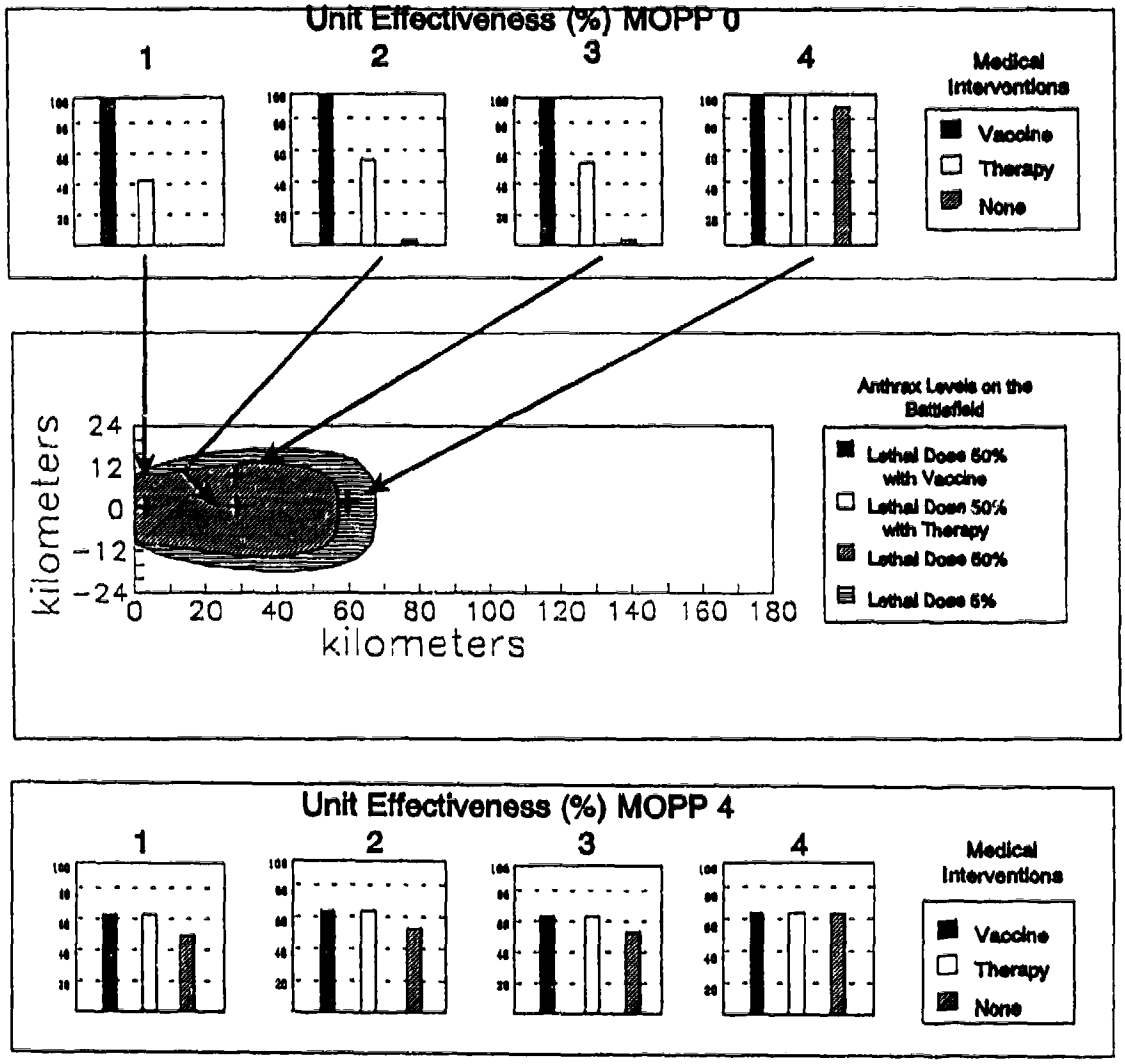

Figure 35. TBM with Submunitions in Southeast Asia at 1900 Hours: Artillery Unit Effectiveness with Medical Interventions

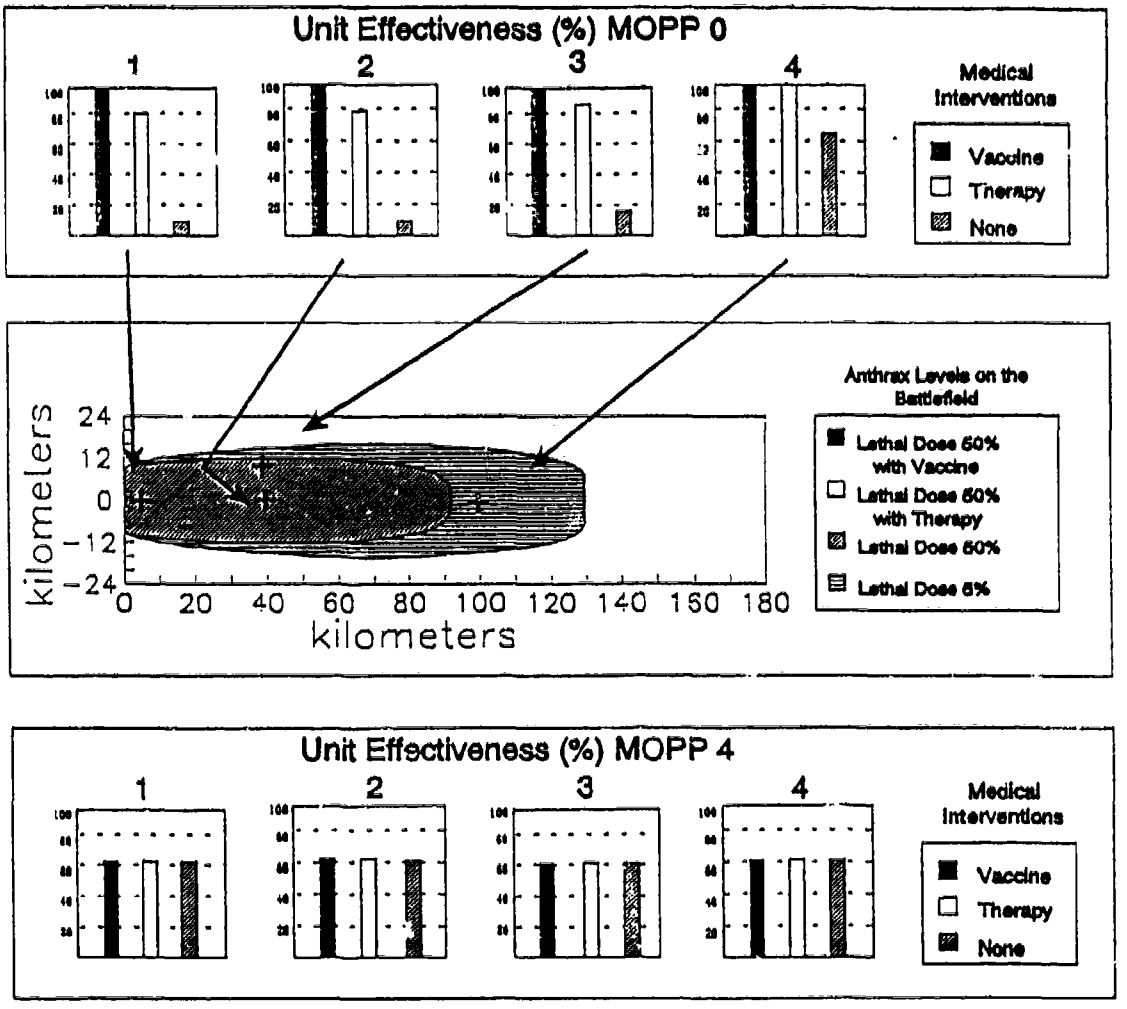

Figure 36. TBM with Submunitions in Central Europe at 0500 Hours: Artillery Unit Effectiveness with Medical Interventions

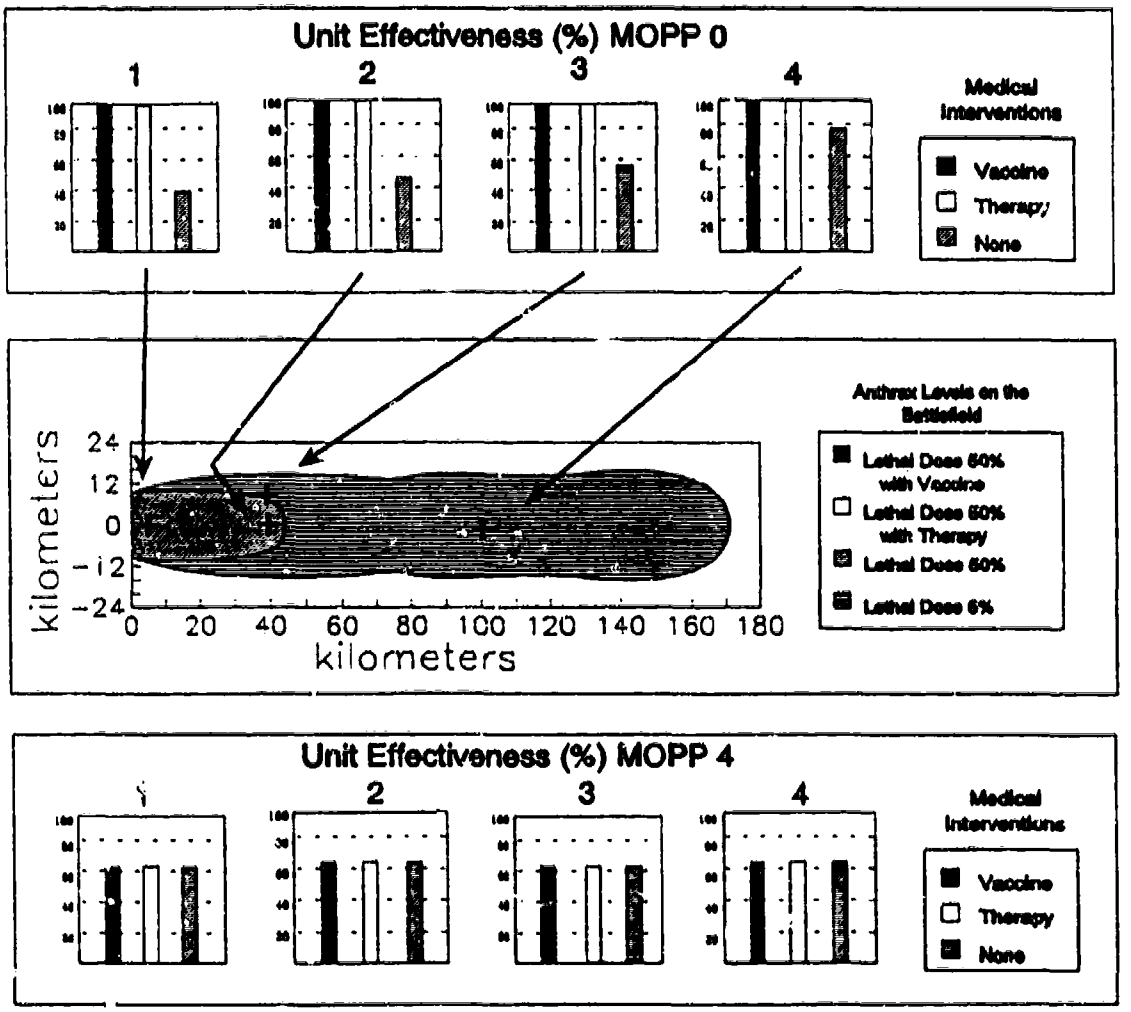

Figure 37. TBM with Submunitions in Central Europe at 1200 Hours: Artillery Unit Effectiveness with Medical Interventions

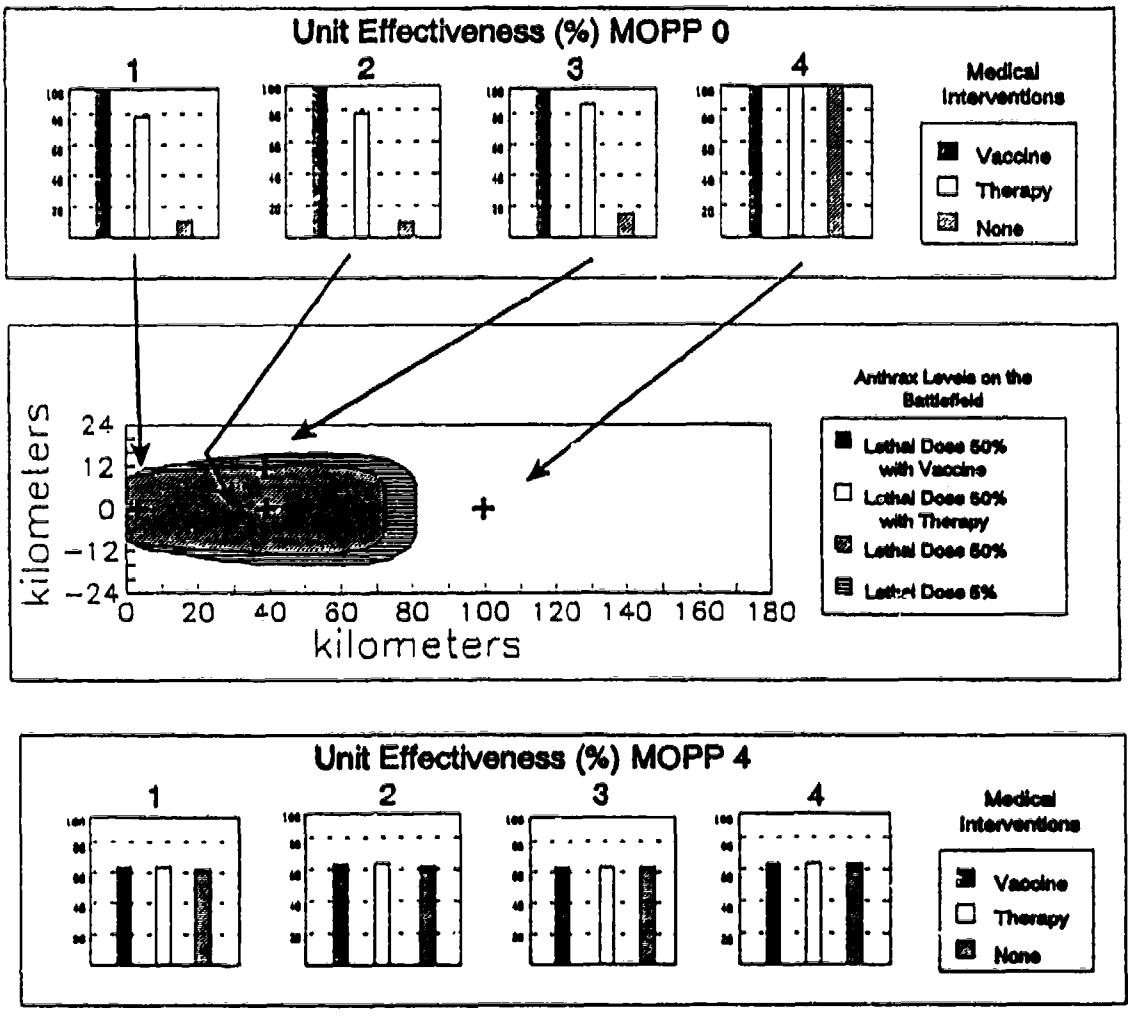

Figure 38. TBM with Submunitions in Central Europe at 1900 Hours: Artillery Unit Effectiveness with Medical Interventions

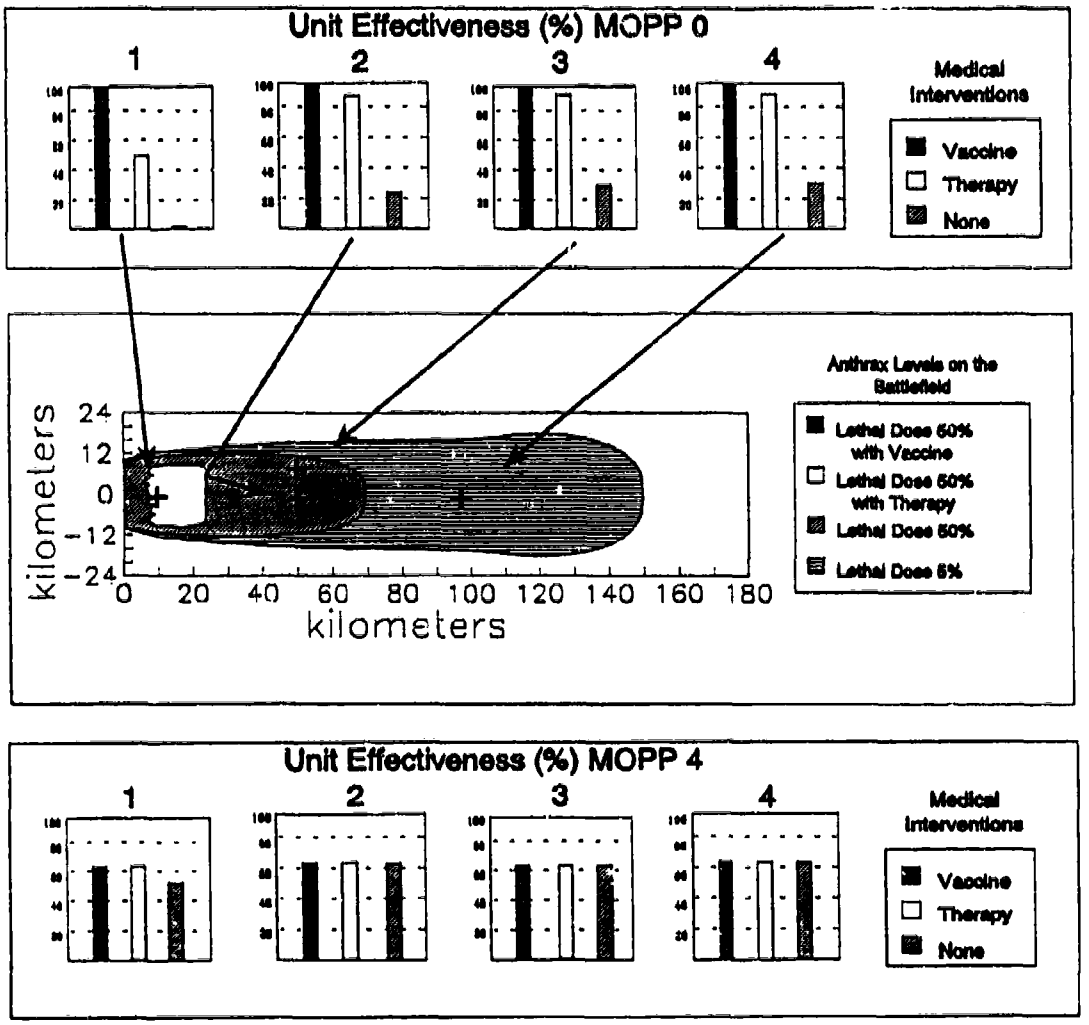

Figure 39. TBM with Submunitions in South Korea at 0500 Hours: Artillery Unit Effectiveness with Medical Interventions

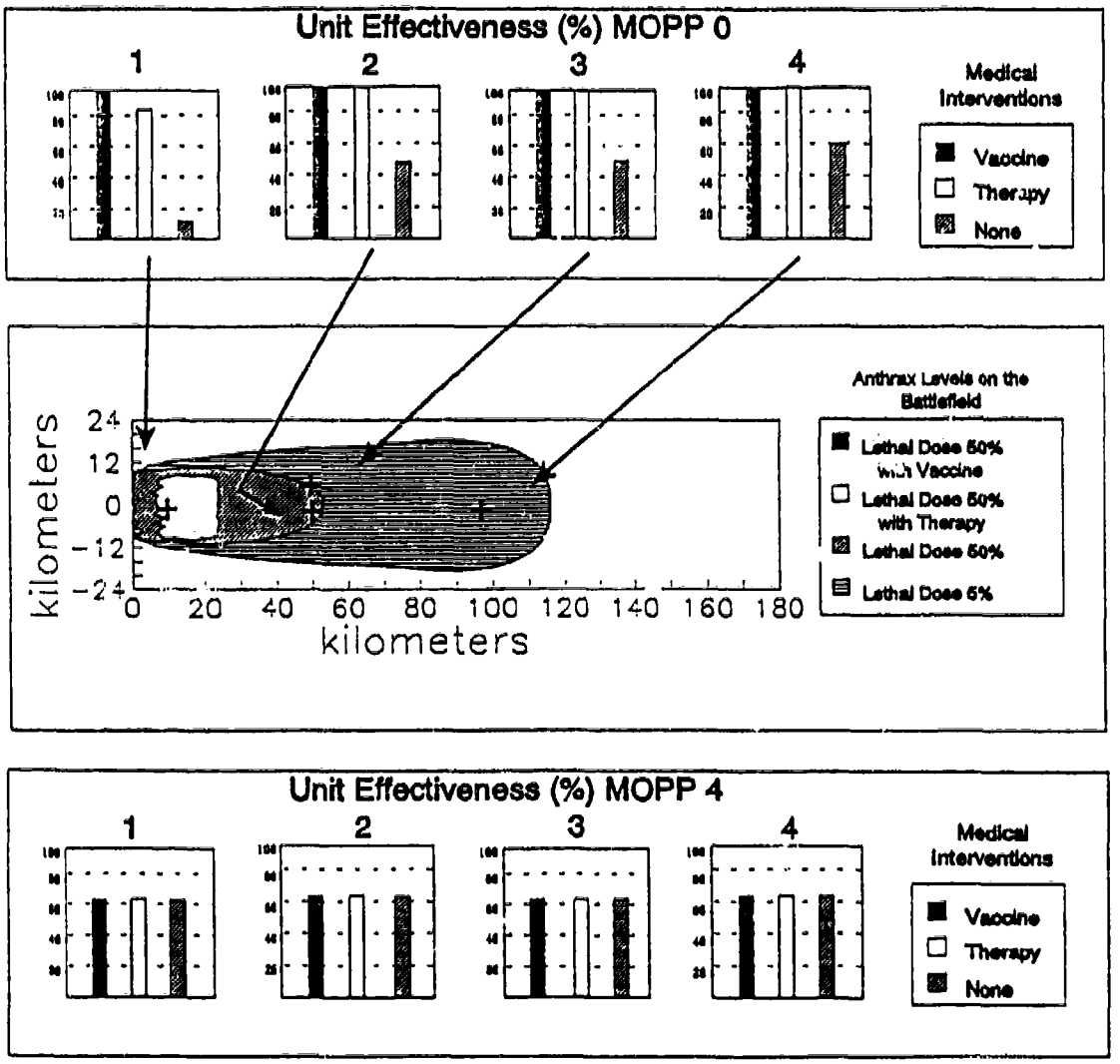

Figure 40. TBM with Submunitions in South Korea at 1200 Hours: Artillery Unit Effectiveness with Medical Interventions

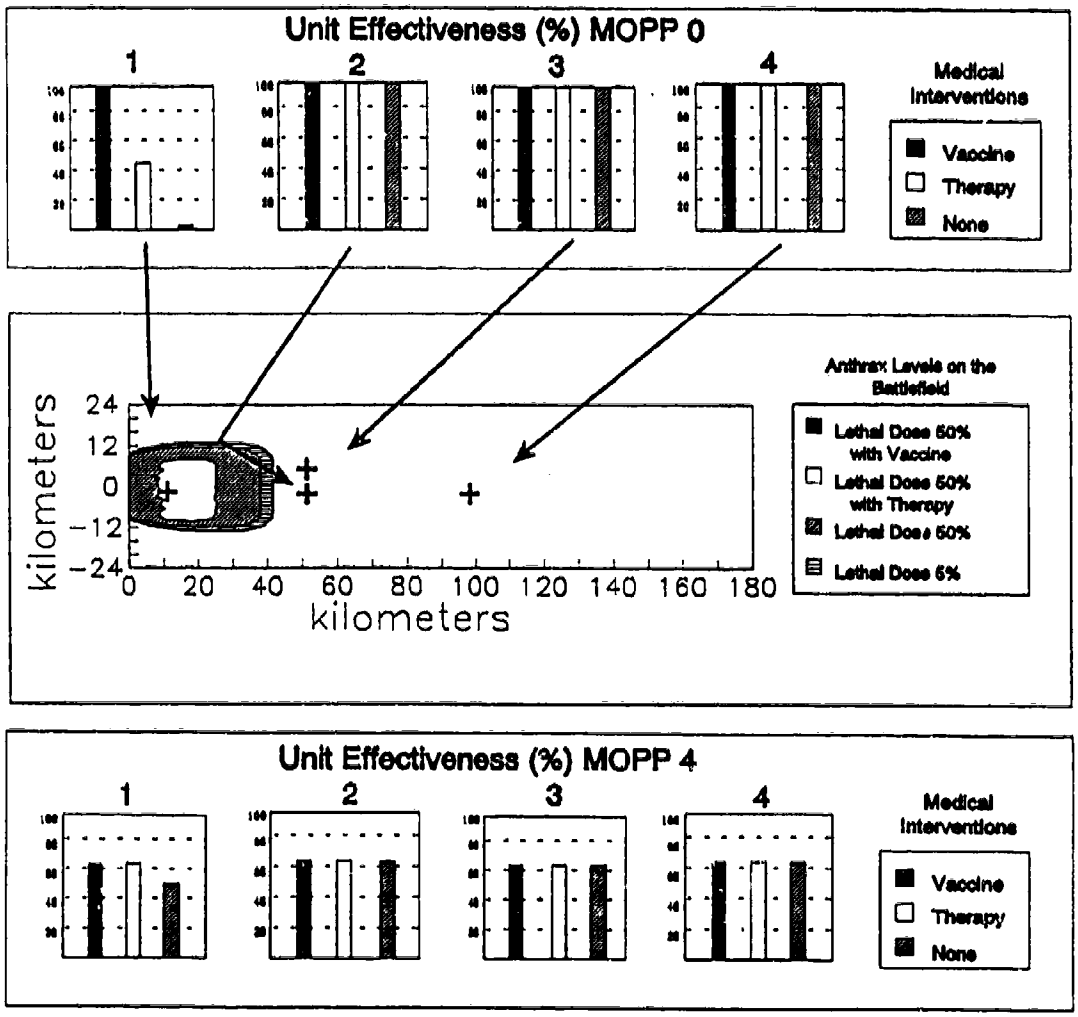

Figure 41. TBM with Submunitions in South Korea at 1900 Hours: Artillery Unit Effectiveness with Medical Interventions

Figures 42-45 depict the spore area coverage potential of a TBM attack for each of the geographical regions for releases at 0500, 1200, and 1900 hours. Note how consistent the TBM attack would be in terms of hazard potential across the regional climates and times of release: the peak number of spores achievable in an area is well within one order of magnitude, and well over 1,000 km² would be covered by at least 8,000-10,000 spores per square meter.

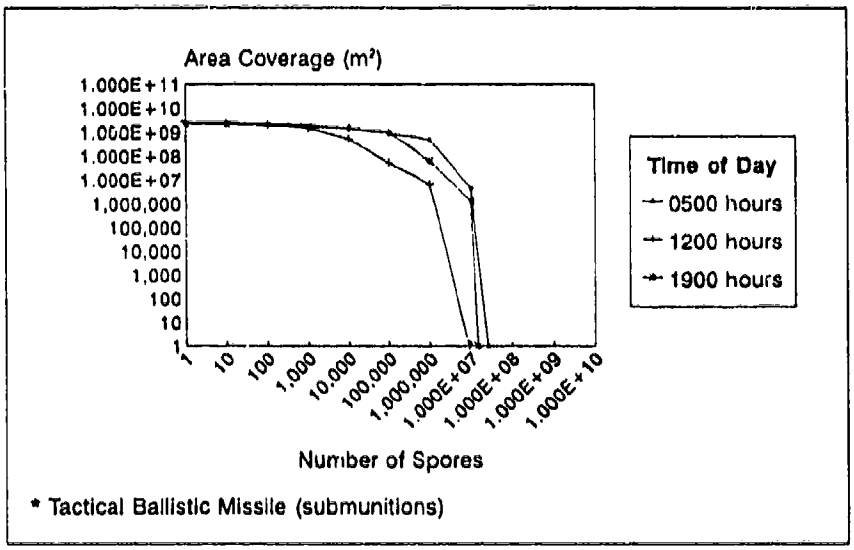

Figure 42. TBM in Southwest Asia: Spore Area Coverage

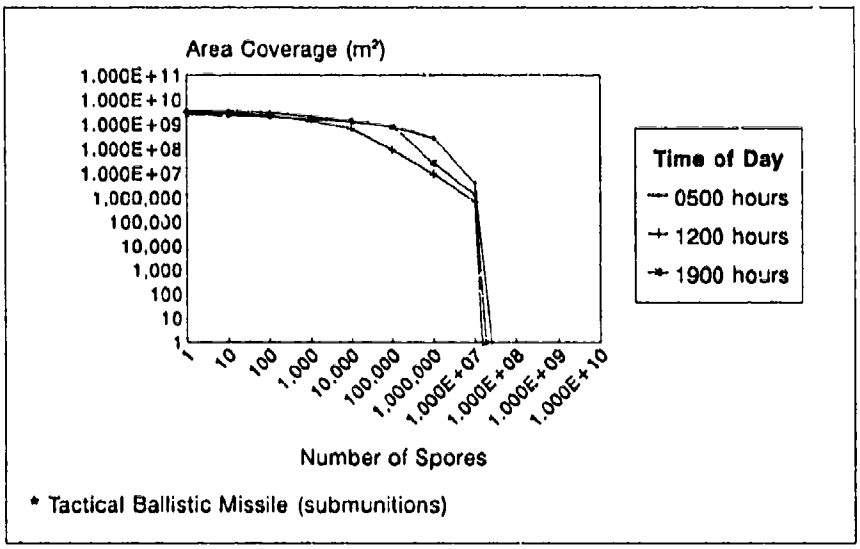

Figure 43. TBM in Southeast Asia: Spore Area Coverage

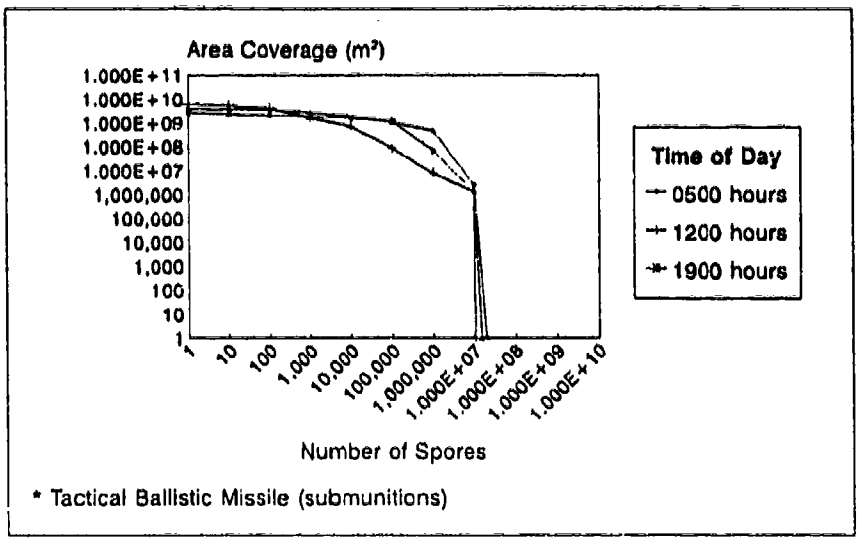

Figure 44. TBM in Central Europe: Spore Area Coverage

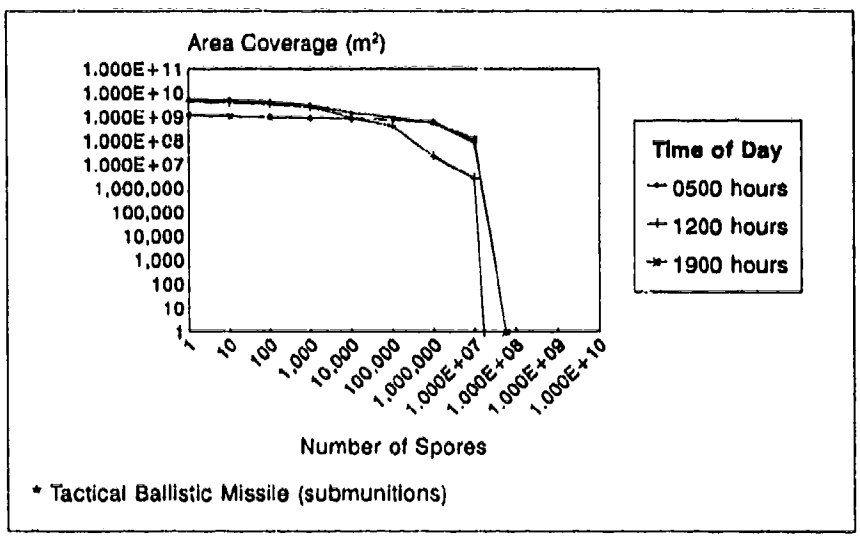

Figure 45. TBM in South Korea: Spore Area Coverage

Another method for assessing the effectiveness of the medical products is casualty area coverage. Figure 46 compares the relative effectiveness of TBM attacks across the four regional areas for three times of day. As noted earlier, the variability in casualty area coverage is a function of the wind speed profile for each region and the atmospheric stability at the time of release. For example, atmospheric conditions for the 1200 hours releases ranged from very unstable for Southwest Asia to slightly unstable for South Korea. Noon is also the time of day experiencing the highest average wind speeds and agent decay due to UV radiation. The action of these meteorological conditions is to lower concentrations of spores and therefore lessen probability of casualties. On the other hand, the 0500 and 1900 hours releases would occur during neutral or slightly stable conditions when wind speeds are

typically lower -- a time of day more conducive to effective dissemination. As can be seen in Figure 46, casualty area coverage without medical interventions would be well within an order of magnitude for all regions and times of release with the equivalent of approximately 1,000 km² receiving a lethal dosage. The vaccine would achieve a reduction in the TBM's casualty area coverage potential of approximately three to four orders of magnitude. More specifically, even in the South Korean climate, the vaccine would reduce the probability of casualty to approximately 1 km² for the 0500 and 1900 hours releases and to approximately 0.01 km² for the 1200 hours release. Antibiotic therapy, in comparison, only reduces casualty area coverage *at best* by one order of magnitude (Southwest Asia).

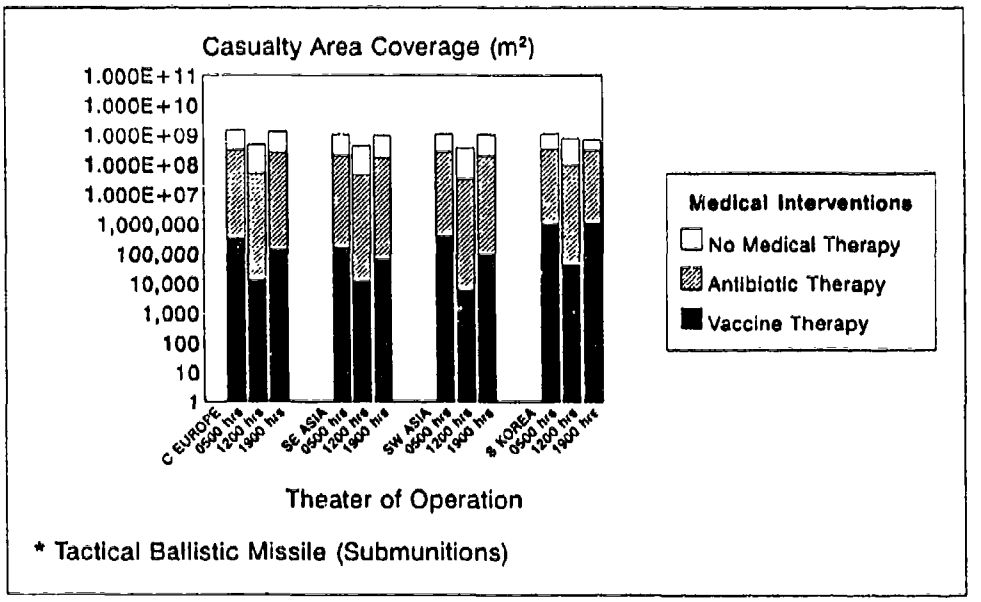

Figure 46. TBM: Casualty Area Coverage

5.2 TERRORIST DEVICE FILLED WITH *B. ANTHRACIS*

The terrorist device was modeled with a 5 kg payload of dry *B. anthracis* disseminated by an explosive charge. The technology of the device is simple, but it is unlikely that a terrorist group would be able to generate the freeze dried product that was chosen as the fill. The freeze drying process would dictate that the material would probably have originated from a sponsor state. It is possible, however, to generate similar results using a liquid *B. anthracis* fill. Liquid *B. anthracis* can be produced by a terrorist group independently from state sponsorship. Liquid *B. anthracis* is not only easier to produce than the dry product, it is much safer to handle and does not require the use of protective equipment and masks for the production process.

Hazard footprints (Figures 47-58) show that even the small quantity of agent disseminated by this system can extend a considerable distance downwind. The footprints for the 0500 and 1900 hours releases roughly approximate 3 to 5 hours of transport while the smaller footprints of the 1200 hours releases approximate 1 to 2 hours of transport. Transport time is the time it takes for the hazard cloud to clear the target area. Of course, the transport of the spores continues beyond these footprint dimensions, but the concentration and dosage is below the LD_5 level chosen to bound the footprint area.

One of the more striking aspects of the terrorist device scenario is its exceptional effectiveness against unprotected personnel. Although labeled as a terrorist device, it could be employed by special forces personnel very effectively. As can be seen from the footprints, the device could potentially achieve LD_{50} levels of hazard 20 to 40 km in length with crosswind widths of 3 to 5 km for releases at 0500 and 1900 hours. The 1200 hours releases would be the least effective due to unstable atmospheric conditions prevailing at noontime, particularly in Southwest Asia.

The implications for unit effectiveness following an attack with the terrorist device simulated are severe. Without the medical interventions of vaccine or antibiotic therapy, the unit effectiveness of an artillery unit in MOPP 0 could easily be degraded below 30 percent for all regional climates for 0500 and 1900 hours releases. In fact, there is a wide window of opportunity for covert release in the hours of darkness between 1900 and 0500 hours. Since dosage is a product of time and agent concentration, the closer the device is activated to the targeted unit, the greater the concentration and the quicker that the lethal dose level could be achieved. For an unprepared unit (MOPP 0), even a brief period of exposure before masking could potentially produce lethal infections. As seen in the unit effectiveness charts, vaccination of personnel prior to deployment could completely eliminate this covert threat. While antibiotic therapy could be expected to maintain unit effectiveness above 80 percent in most of the scenarios, there are environmental conditions such as those of the South Korean winter climate that could enable a 5 kg terrorist device to break the protective value of antibiotic therapy (Figures 56 and 58). Additionally, the time required for diagnosis of infection with *B. anthracis* is critical to the therapeutic value of antibiotics -- a considerable uncertainty given a covert attack.

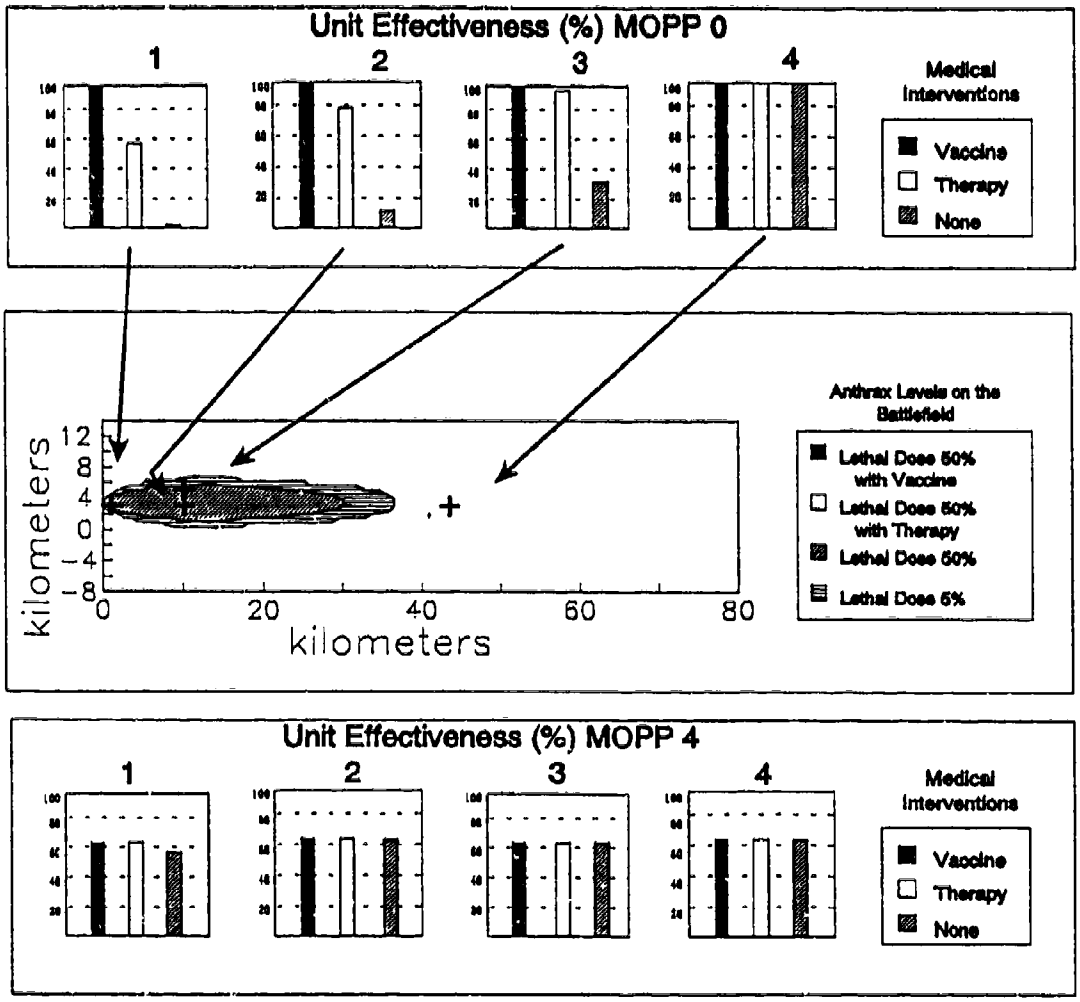

Figure 47. Terrorist Device in Southwest Asia at 0500 Hours: Artillery Unit Effectiveness with Medical Interventions

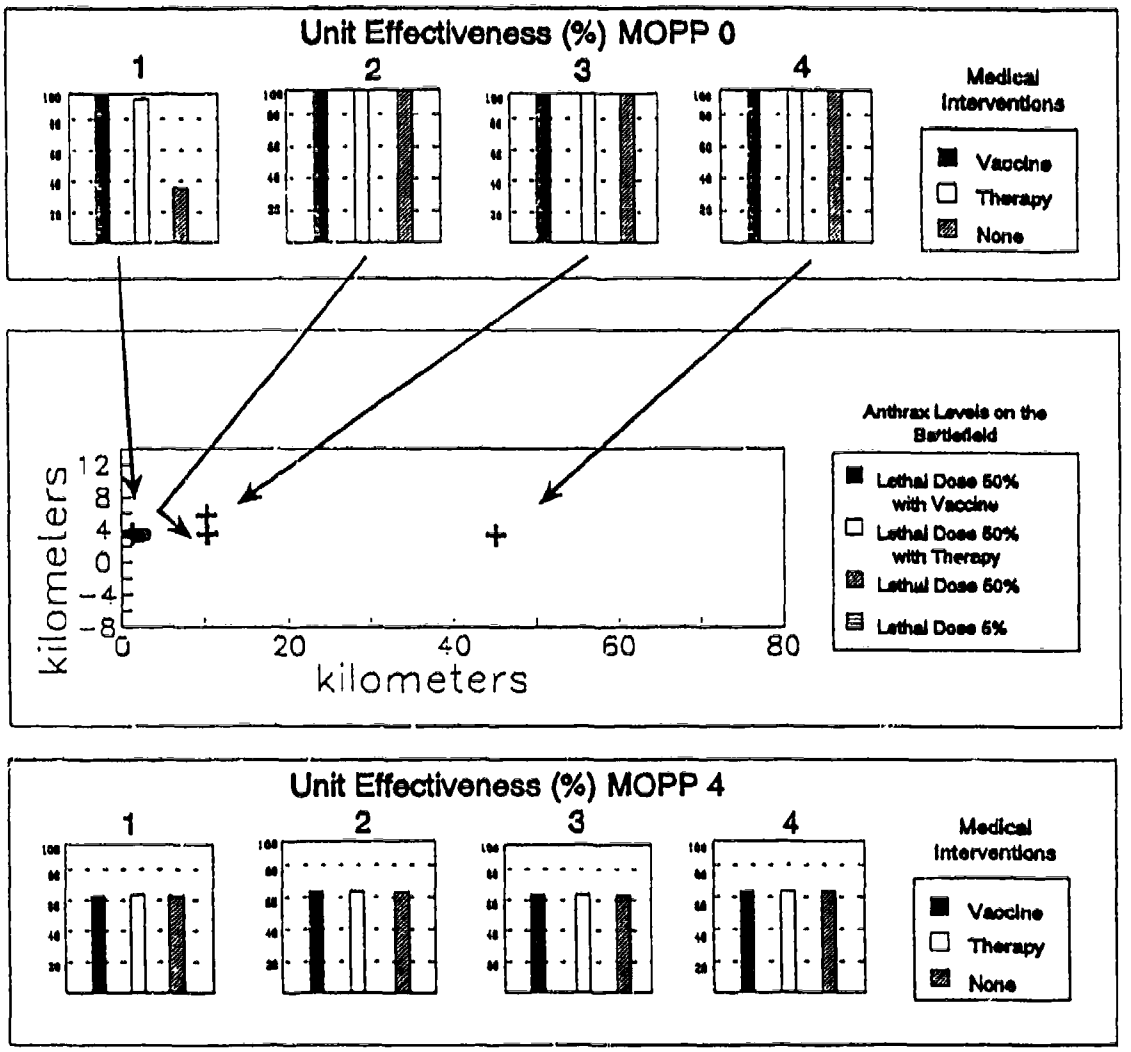

Figure 48. Terrorist Device in Southwest Asia at 1200 Hours: Artillery Unit Effectiveness with Medical Interventions

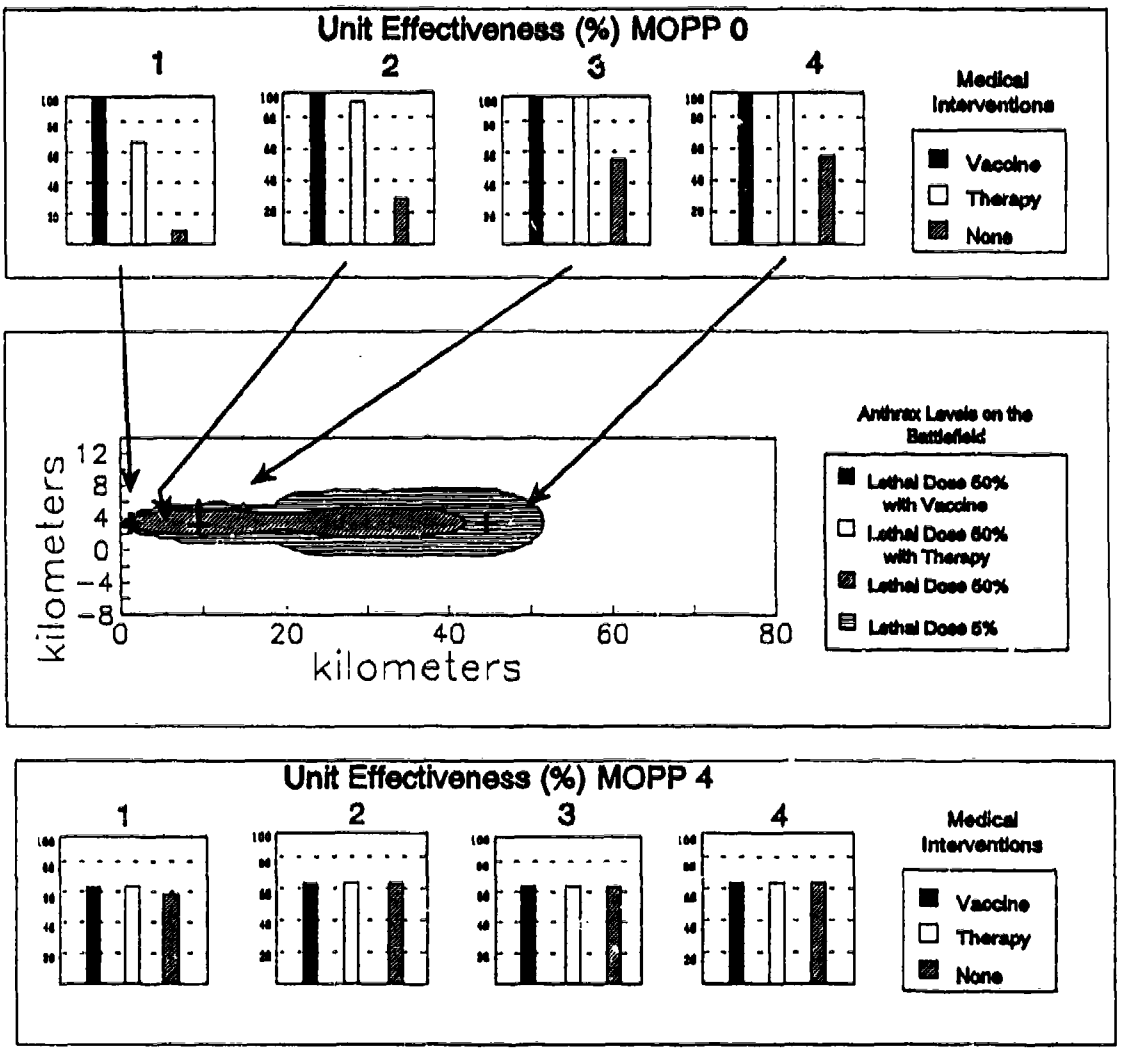

Figure 49. Terrorist Device in Southwest Asia at 1900 Hours: Artillery Unit Effectiveness with Medical Interventions

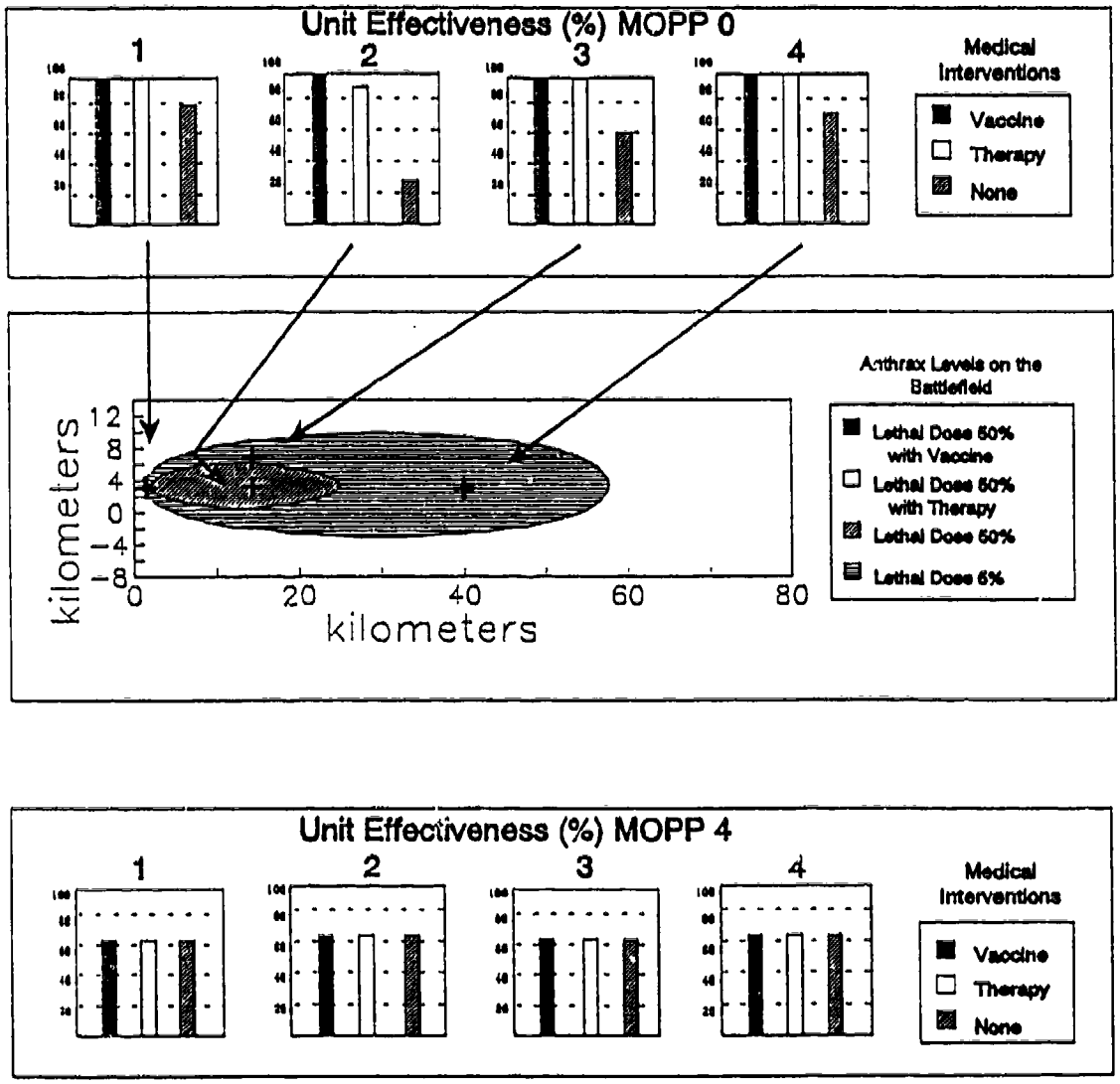

Figure 50. Terrorist Device in Southeast Asia at 0500 Hours: Artillery Unit Effectiveness with Medical Interventions

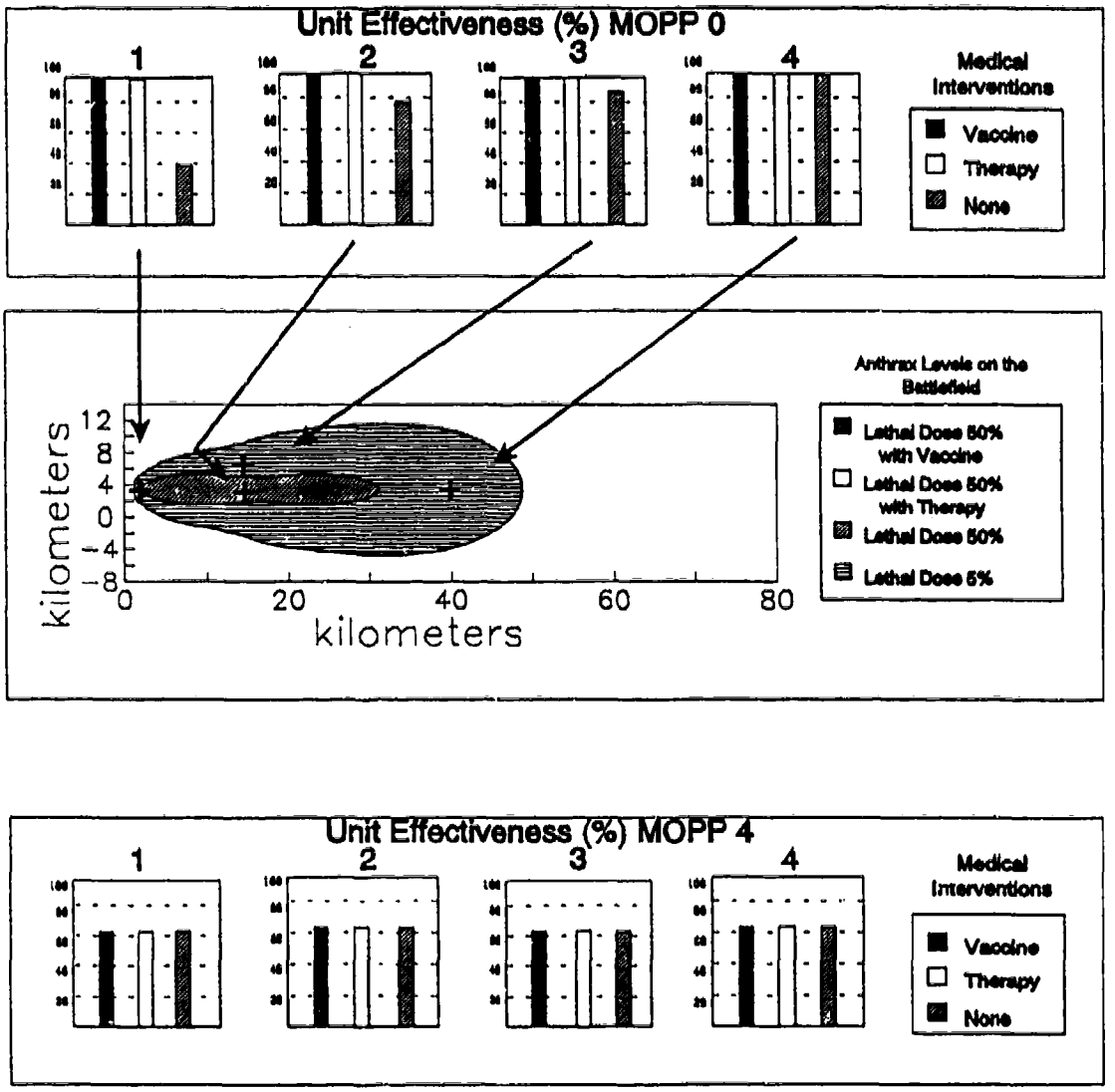

Figure 51. Terrorist Device in Southeast Asia at 1200 Hours: Artillery Unit Effectiveness with Medical Interventions

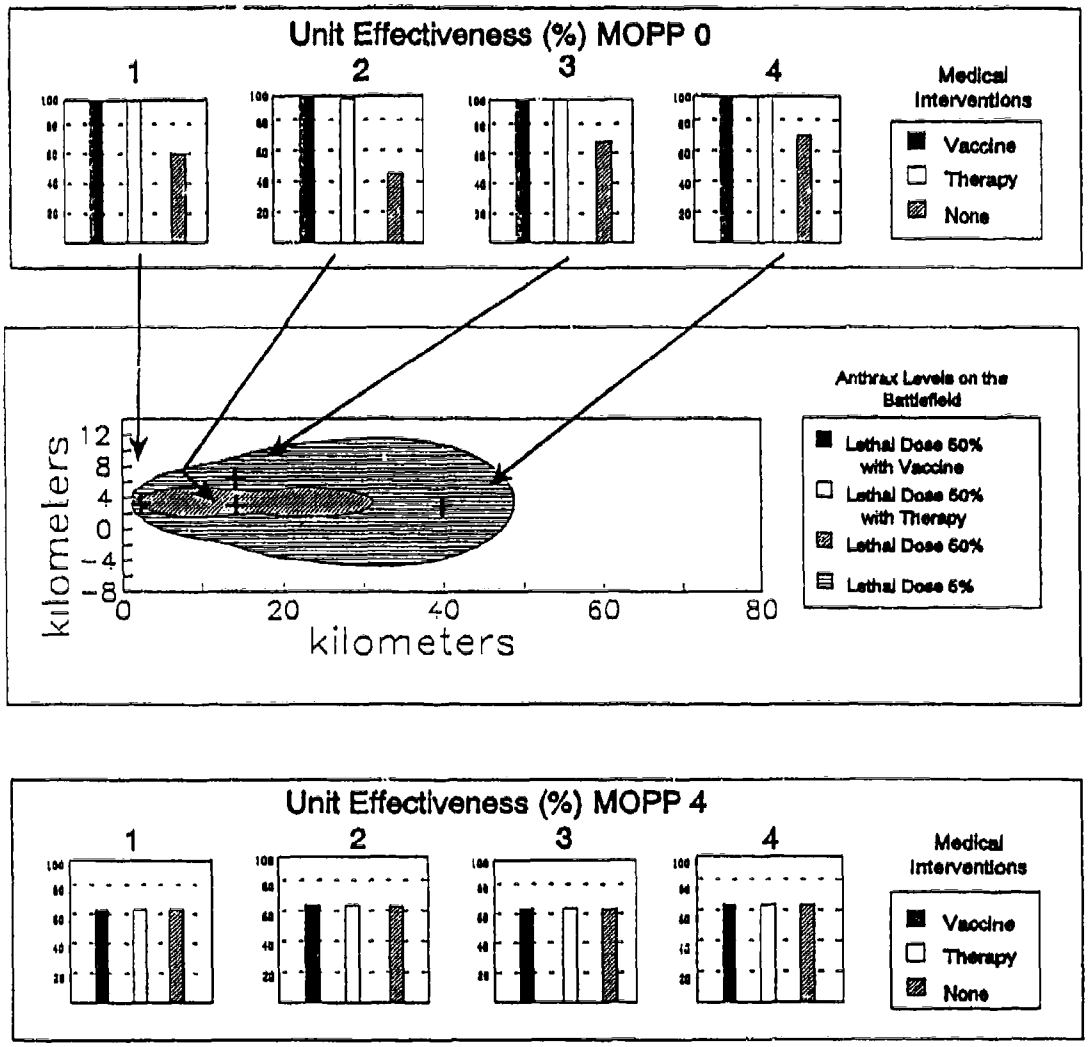

Figure 52. Terrorist Device in Southeast Asia at 1900 Hours: Artillery Unit Effectiveness with Medical Interventions

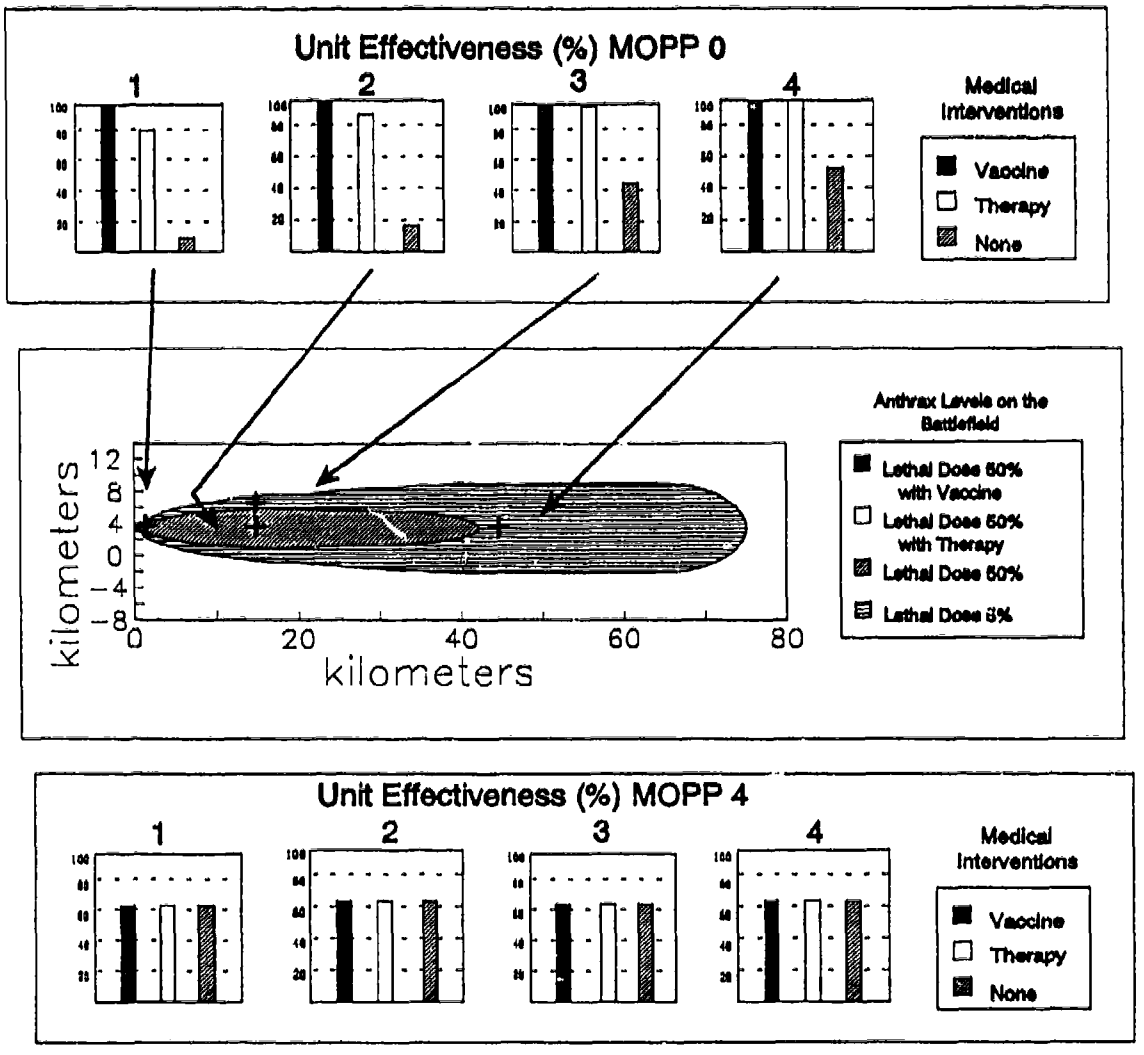

Figure 53. Terrorist Device in Central Europe at 0500 Hours: Artillery Unit Effectiveness with Medical Interventions

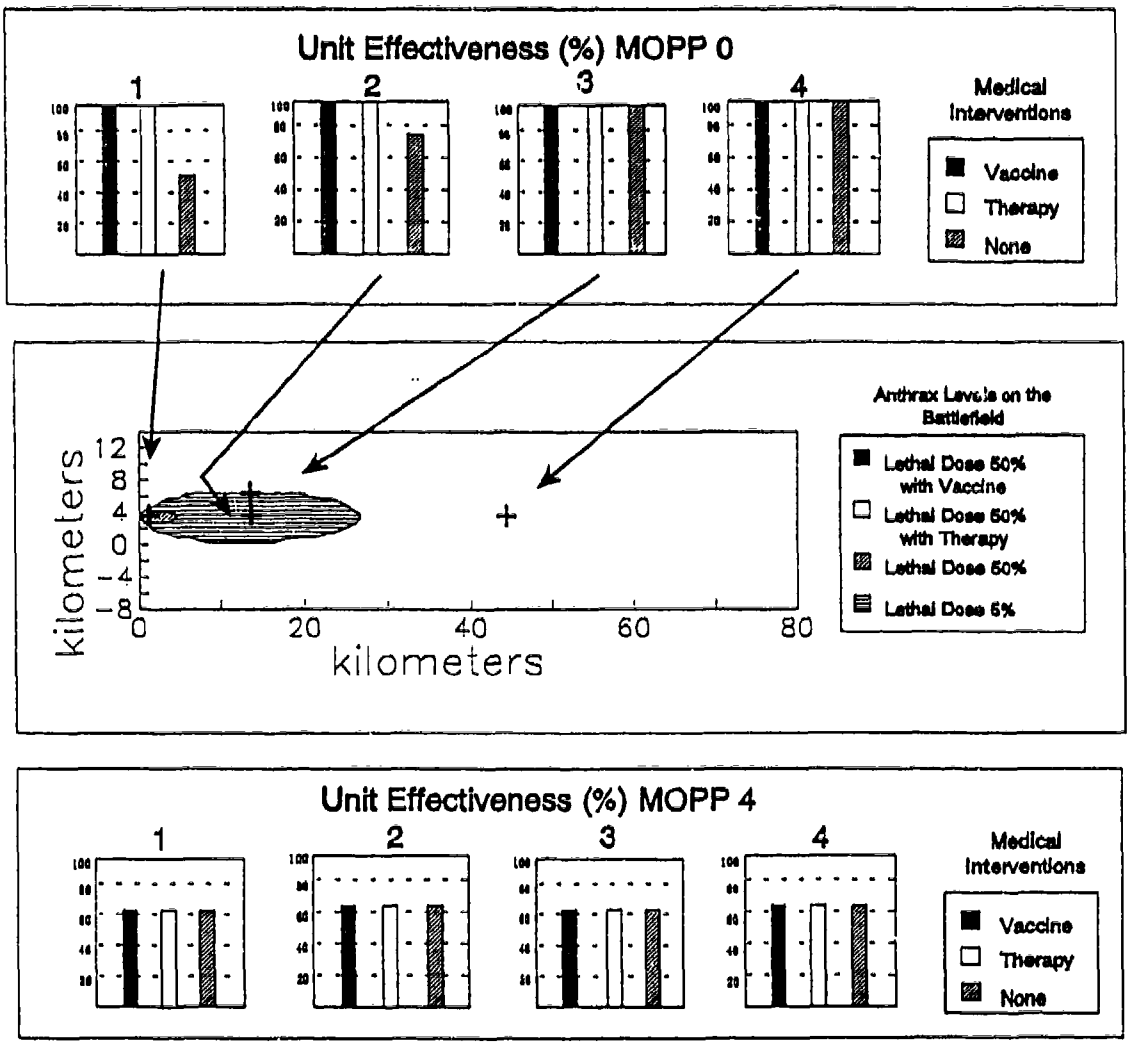

Figure 54. Terrorist Device in Central Europe at 1200 Hours: Artillery Unit Effectiveness with Medical Interventions

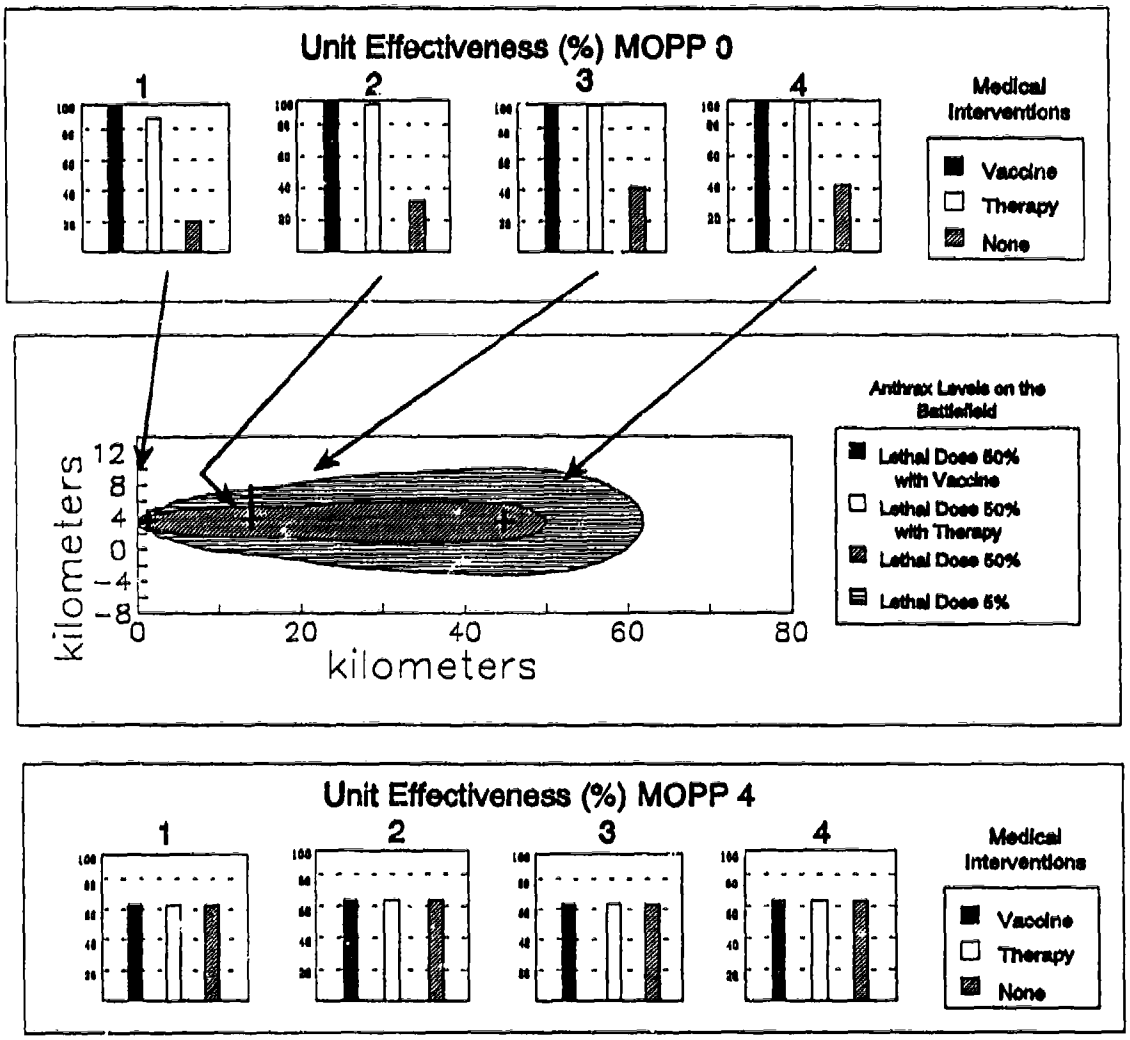

Figure 55. Terrorist Device in Central Europe at 1900 Hours: Artillery Unit Effectiveness with Medical Interventions

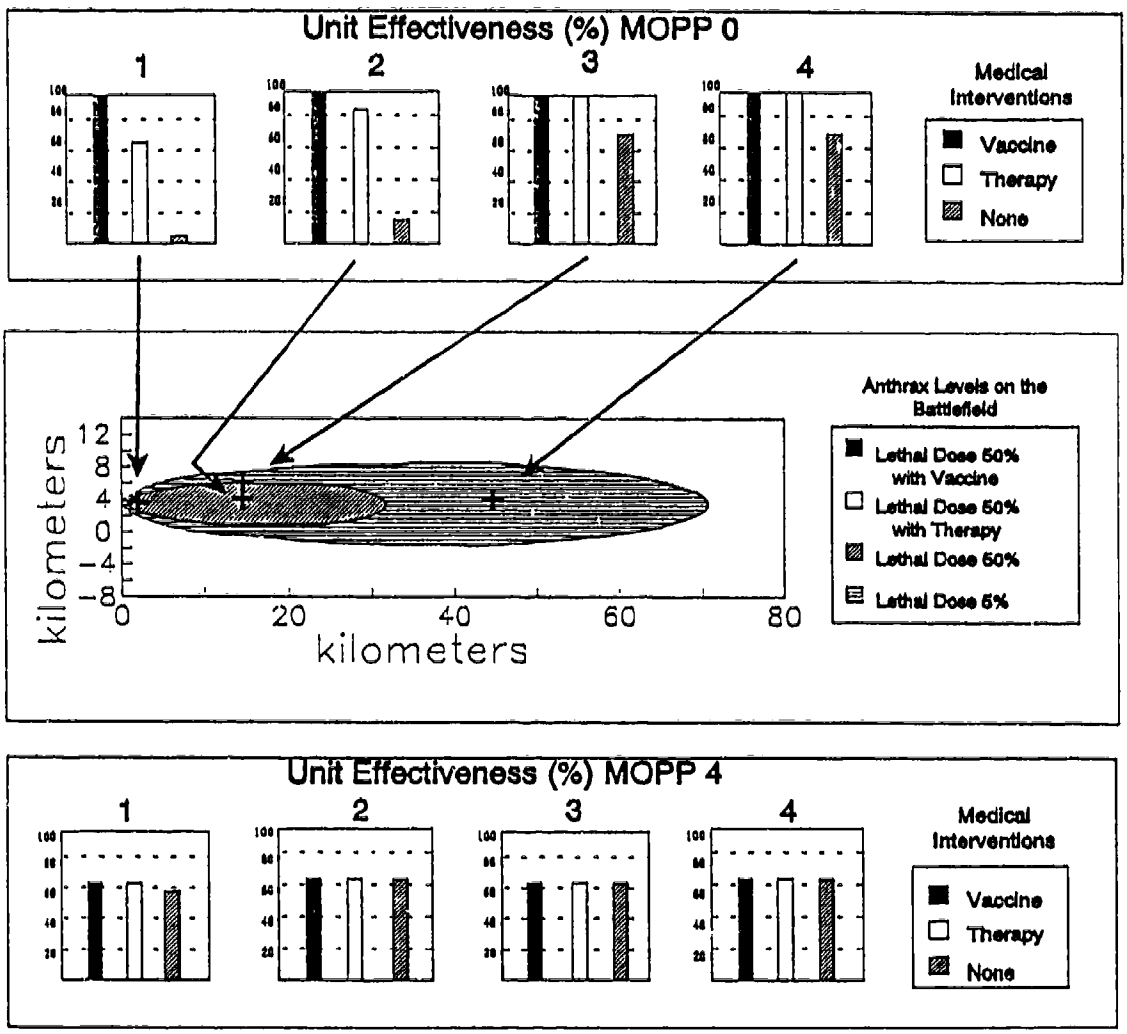

Figure 56. Terrorist Device in South Korea at 0500 Hours: Artillery Unit Effectiveness with Medical Interventions

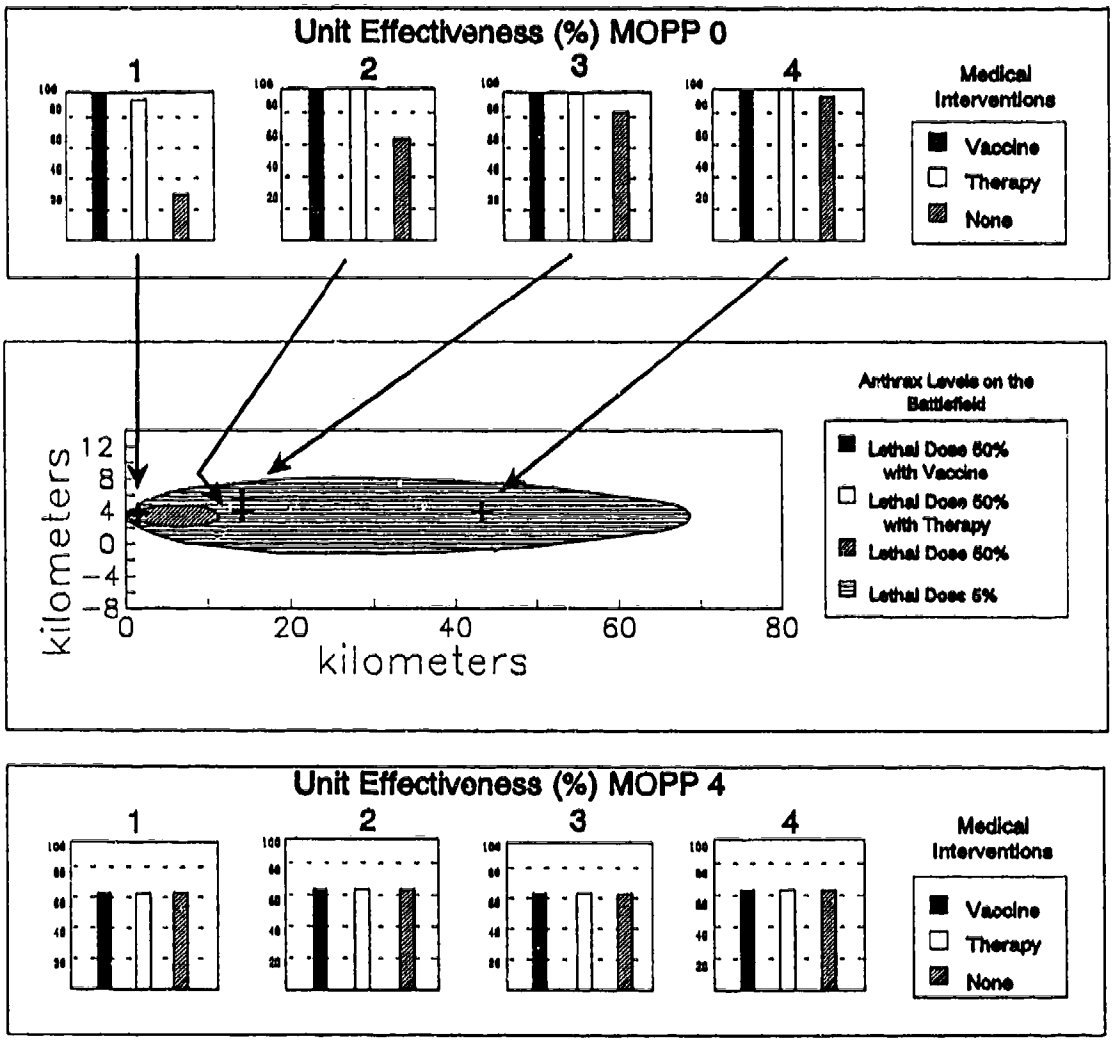

Figure 57. Terrorist Device in South Korea at 1200 Hours: Artillery Unit Effectiveness with Medical Interventions

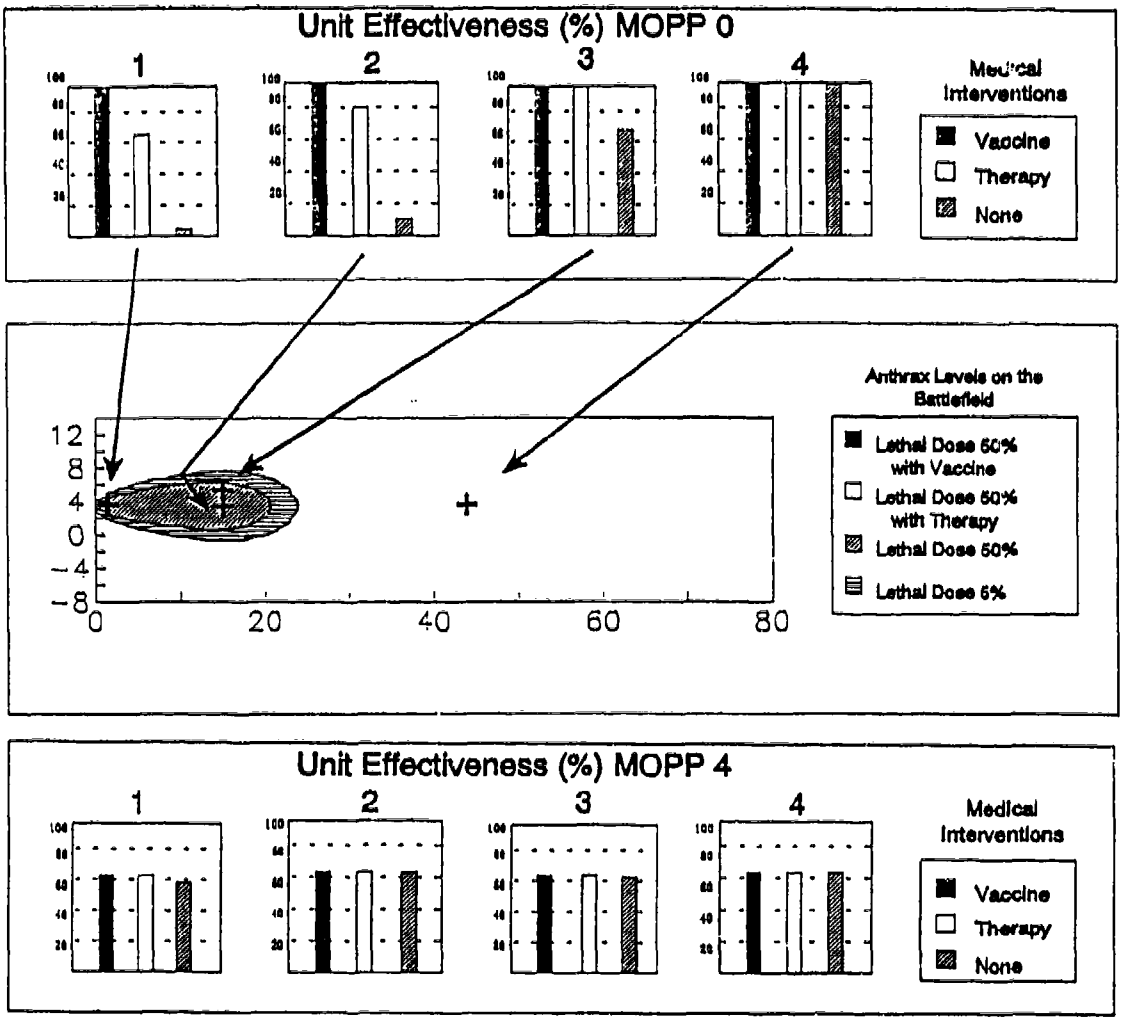

Figure 58. Terrorist Device in South Korea at 1900 Hours: Artillery Unit Effectiveness with Medical Interventions

The spore area coverage charts (Figures 59-62) provide additional insight into the hazard potential of 5 kg of agent explosively released by a terrorist device. As was seen in the footprint charts, the 1200 hours releases would be the least effective in all four regional climatic conditions for both peak number of spores achievable (X-axis) and spore area coverage (Y-axis).

Very noticeable for the 1200 hours releases were the effects of relatively higher wind speeds, unstable atmospheric conditions, and accelerated agent decay rate due to exposure to sunlight. The overall result was a combined reduction in the peak number of spores as well as the area covered by at least one spore. This reduction would be very significant for every climate examined.

Overall, the 5 kg device is approximately an order of magnitude less effective than the 78 kg TBM release discussed earlier, in terms of peak numbers of spores per square meter and area coverage at the 8,000 to 10,000 spores per square meter level. It is interesting to note that the 1200 hours terrorist device releases were from one to two orders of magnitude less effective in area coverage at the 8,000 to 10,000 spores per square meter level than either the 0500 or 1900 hours releases. This difference was at a minimum for the South Korean climate conditions where the noontime winter environment would be only slightly unstable.

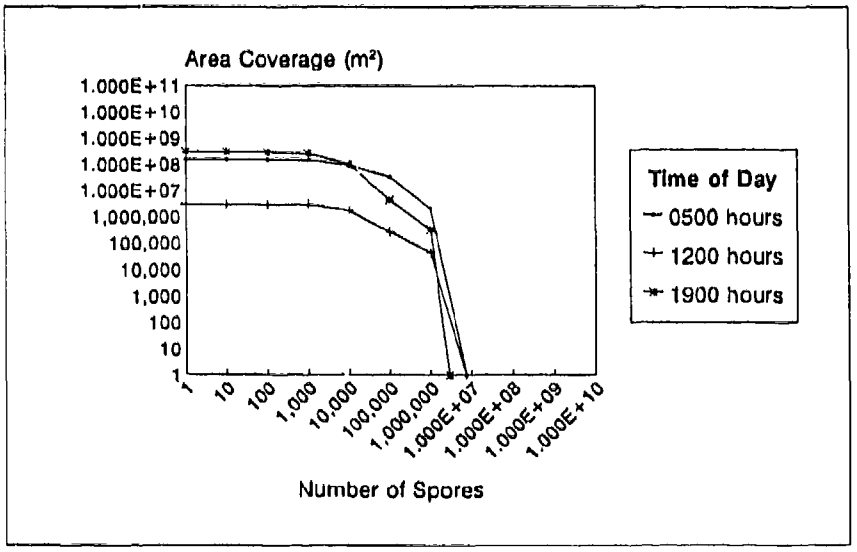

Figure 59. Terrorist Device in Southwest Asia: Spore Area Coverage

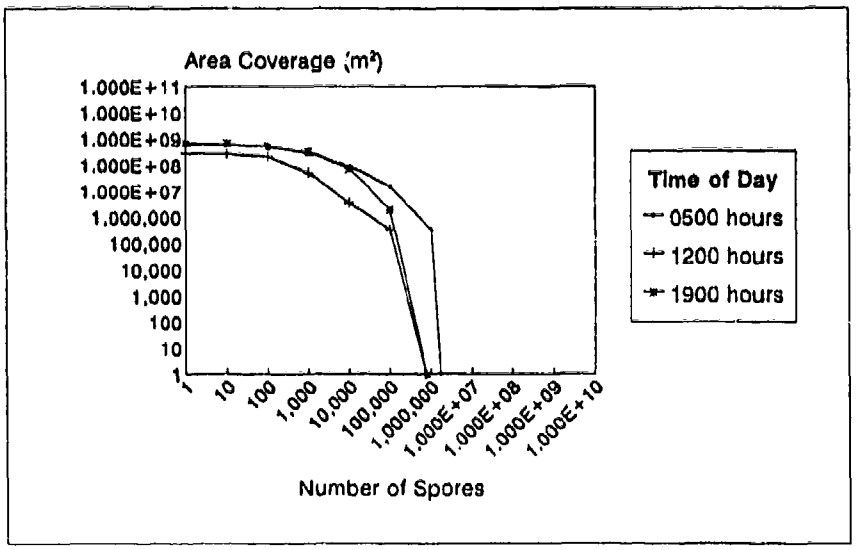

Figure 60. Terrorist Device in Southeast Asia: Spore Area Coverage

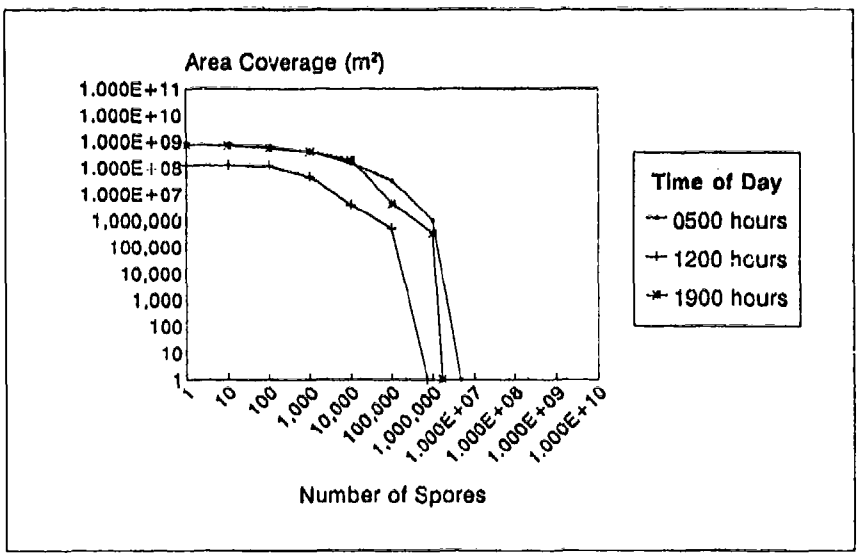

Figure 61. Terrorist Device in Central Europe: Spore Area Coverage

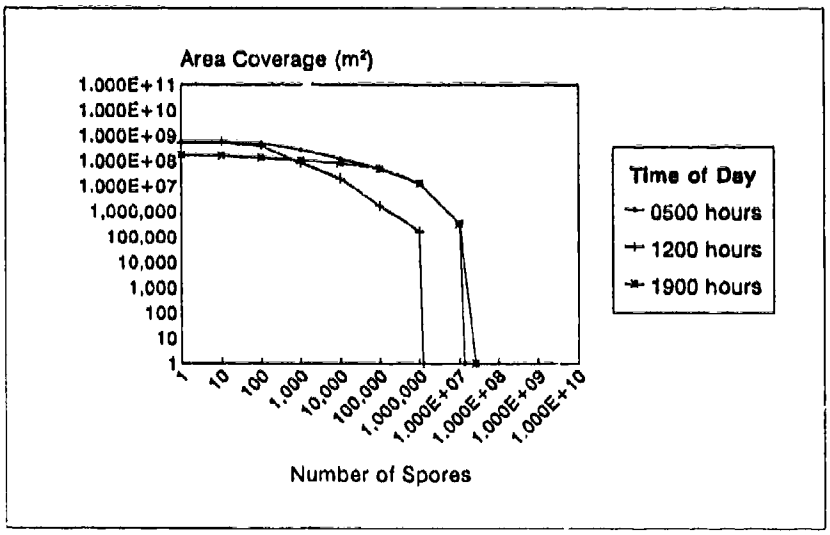

Figure 62. Terrorist Device in South Korea: Spore Area Coverage

The casualty production potential of the terrorist device is depicted in Figure 63. Note that the vaccine would provide a very high level of protection from anthrax for all conditions examined as evidenced by reduction of the lethal area coverage to between 10 and 10,000 square **meters.** By comparison, the lethal area coverage for personnel with no medical protection would range from 1 to 100 square **kilometers.** While antibiotic therapy would provide approximately a 90 percent decrease in lethal area coverage compared to the use of no medical interventions, a considerable area of the target (0.1 to 10 km²) would still experience life threatening levels without the additional use of protective gear. For personnel protected by the vaccine, even the low wind speed, stable atmospheric case of South Korean winter conditions resulted in less than 0.01 km² of probable lethal area coverage compared to a potential lethal area of approximately 100 km² for unprotected personnel. In summary, the appropriate use of antibiotic therapy is effective in reducing the probable lethal area against the simulated terrorist device attack by approximately one order of magnitude or by 90 percent, while the vaccine reduces the probable lethal area by four to five orders of magnitude.

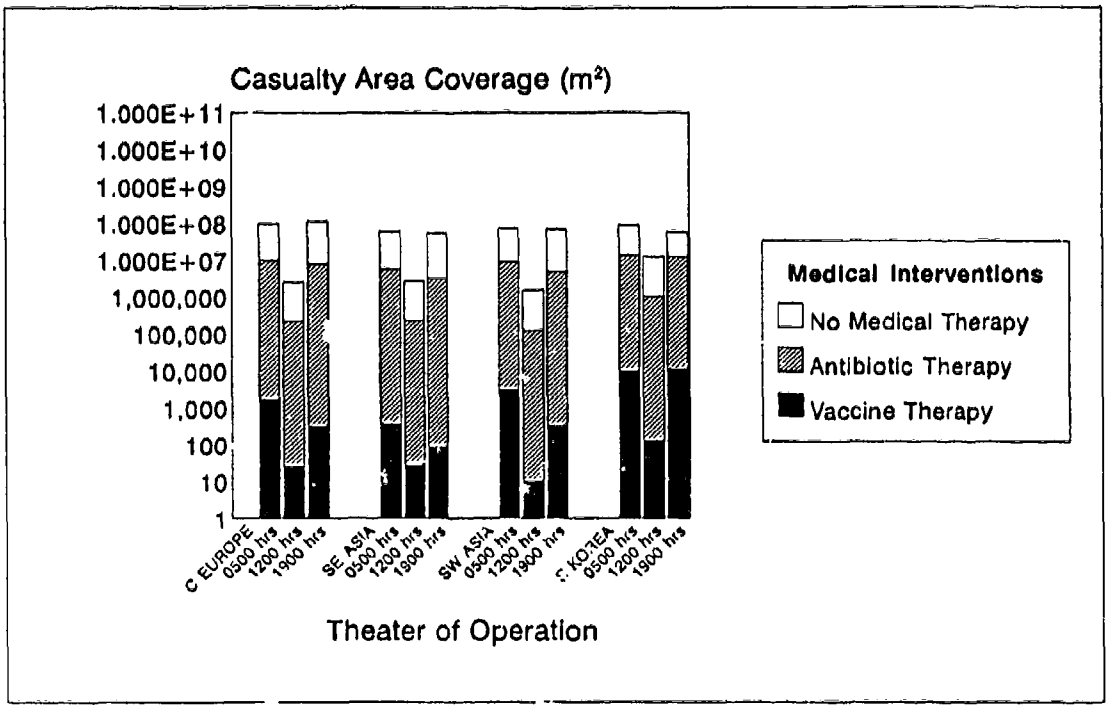

Figure 63. Terrorist Device: Casualty Area Coverage

5.3 TWENTY-FOUR (24) ARTILLERY SHELLS FILLED WITH *B. ANTHRACIS*

This simulation represented an attack with twenty-four 152 millimeter artillery rounds each filled with 1 kg of dry *B. anthracis* spores, released explosively. This attack was represented for three release times in four climates. It is possible to generate similar results from a liquid *B. anthracis* fill. The fireplan was constructed based on doctrine originated by the former Soviet Union for a 3-volley battery fire. A 6-tube artillery battery is typical of the former Soviet Union force structure.

The hazard footprints (Figures 64-75) show that even the small quantity of agent (24 kg) disseminated by this attack could affect considerable distances downwind which roughly approximate 5 to 10 hours of transport with the 0500 and 1900 hours releases and 1 to 2 hours for the 1200 hours releases The footprint charts also show the resultant unit effectiveness of an artillery unit located at four points within the footprint for the three potential therapy options. The longer range 152 millimeter artillery could reach U.S. Army artillery units at Position 1. Positions 2, 3 and 4 could reflect unit deployments to the rear of the forward line of troops.

A comment on the effectiveness of the simulated artillery attack relative to the previously reviewed tactical ballistic missile and terrorist device attacks is instructive. Although these attack scenarios are subject to the same meteorological parameters and times of attack, the shape of the footprints was driven by the fireplan (warhead impact points) and total mass of agent delivered. The tactical ballistic missile attack was based on a total of 78 kg of mass dispersed by 2,000 submunitions (about three times the total mass of the artillery attack with 83 times as many impact points). The terrorist device delivered 5 kg at one release point compared to the artillery attack in which a total of 24 kg of agent was delivered at 24 release points. The capability of a 1 kg artillery round to achieve greater effect than the 5 kg release of the terrorist device would be due to the reinforcing effect of 24 rounds in producing agent concentration and dosage. The effect of the artillery fireplan would be to saturate a comparatively small target area with a fairly well-distributed hazard. In this way, the artillery attack is more similar to the fireplan for the tactical ballistic missile attacks, but on a smaller scale. Thus, the artillery footprints show significant areas where even antibiotic therapy would allow for more than 50 percent casualties (as noted by the white contours).

The implications for unit effectiveness would be severe, especially for 0500 hours releases in all regional climates. For the 0500 hours releases, units in MOPP 0 and relying on antibiotic therapy suffer greater sacrifices in unit effectiveness in relation to their proximity to the centroid of the fireplan. Protective equipment would be needed to supplement the antibiotic therapy in order to avoid considerable loss of life and to maintain unit effectiveness. Even so, for this time of day, the best unit effectiveness that could be expected for units in any position with antibiotic prophylaxis would be the 63 percent inherent for MOPP 4. In contrast, the vaccine would be expected to provide 100 percent unit effectiveness even against a direct attack at 0500 hours with no protective gear.

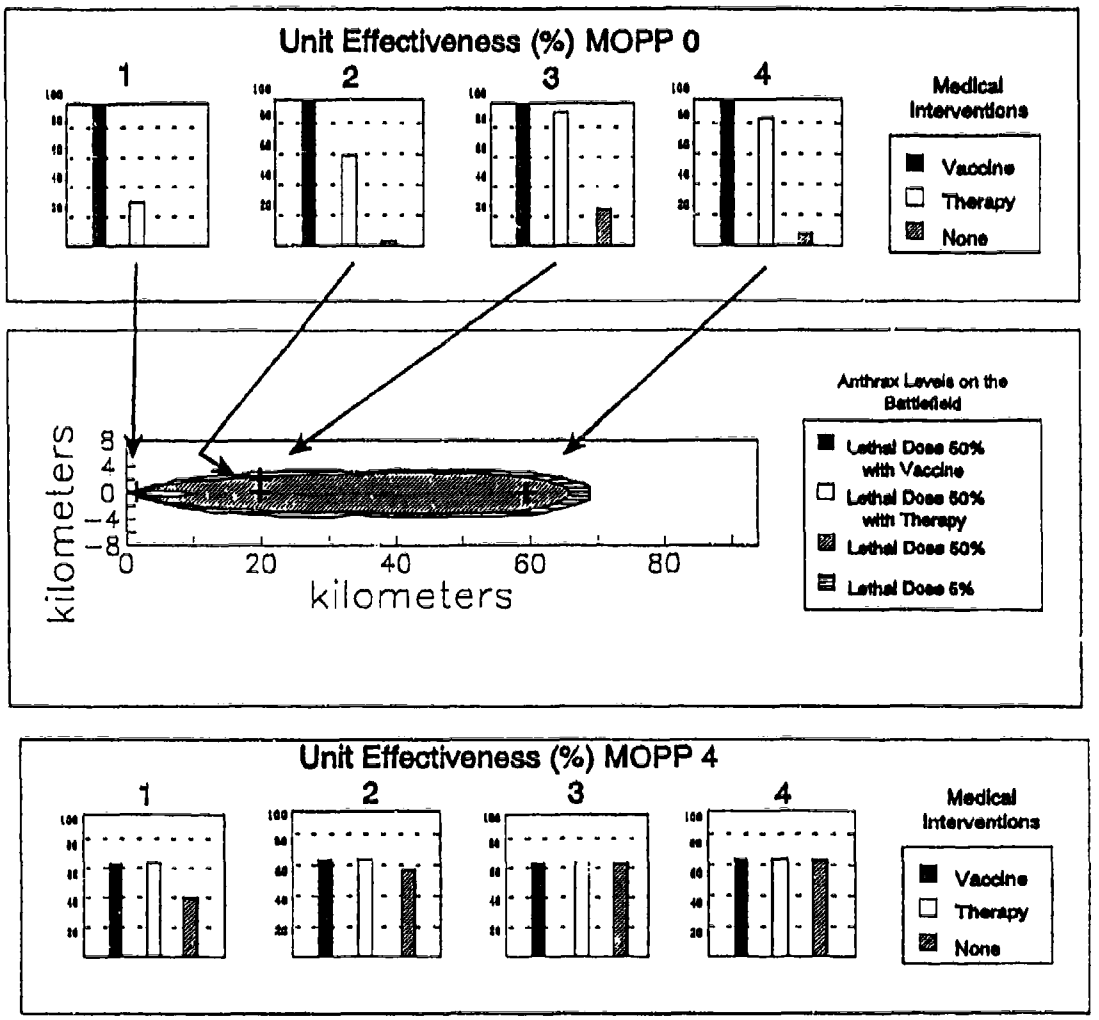

Figure 64. Artillery in Southwest Asia at 0500 Hours: Artillery Unit Effectiveness with Medical Interventions

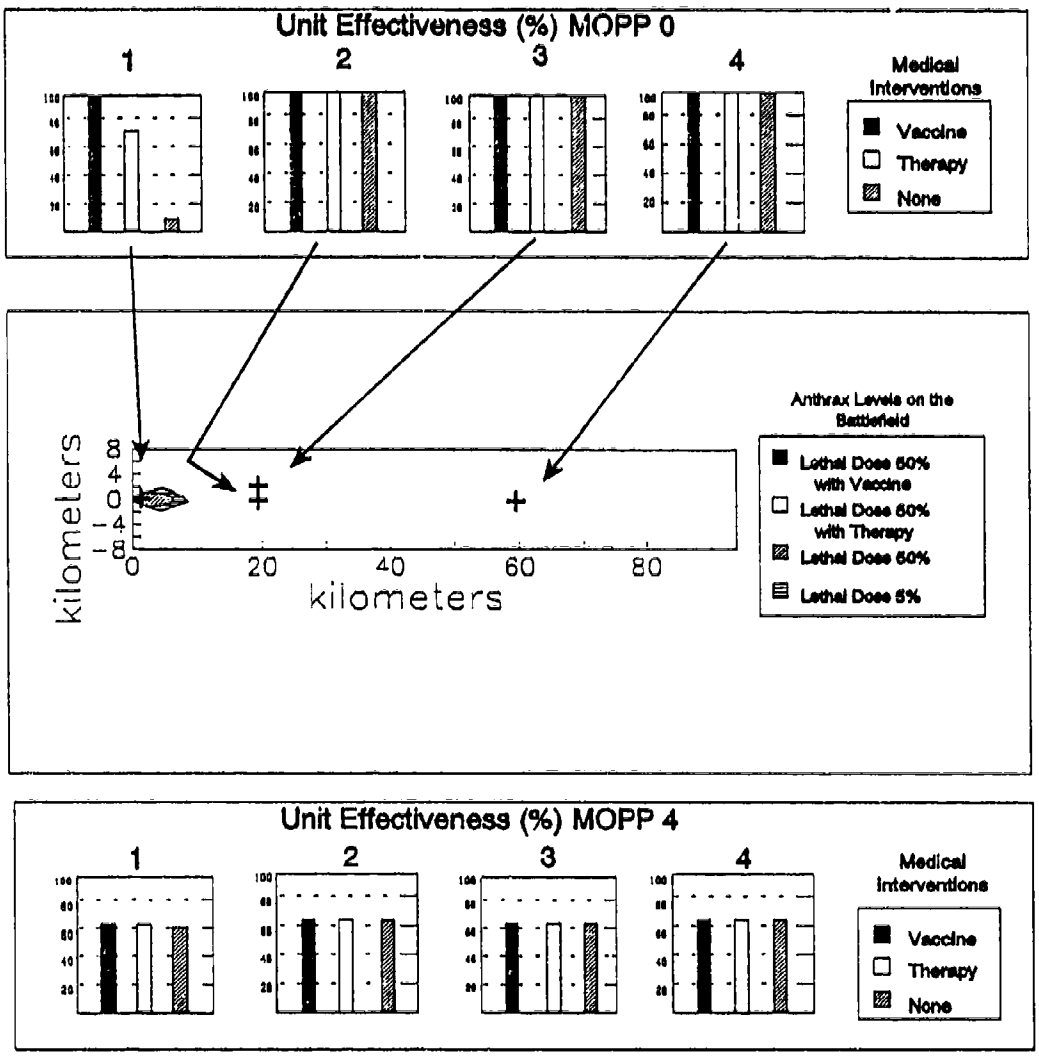

Figure 65. Artillery in Southwest Asia at 1200 Hours: Artillery Unit Effectiveness with Medical Interventions

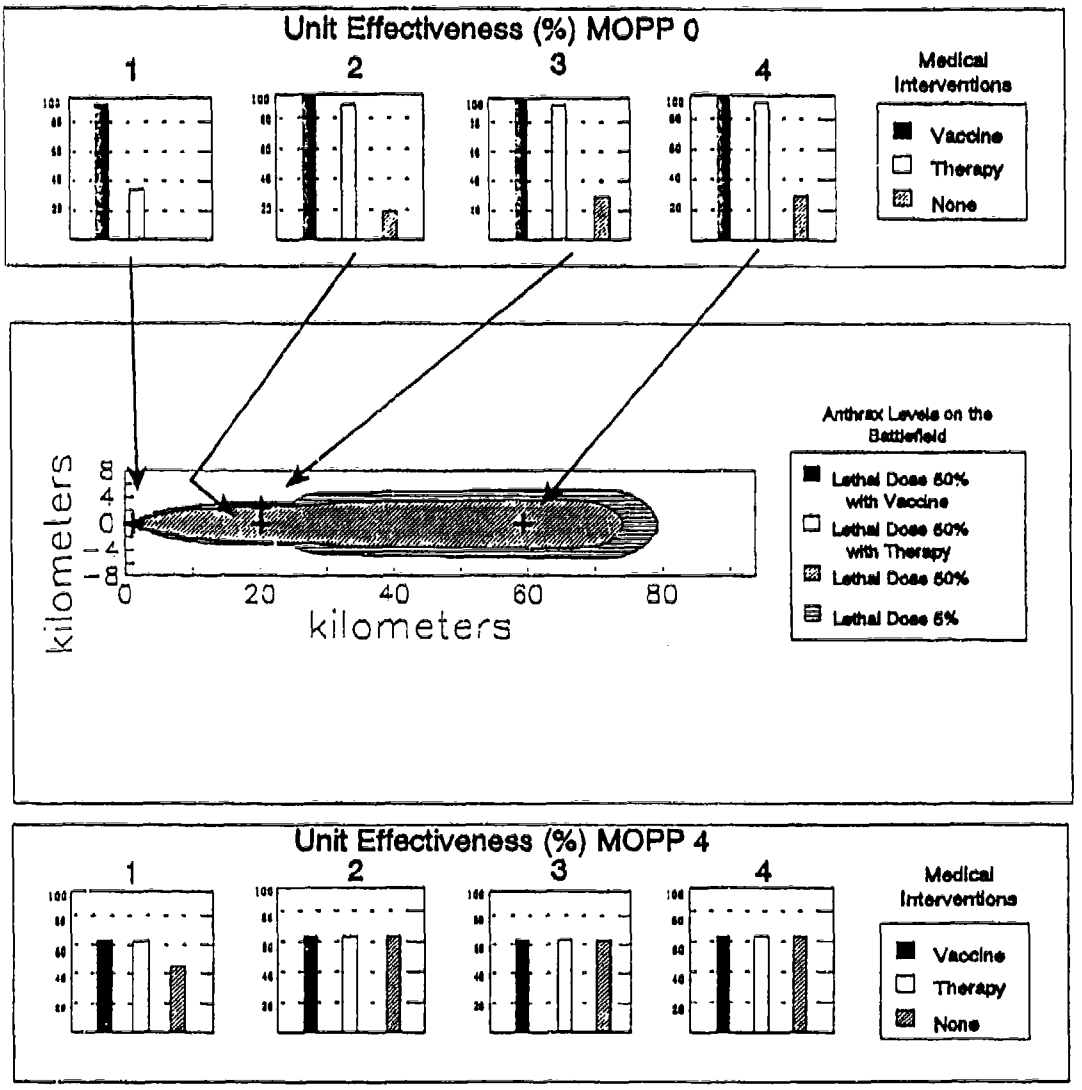

Figure 66. Artillery in Southwest Asia at 1900 Hours: Artillery Unit Effectiveness with Medical Interventions

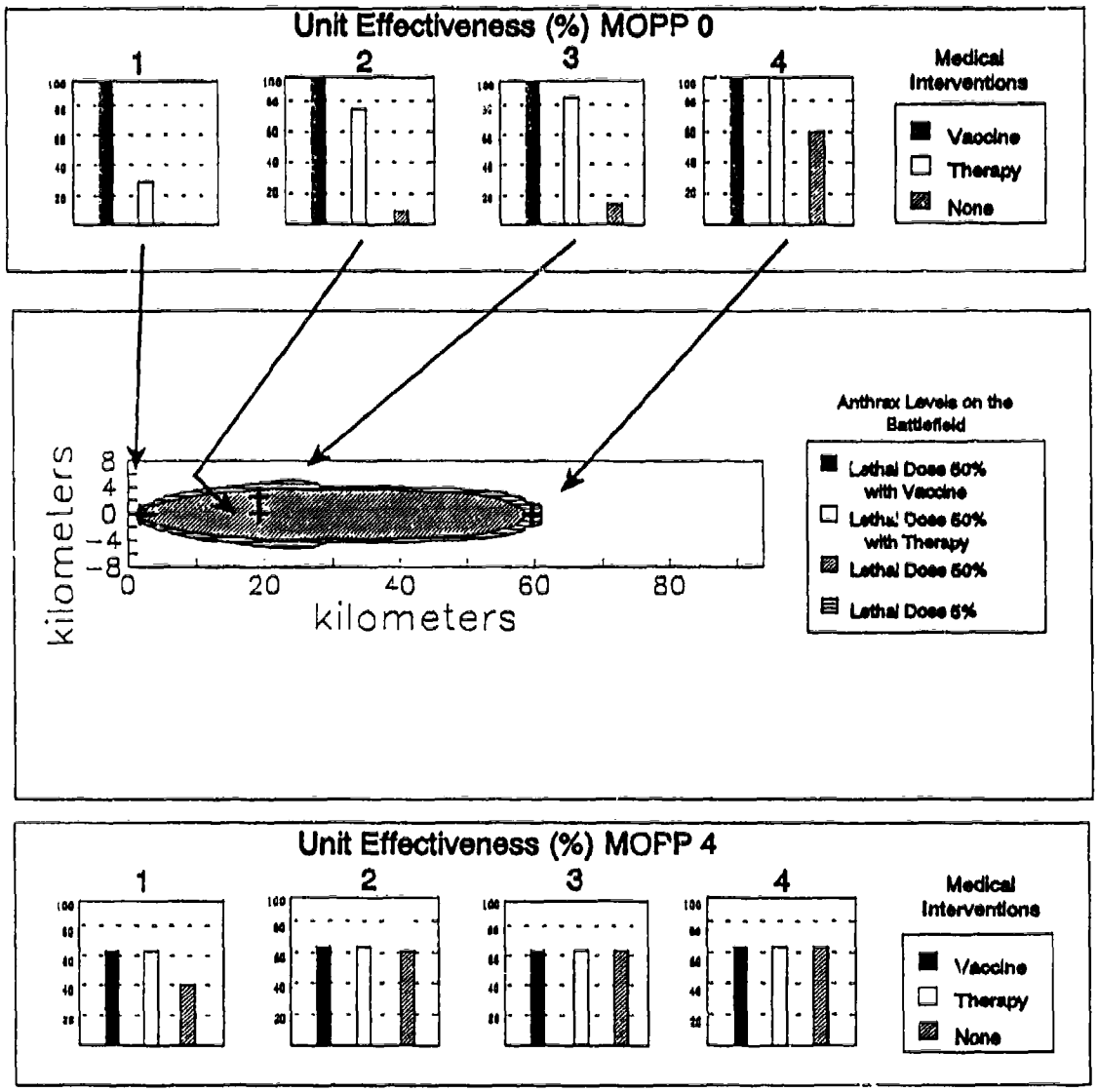

Figure 67. Artillery in Southeast Asia at 0500 Hours: Artillery Unit Effectiveness with Medical Interventions

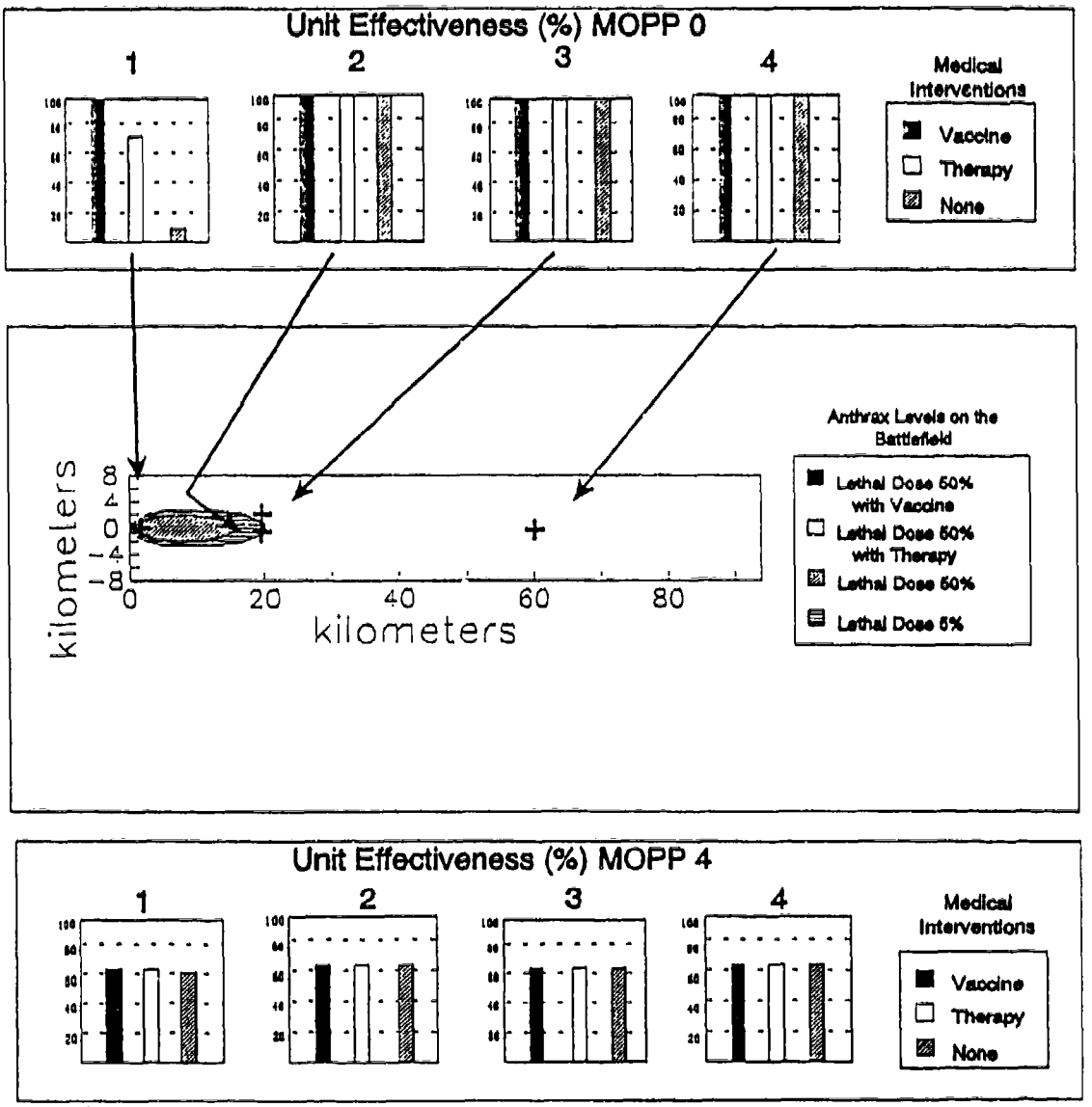

Figure 68. Artillery in Southeast Asia at 1200 Hours: Artillery Unit Effectiveness with Medical Interventions

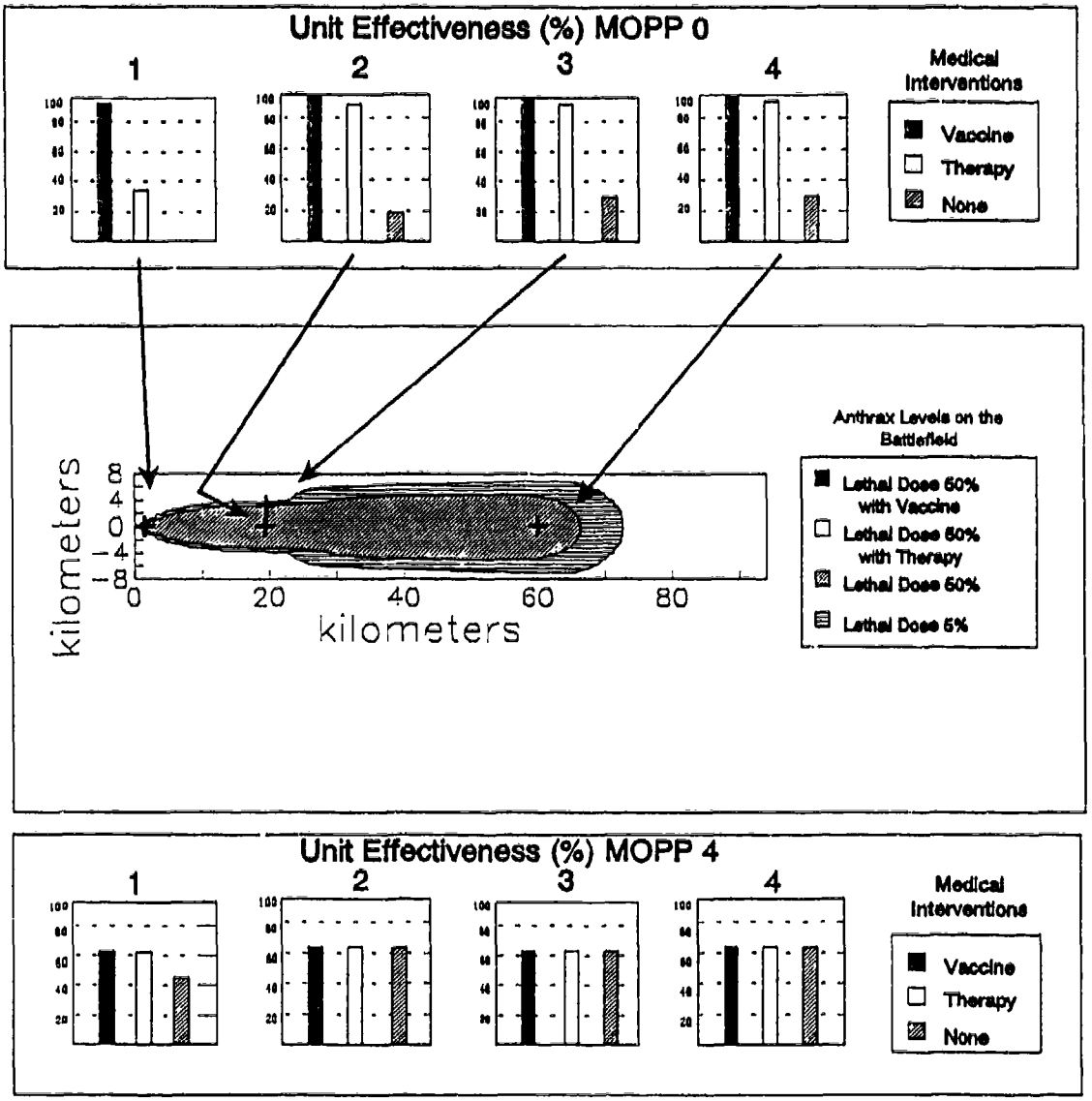

Figure 69. Artillery in Southeast Asia at 1900 Hours: Artillery Unit Effectiveness with Medical Interventions

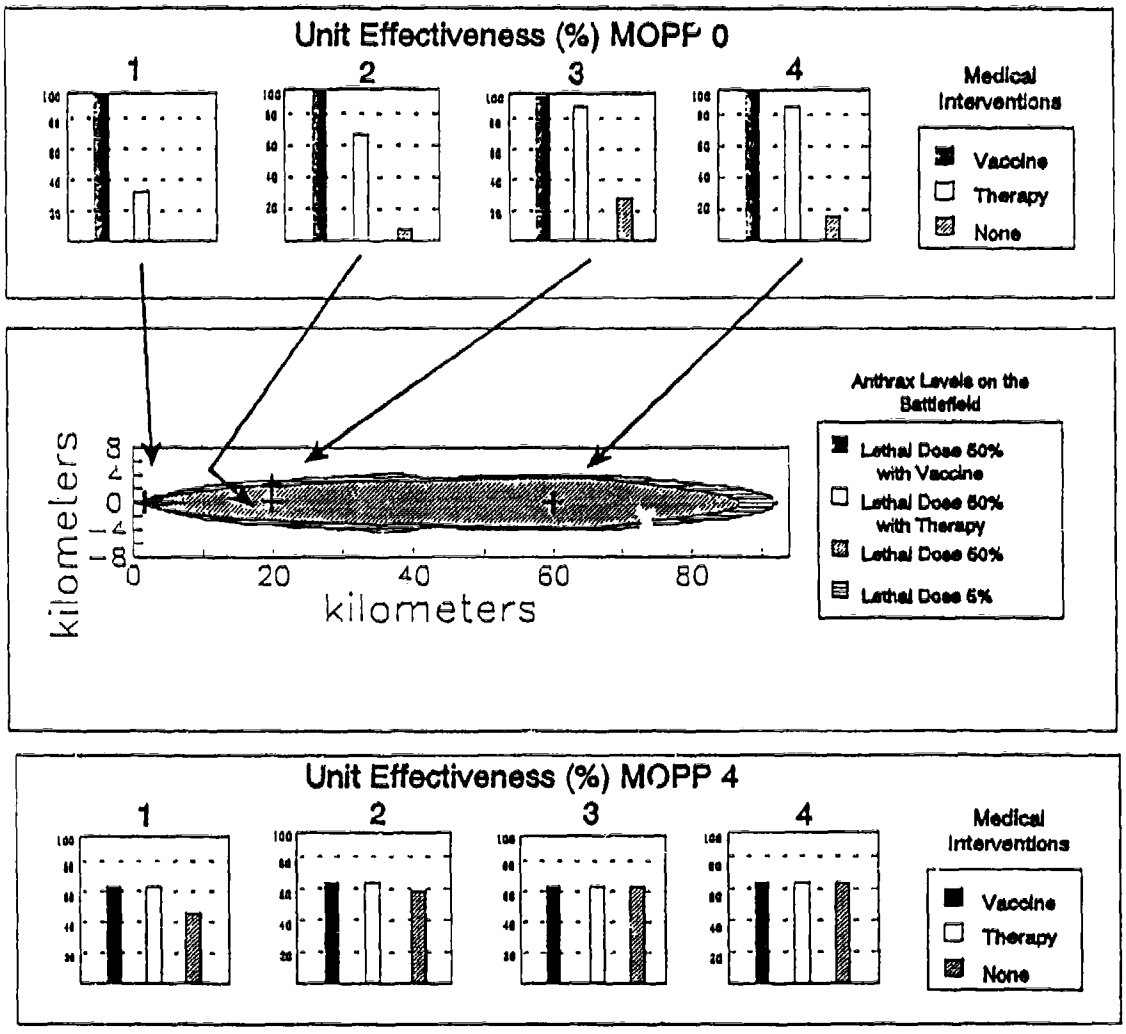

Figure 70. Artillery in Central Europe at 0500 Hours: Artillery Unit Effectiveness with Medical Interventions

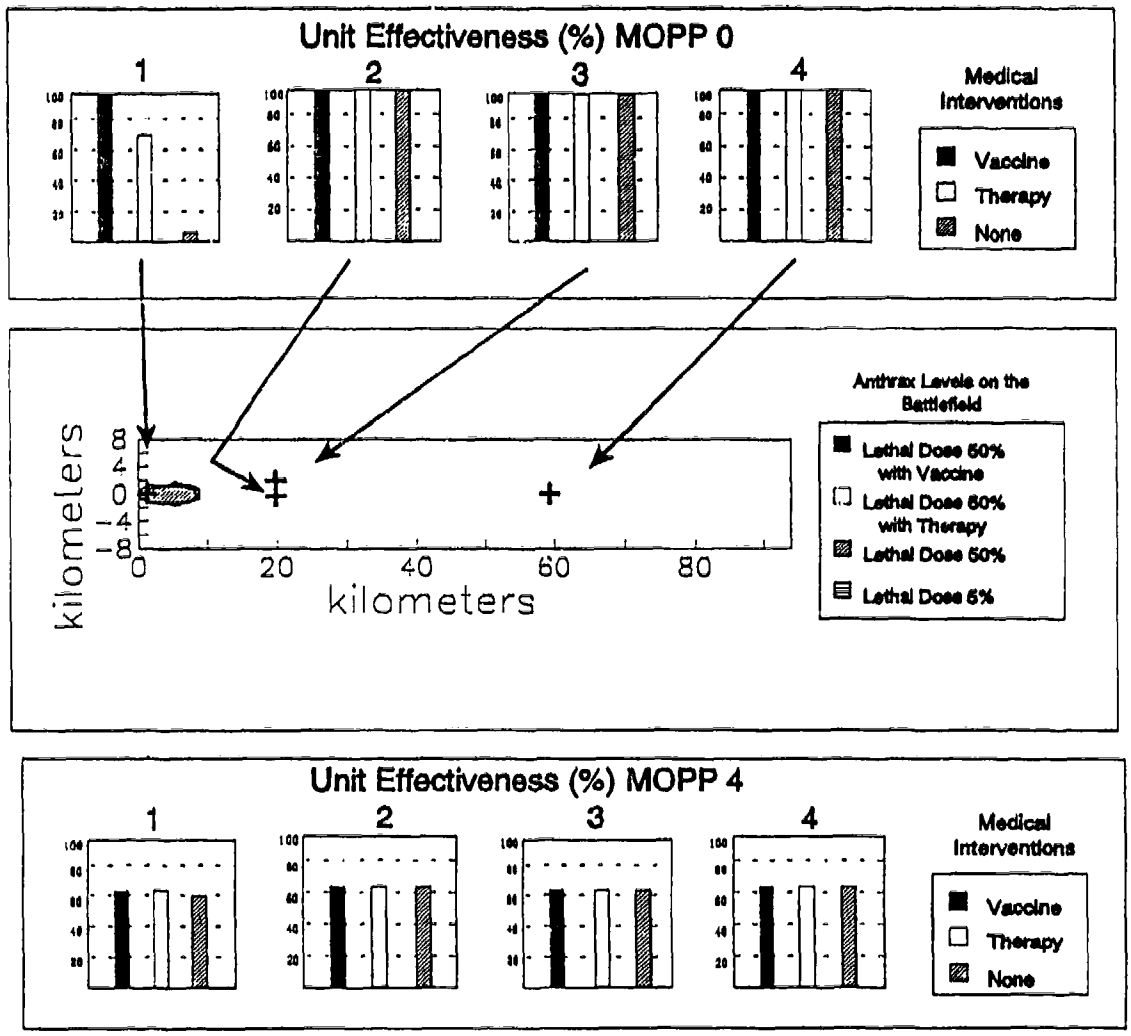

Figure 71. Artillery in Central Europe at 1200 Hours: Artillery Unit Effectiveness with Medical Interventions

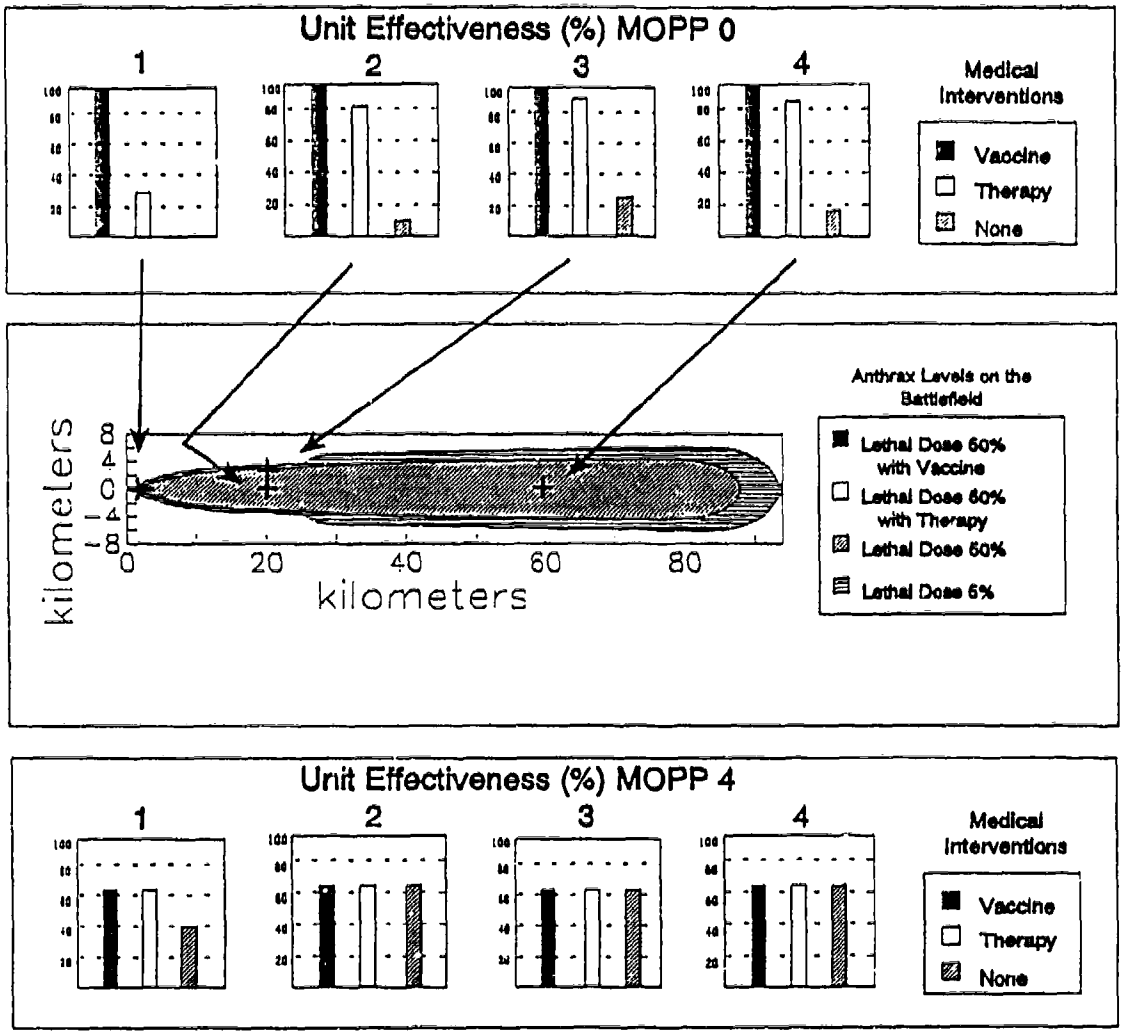

Figure 72. Artillery in Central Europe at 1900 Hours: Artillery Unit Effectiveness with Medical Interventions

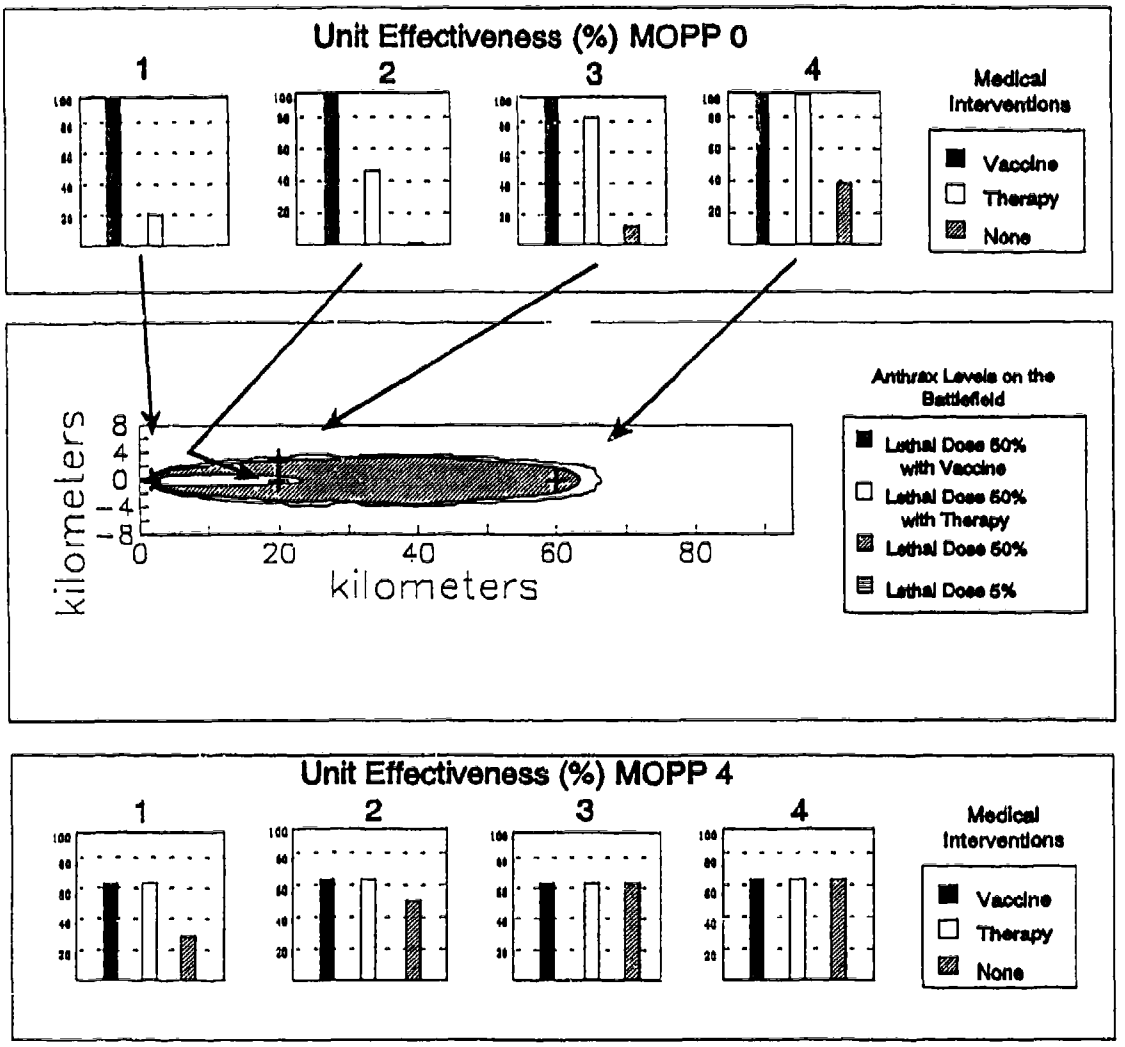

Figure 73. Artillery in South Korea at 0500 Hours: Artillery Unit Effectiveness with Medical Interventions

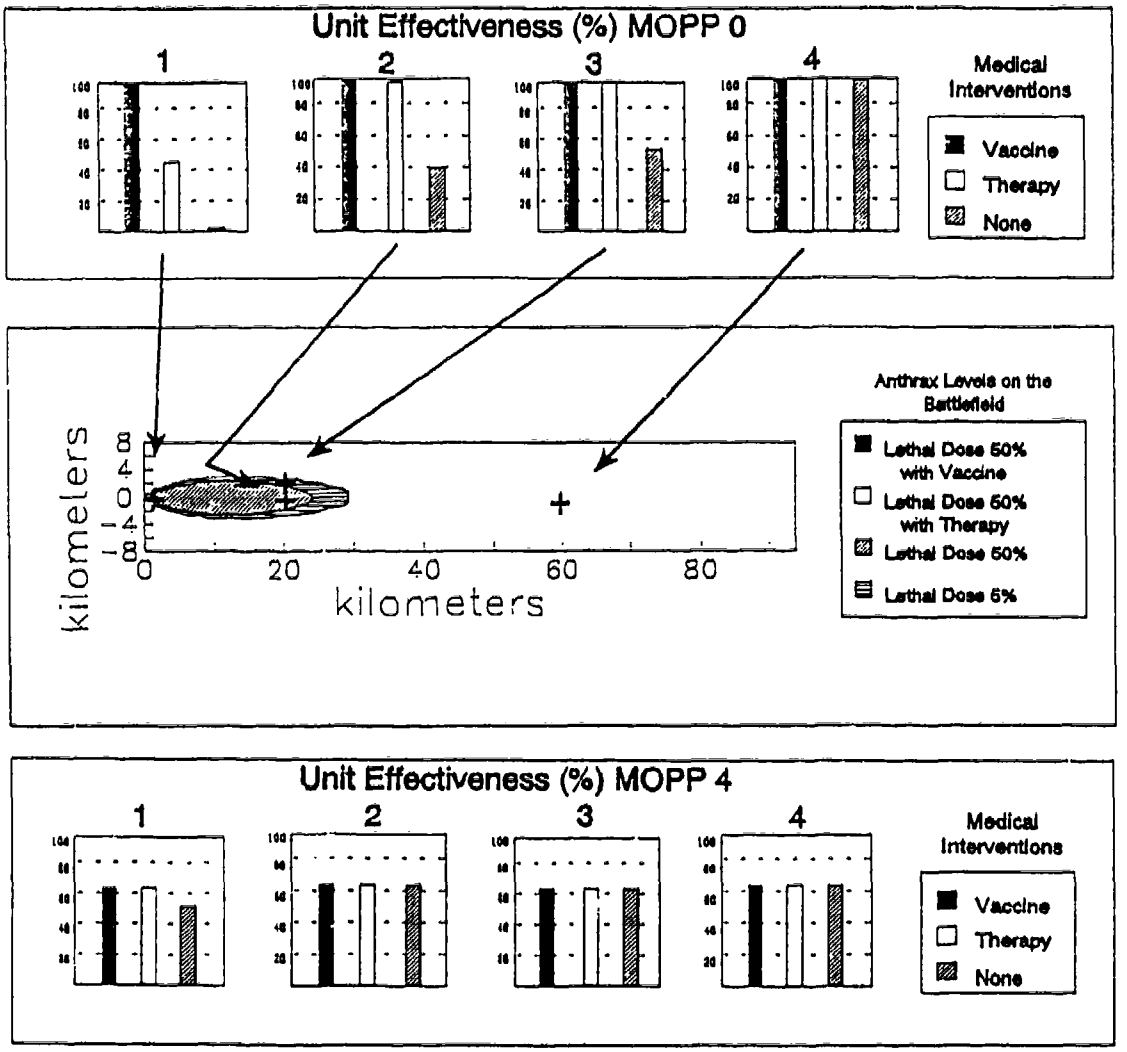

Figure 74. Artillery in South Korea at 1200 Hours: Artillery Unit Effectiveness with Medical Interventions

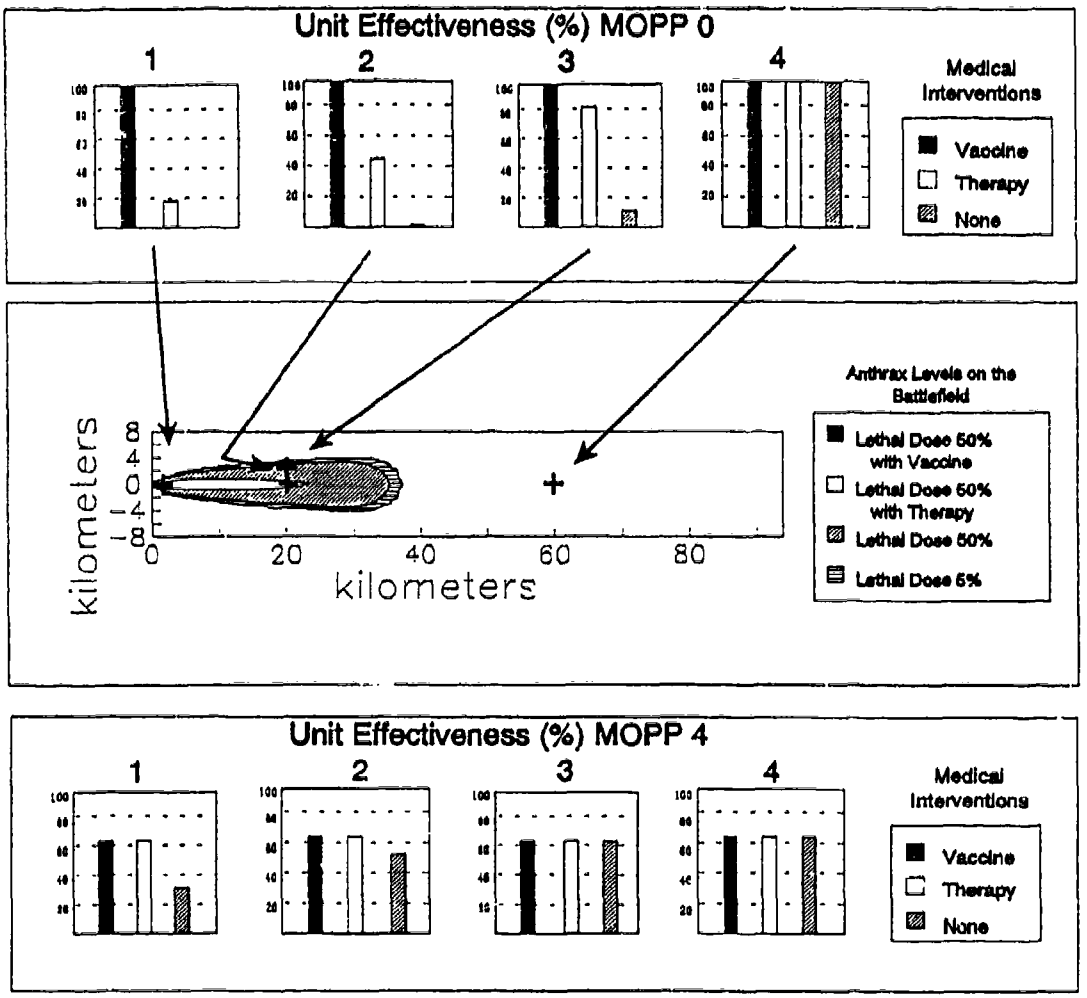

Figure 75. Artillery in South Korea at 1900 Hours: Artillery Unit Effectiveness with Medical Interventions

The hazard potential in terms of spore area coverage is depicted in Figures 76-79. Note that the range for the peak number of spores achievable for all regions and release times was well within an order of magnitude and in absolute terms exceeds 10 million spores per square meter. For the climatic conditions of South Korean winter, the peak number of spores was essentially the same for all three times of release (approximately 100 million spores per square meter). The 1200 hours release, affected by higher wind speeds, lapse atmospheric conditions and increased agent decay due to sunlight, would achieve considerably less spore area coverage. This decrease applies both to the overall area covered by at least one spore per square meter and to areas covered by at least 10,000 spores per square meter (an area coverage of interest since a dose of 8,000-10,000 spores can be lethal without medical intervention).

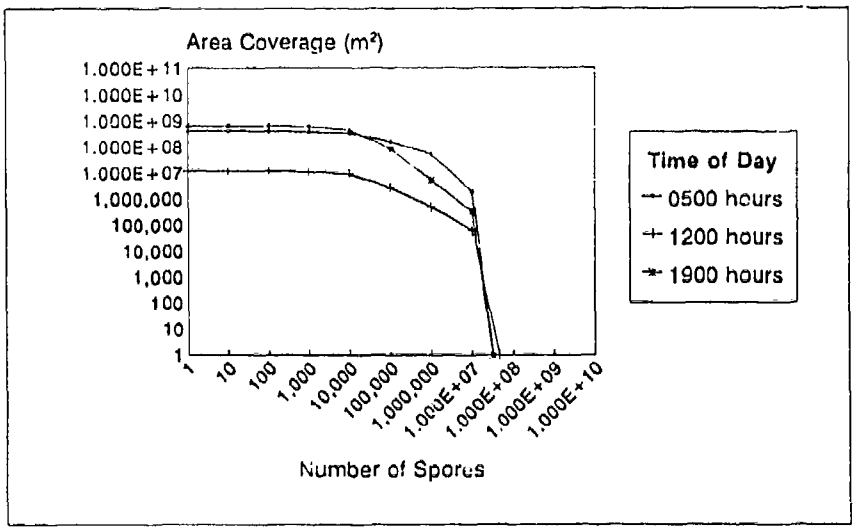

Figure 76. Artillery in Southwest Asia: Spore Area Coverage

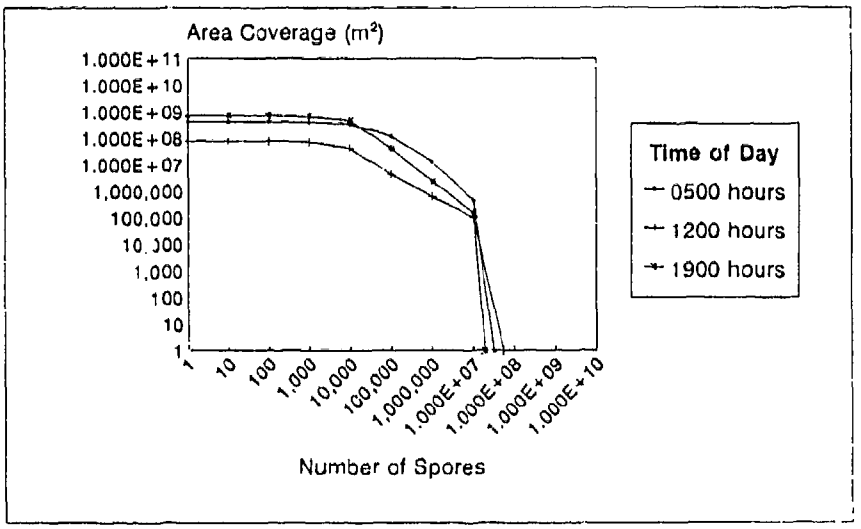

Figure 77. Artillery in Southeast Asia: Spore Area Coverage

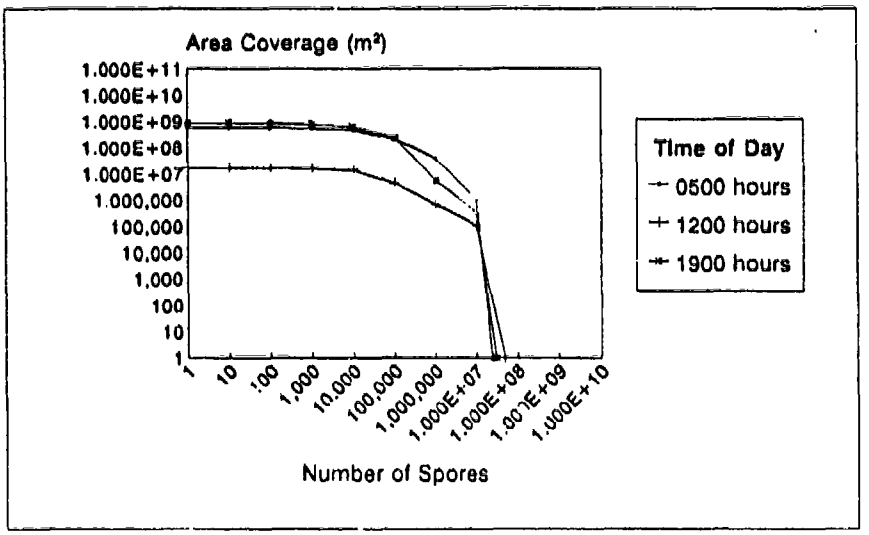

Figure 78. Artillery in Central Europe: Spore Area Coverage

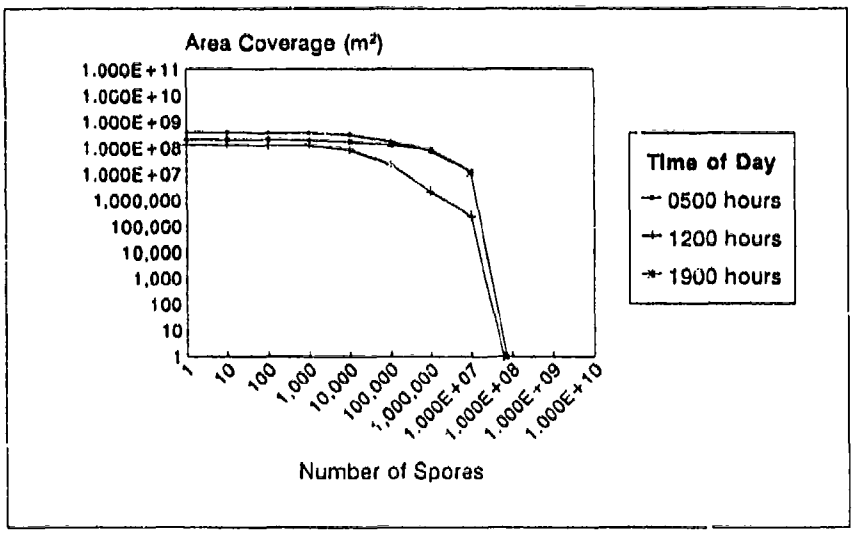

Figure 79. Artillery in South Korea: Spore Area Coverage

The highly beneficial effects of medical interventions, as seen in the earlier attack scenarios, are confirmed again in Figure 80. However, the artillery attack scenario would achieve the greatest peak number of spores presented thus far. The vaccine would limit the casualty area coverage to a maximum of about 100,000 m^2 (0.1 km^2) in the South Korean climatic environment, the worst case scenario. Overall the vaccine would reduce the potential casualty area coverage by four to five orders of magnitude for the 0500 and 1900 hours releases and by about four orders of magnitude for the 1200 hours releases. The antibiotic therapy would achieve approximately a one order of magnitude or 90 percent reduction in overall casualty area coverage.

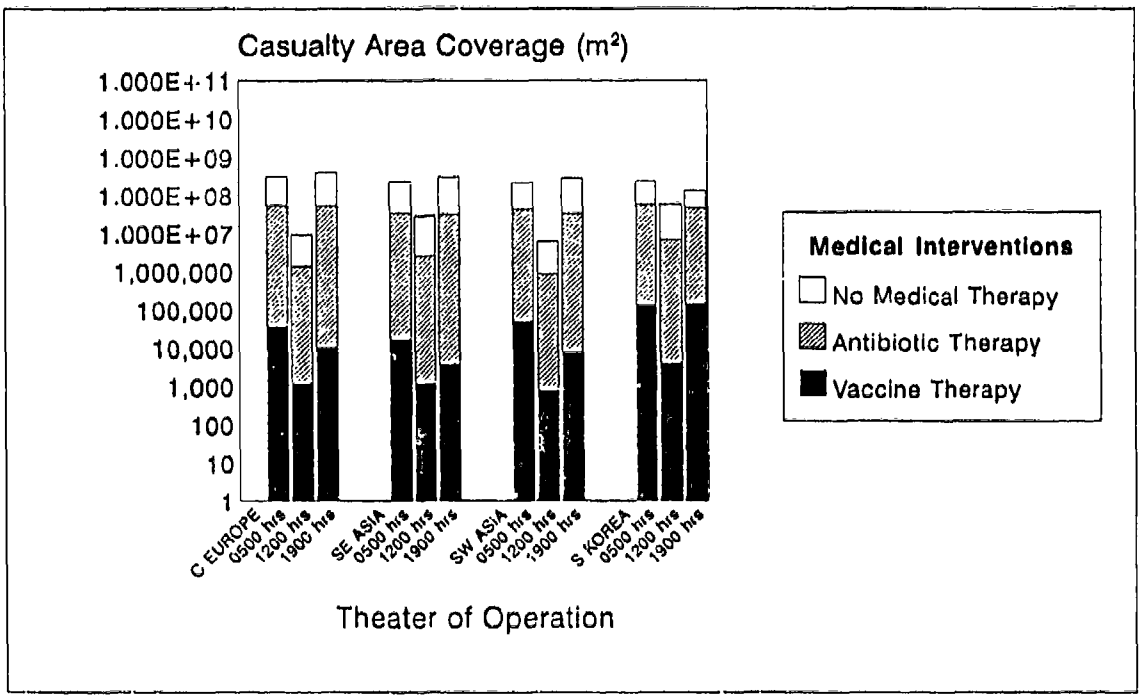

Figure 80. Artillery: Casualty Area Coverage

5.4 TWO HUNDRED-FORTY (240) ROCKETS FILLED WITH *B. ANTHRACIS*

This simulation represented a multiple rocket launcher (MRL) attack with two hundred-forty 122 millimeter rockets each filled with 1 kg of dry *B. anthracis* released explosively. This attack was represented for three release times in four climates. The fireplan was constructed based on doctrine originated by the former Soviet Union for 40 rockets on 6 multiple rocket launchers. In terms of level of effort, the rocket attack represents a tenfold increase in agent released compared to the twenty-four 1 kg artillery (24 kg total agent mass) scenarios. Transport time for the 0500 and 1900 hours releases was approximately 5 to 10 hours, and the 1200 hours releases would take approximately 3 to 5 hours to clear the target.

The footprint charts (Figures 81-92) clearly reflect the severity of the hazard that would result from the delivery of this mass of agent (240 kg) as compared to the tactical ballistic missile which released a total of 78 kg of agent over a much larger area. This attack would achieve the greatest peak concentration of spores and, in turn, the most severe challenge to the medical products. Note the extent of the white contours within the footprints representing lethal doses of 50 percent or greater even for units protected by antibiotic therapy.

The intensity of the MRL attack at Position 1 in the footprint would break through the protective ratios of the vaccine for the 0500 and 1900 hours releases in the South Korean winter climate (Figures 90 and 92), the only instances in all the scenarios portrayed in this study where the vaccine would fail to provide 100 percent unit effectiveness to soldiers in MOPP 0. Even though the MRL attack could present a challenge to the vaccine in the South Korean winter climate, unit effectiveness would still be expected to remain well above 90 percent. This would indicate that the intensity of the attack, as indicated by the peak number of spores, would only slightly breach the protective barrier of the vaccine. The implication for antibiotic therapy is that in an attack of this intensity, there would be a militarily significant portion of the target area for which the antibiotic therapy provides insufficient protection. Note that the white contour, representing the area of the hazard where antibiotic therapy would be challenged without masking, extends 20 km downwind from the point of the attack for the 0500 and 1900 hours releases in South Korea. Note also that MOPP 4 alone in the Korean environments could only achieve a 30 percent level of unit effectiveness for the 0500 and 1900 hours releases for units under direct attack. Antibiotic therapy supplemented by masking would be required to sustain unit effectiveness following an attack of this severity. Further, masking would have to occur prior to the attack to achieve the protective benefits depicted in this study since MOPP 4 was simulated as a preparatory stance in advance of the attack. This attack scenario makes an exceedingly strong case for predeployment vaccination.

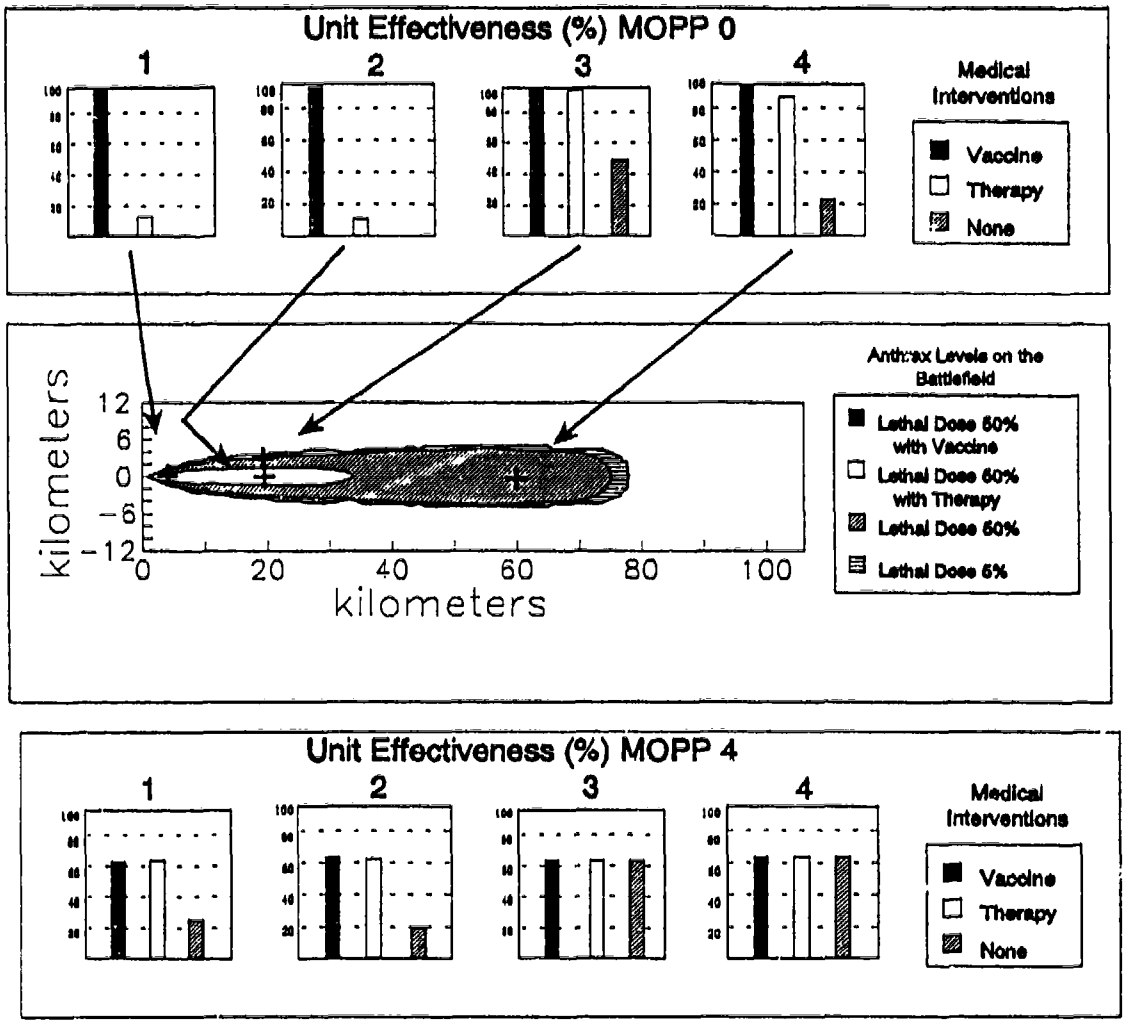

Figure 81. MRL in Southwest Asia at 0500 Hours: Artillery Unit Effectiveness with Medical Interventions

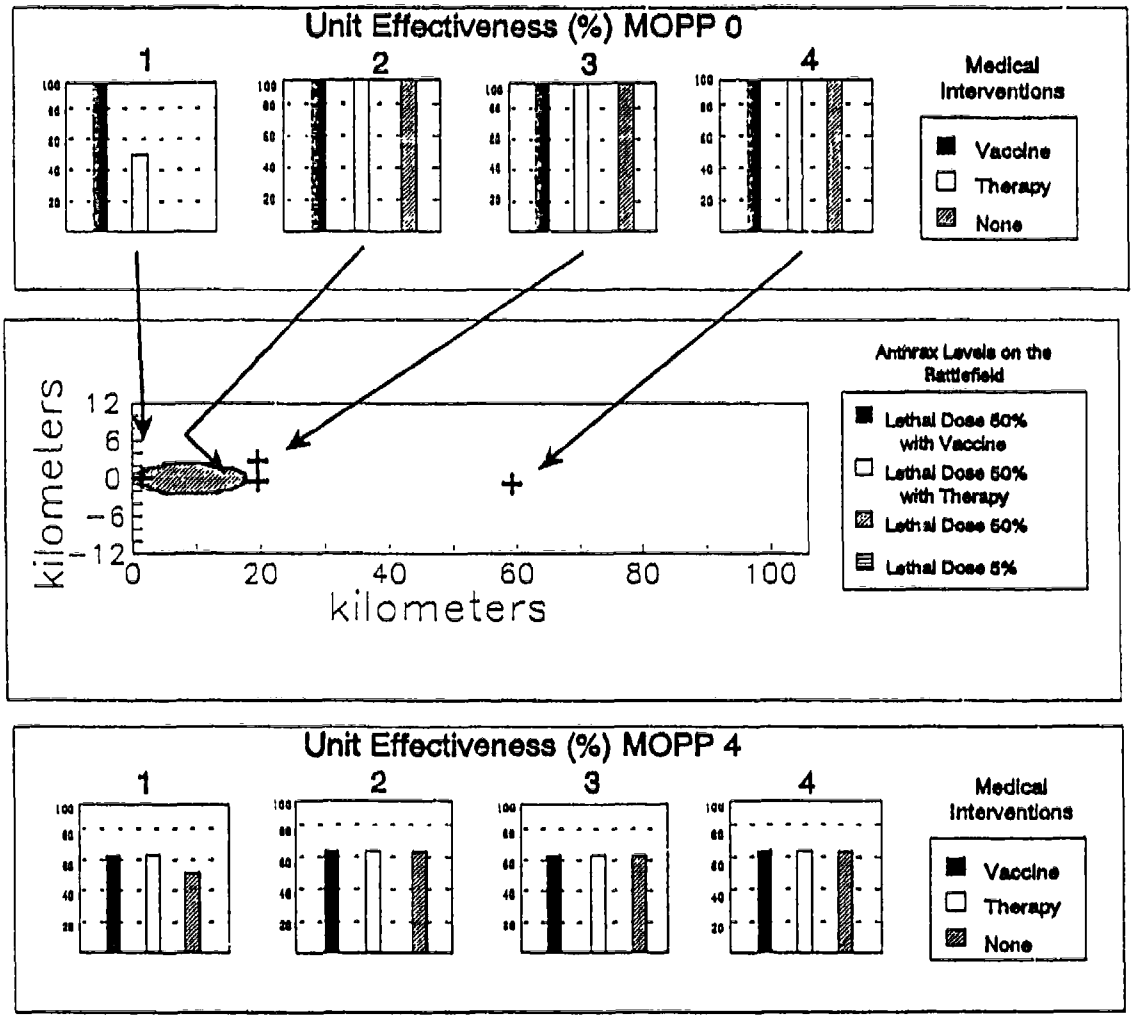

Figure 82. MRL in Southwest Asia at 1200 Hours: Artillery Unit Effectiveness with Medical Interventions

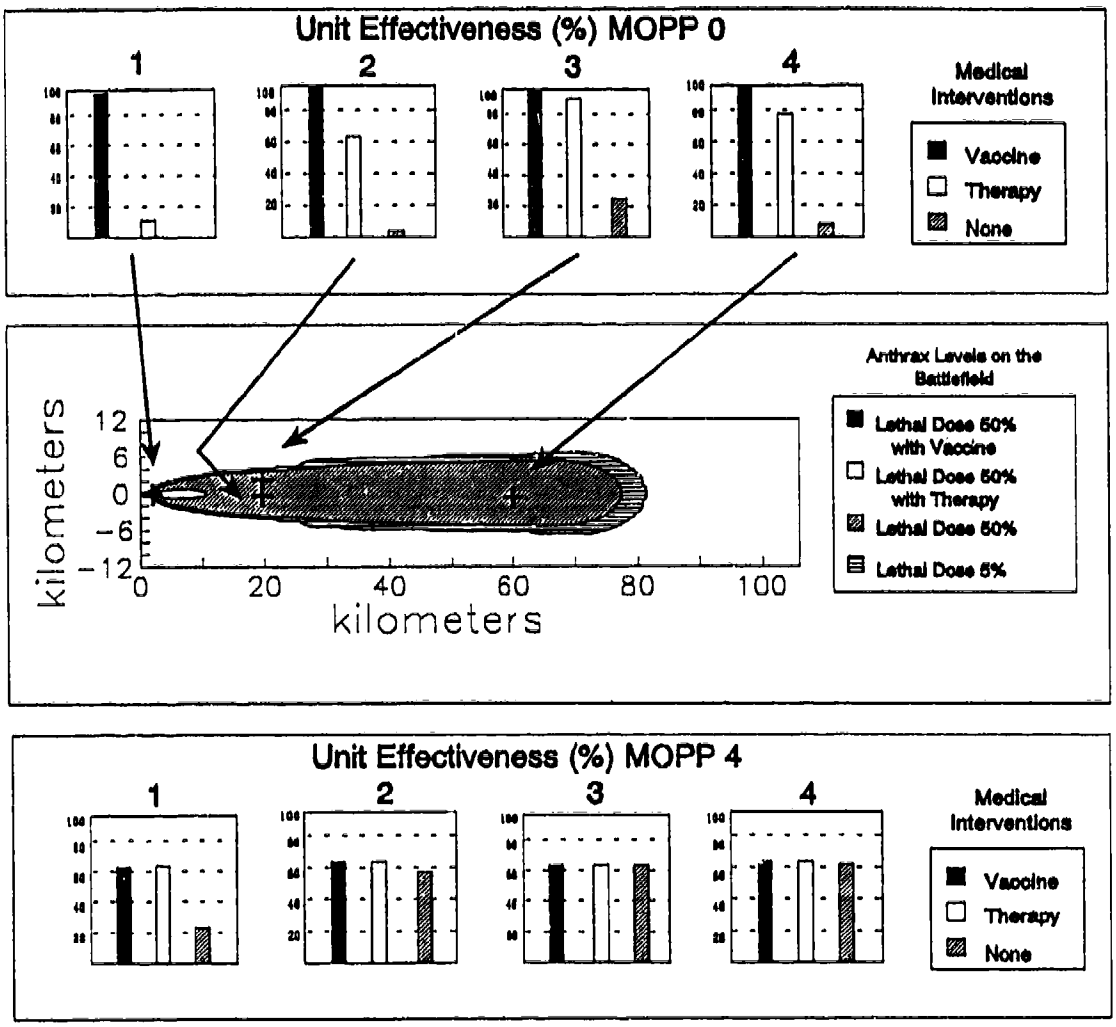

Figure 83. MRL in Southwest Asia at 1900 Hours: Artillery Unit Effectiveness with Medical Interventions

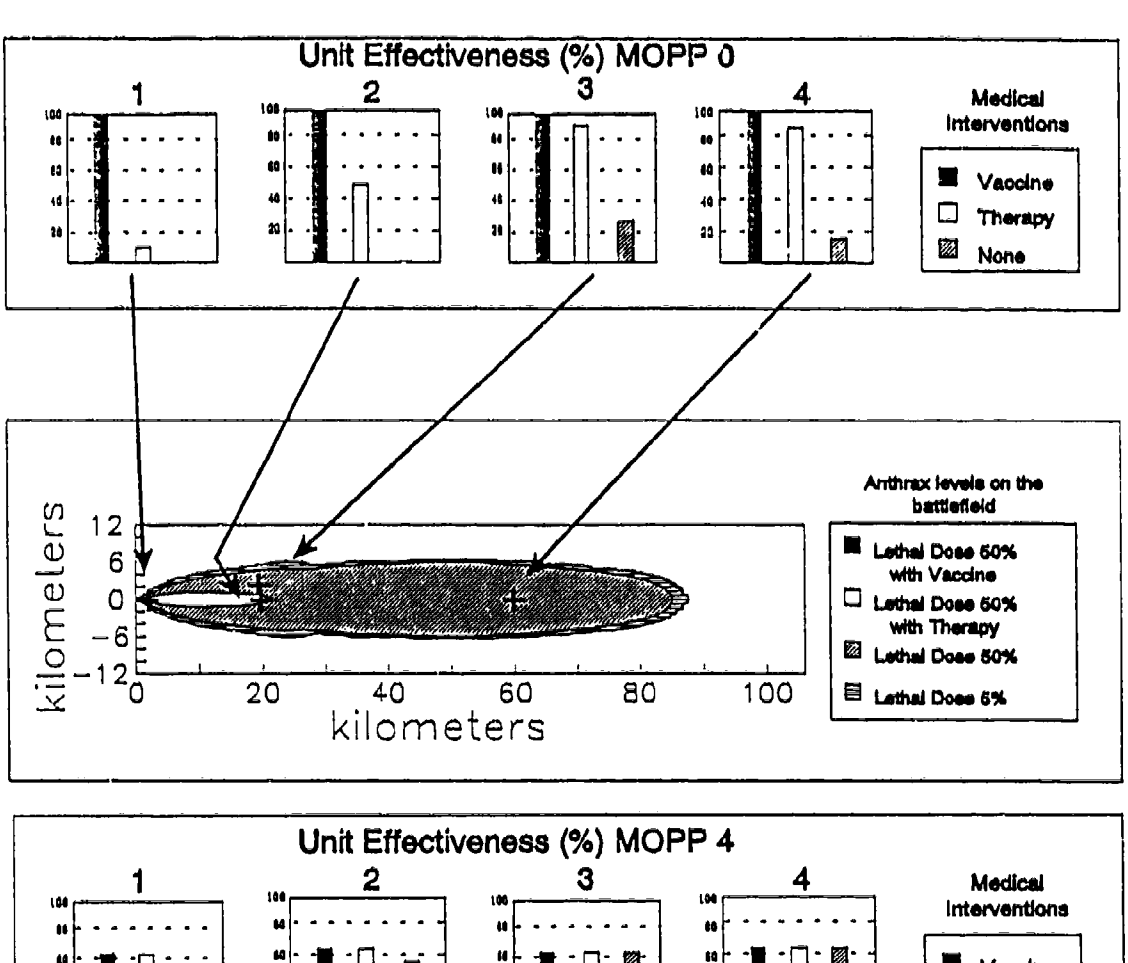

Figure 84. MRL in Southeast Asia at 0500 Hours: Artillery Unit Effectiveness with Medical Interventions

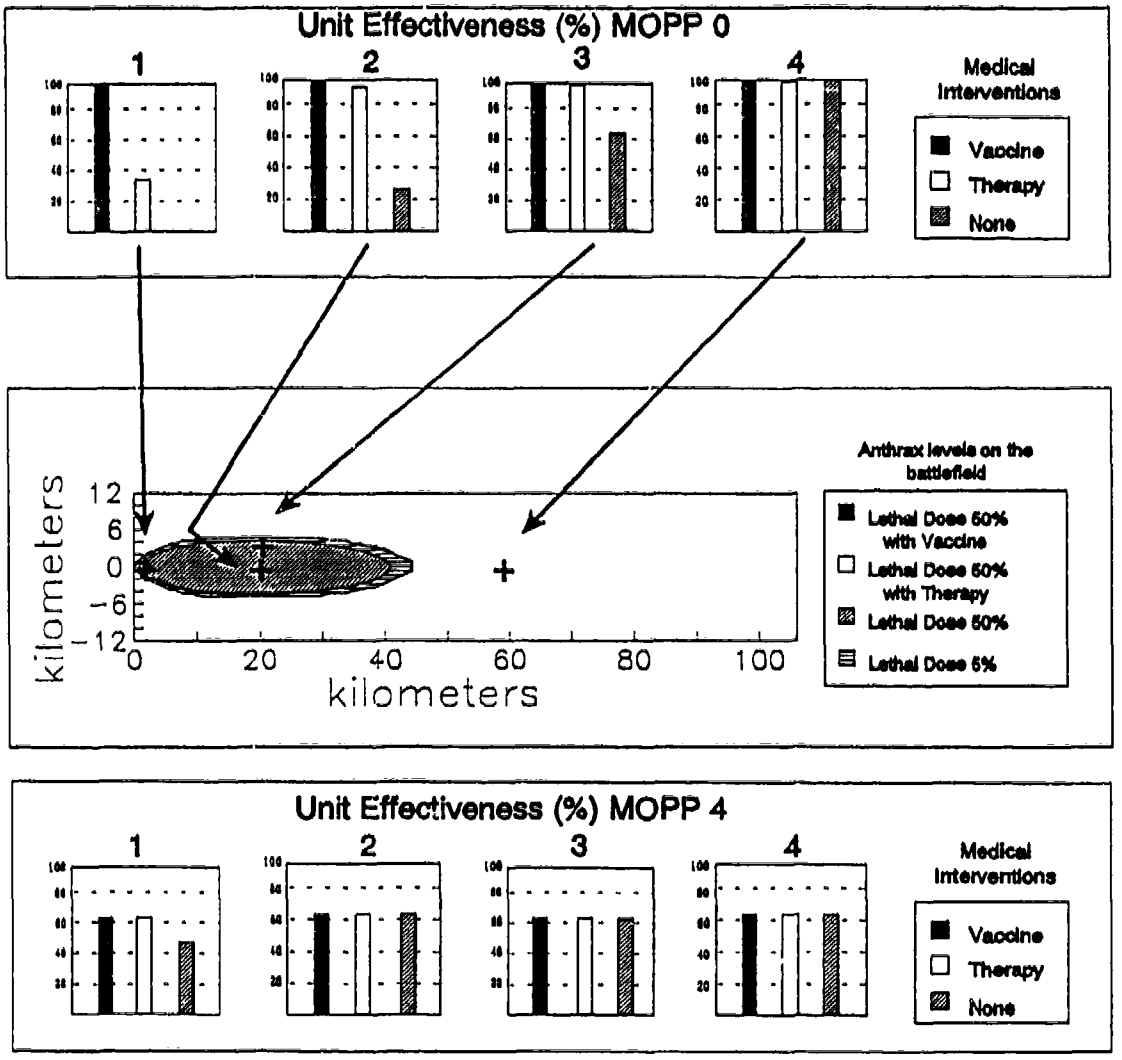

Figure 85. MRL in Southeast Asia at 1200 Hours: Artillery Unit Effectiveness with Medical Interventions

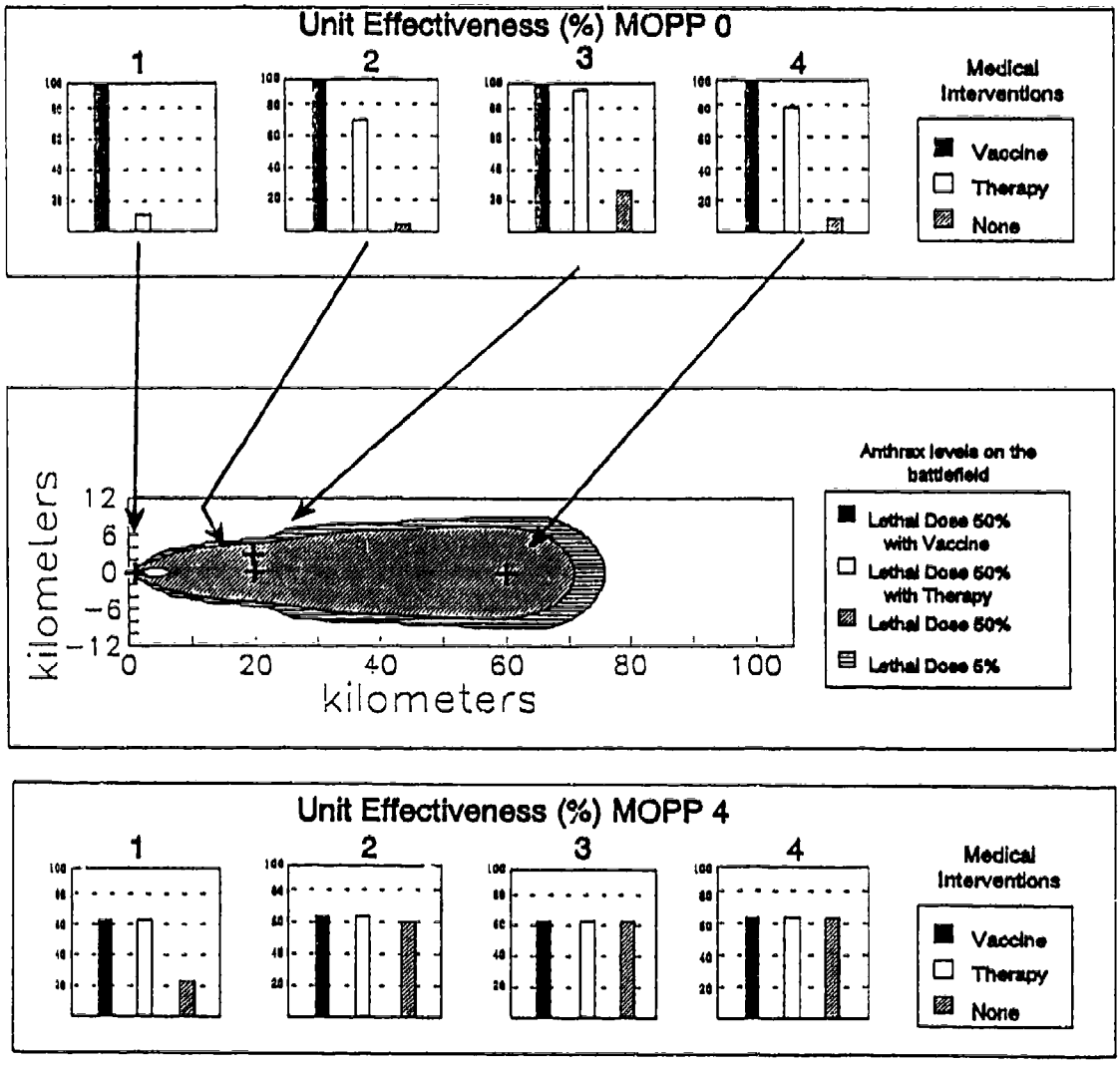

Figure 86. MRL in Southeast Asia at 1900 Hours: Artillery Unit Effectiveness with Medical Interventions

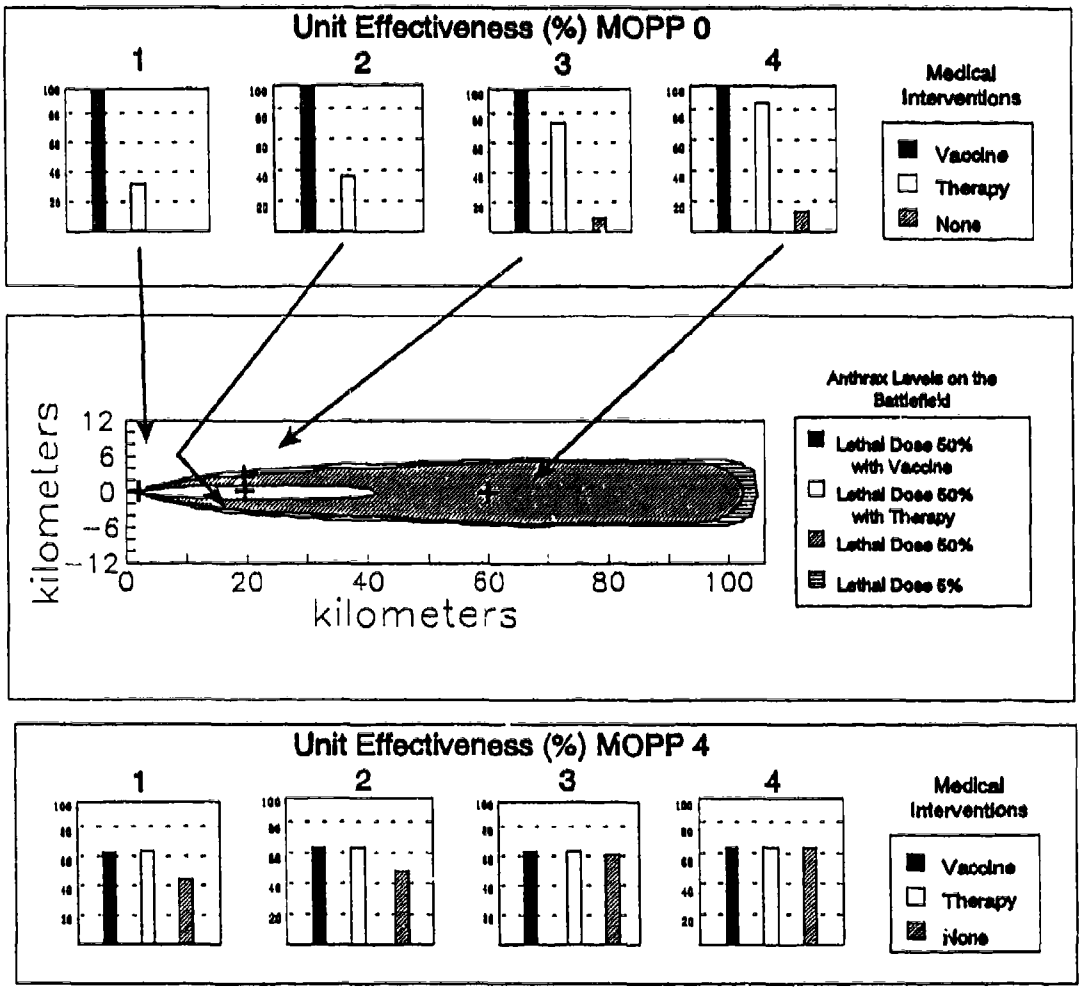

Figure 87. MRL in Central Europe at 0500 Hours: Artillery Unit Effectiveness with Medical Interventions

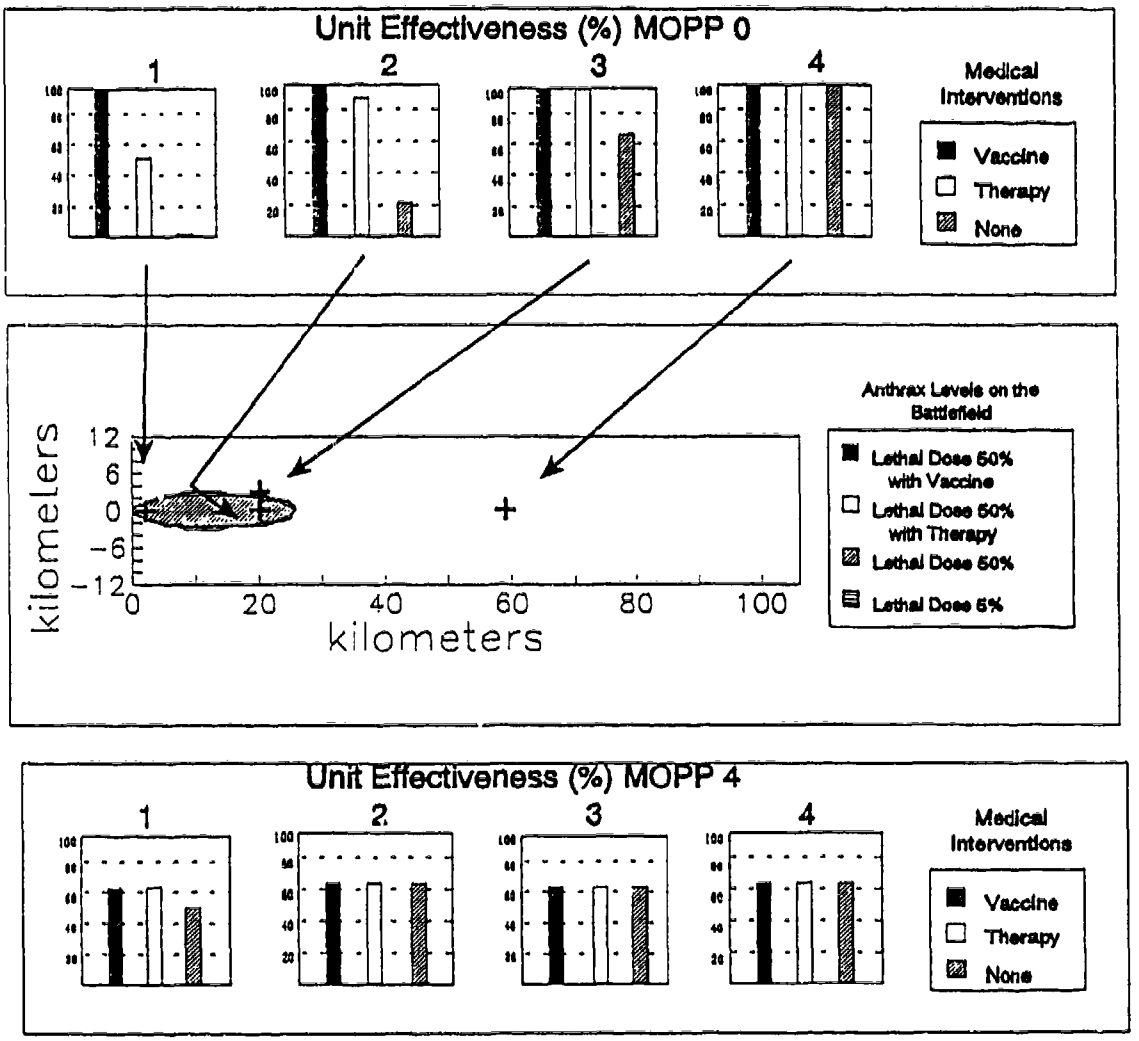

Figure 88. MRL in Central Europe at 1200 Hours: Artillery Unit Effectiveness with Medical Interventions

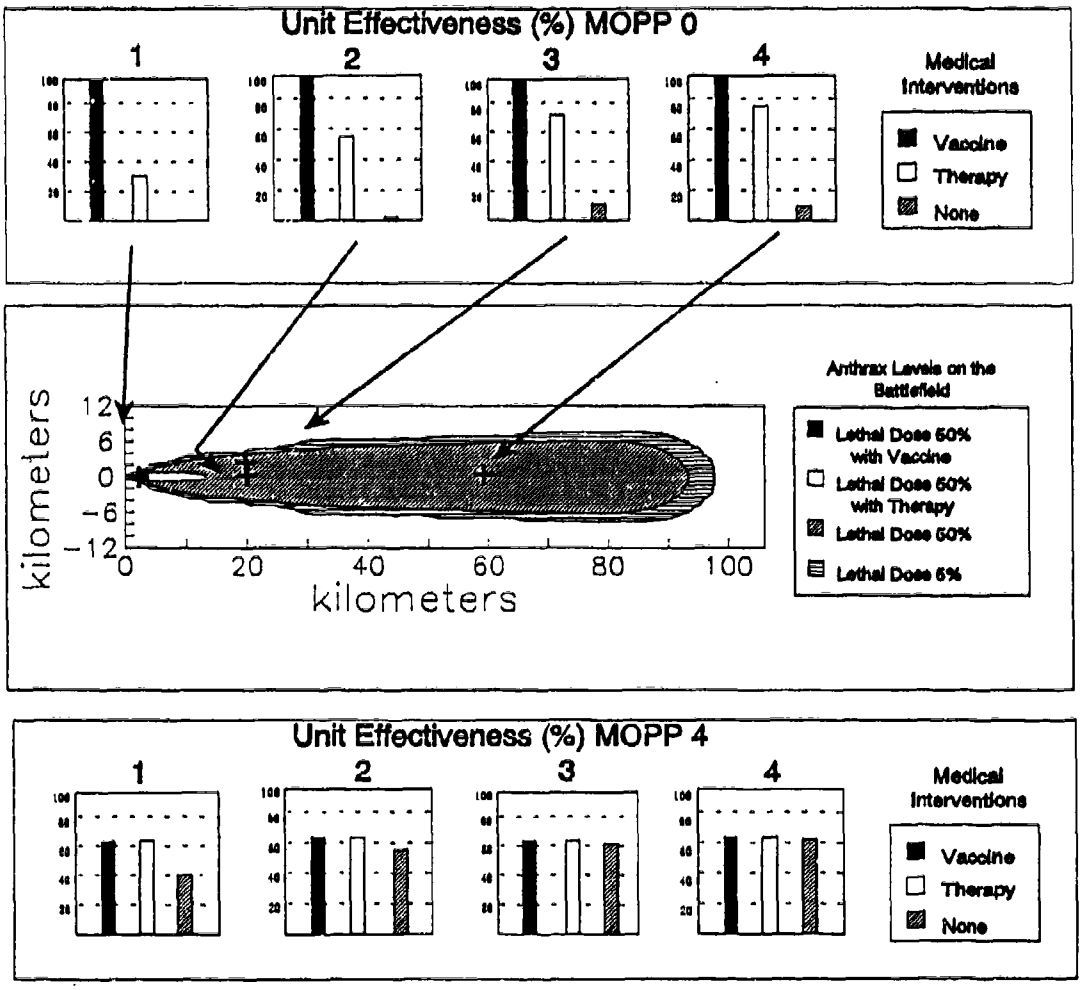

Figure 89. MRL in Central Europe at 1900 Hours: Artillery Unit Effectiveness with Medical Interventions

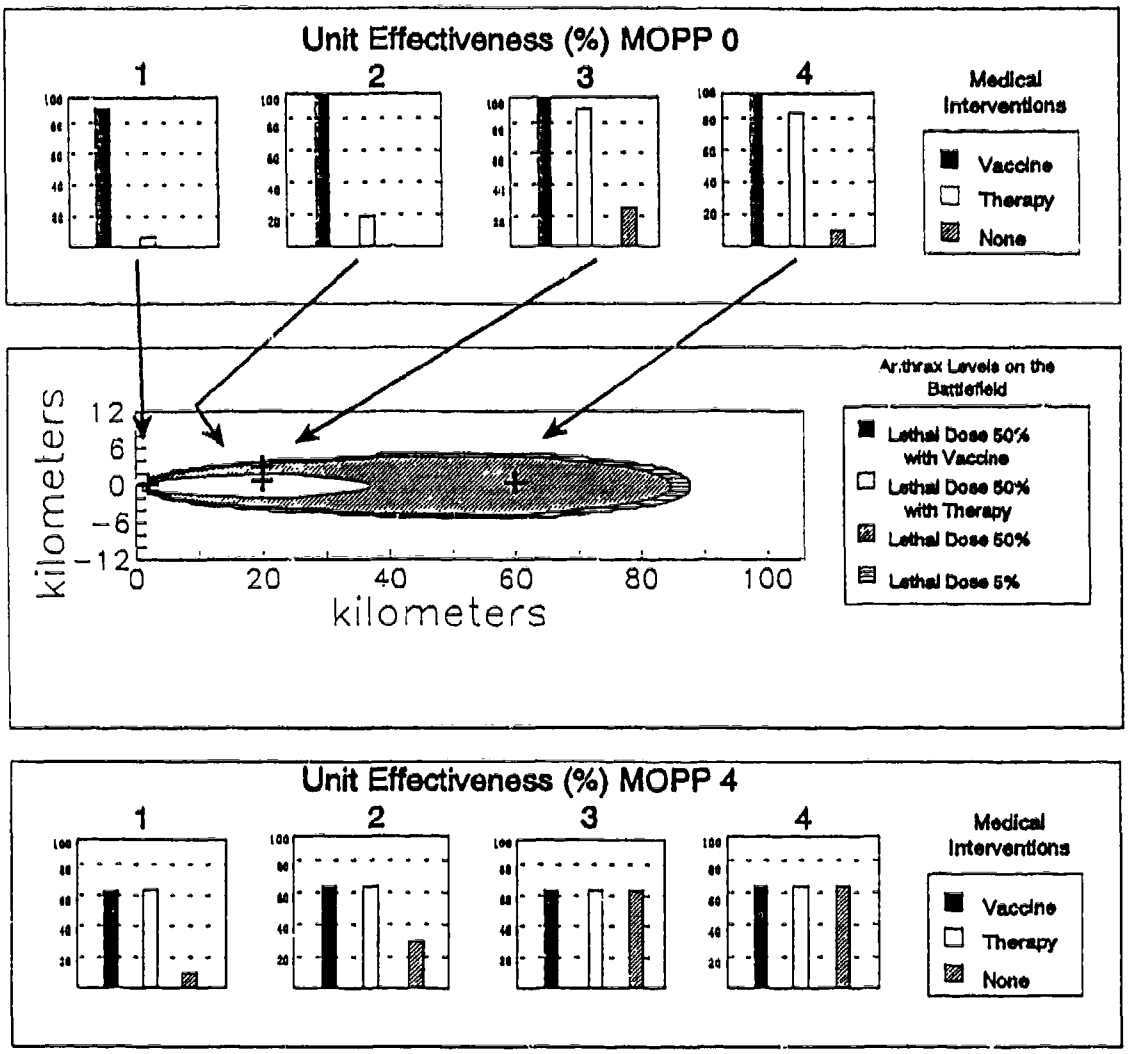

Figure 90. MRL in South Korea at 0500 Hours: Artillery Unit Effectiveness with Medical Interventions

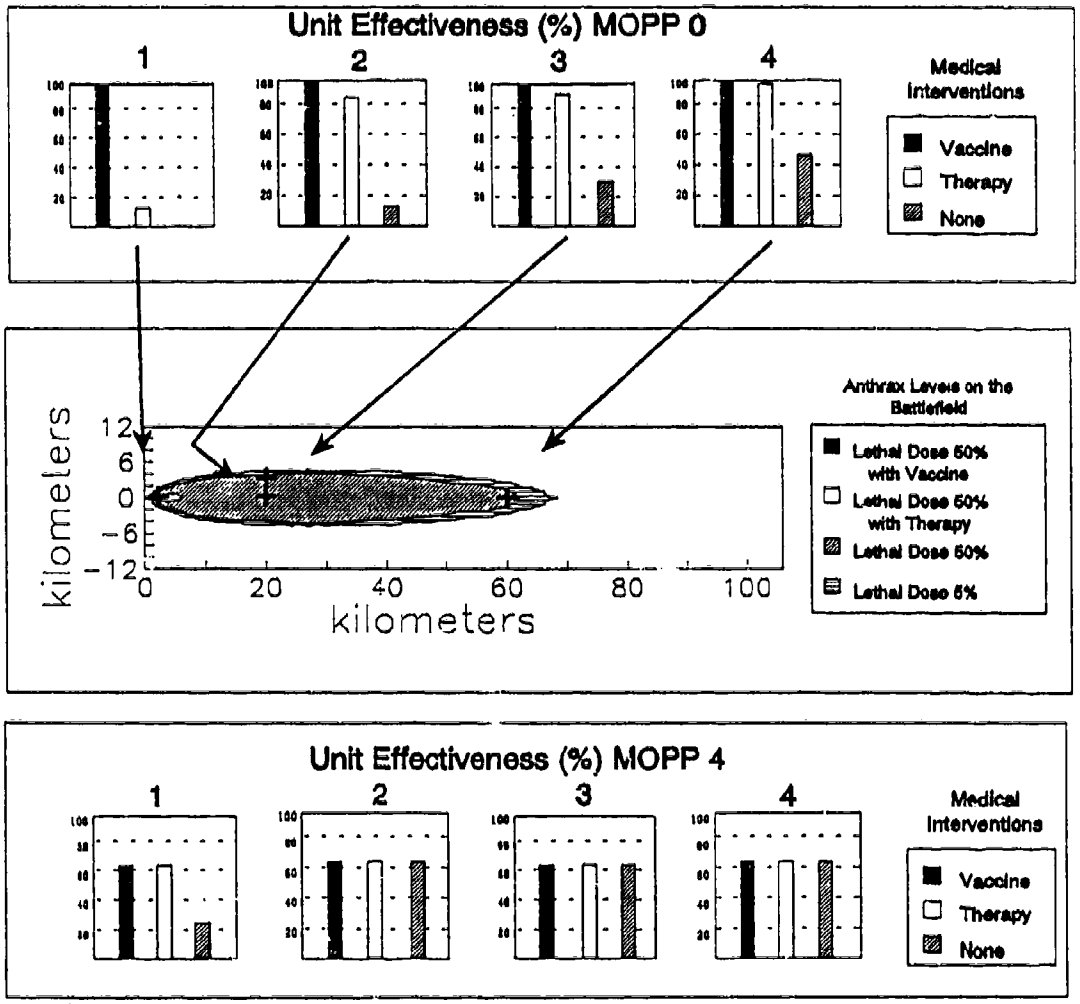

Figure 91. MRL in South Korea at 1200 Hours: Artillery Unit Effectiveness with Medical Interventions

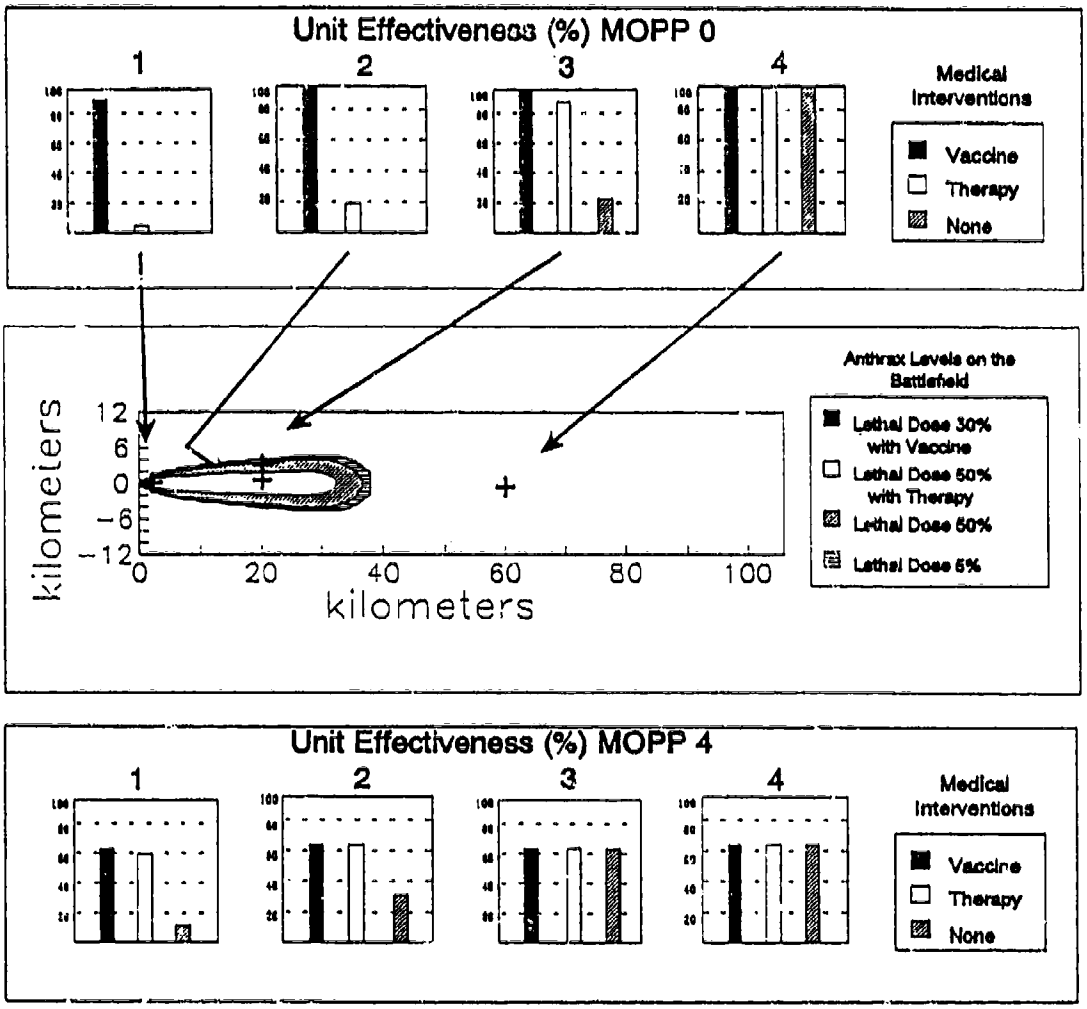

Figure 92. MRL in South Korea at 1900 Hours: Artillery Unit Effectiveness with Medical Interventions

The spore area coverage charts (Figures 93-96) for the MRL and artillery attacks are remarkably similar with the exception that the MRL peak number of spores was about an order of magnitude greater than that of the artillery for all regional climates and times of release. The similarity of the MRL and artillery fireplans is the ability to achieve an area of fairly even saturation, albeit over a smaller area of the target than would be covered by weapon systems such as the tactical ballistic missile, spray device or intercontinental ballistic missile. There is a pronounced difference in the spore area coverage for the 1200 hours releases of the two weapon systems, attributable to differences in the total source strengths of the two attack scenarios of an order of magnitude, i.e., 24 kg for the artillery attack versus 240 kg for the MRL attack.

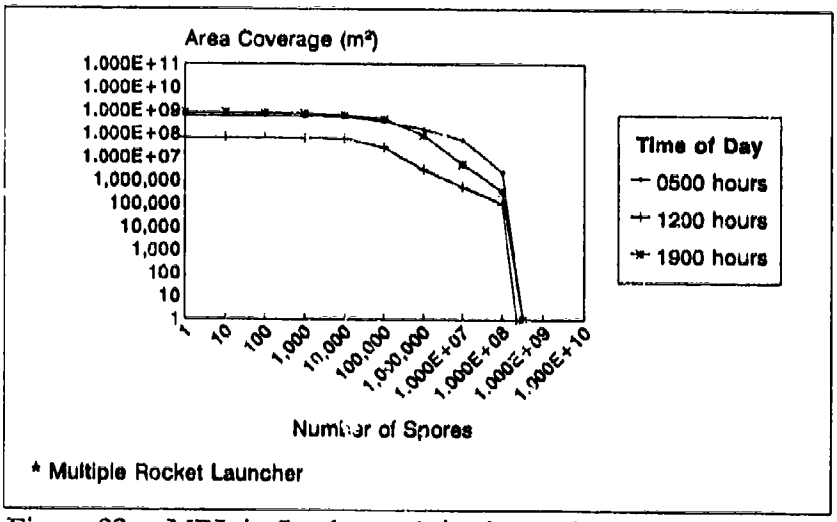

Figure 93. MRL in Southwest Asia: Spore Area Coverage

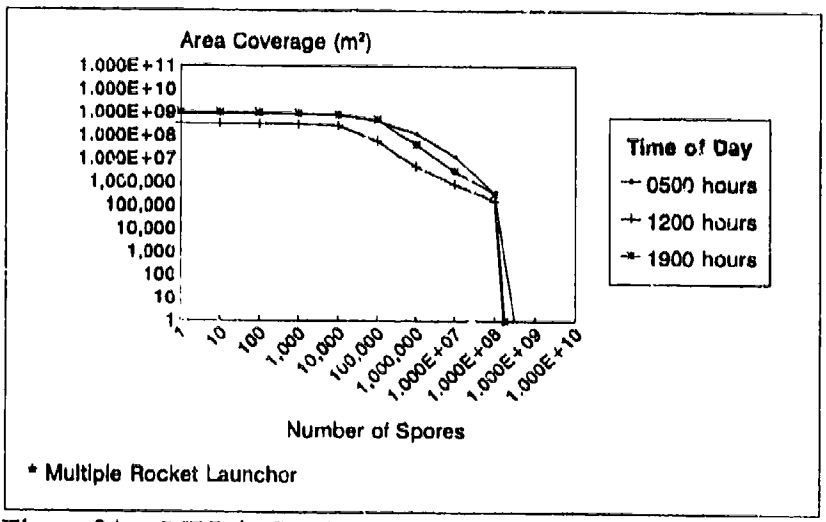

Figure 94. MRL in Southeast Asia: Spore Area Coverage

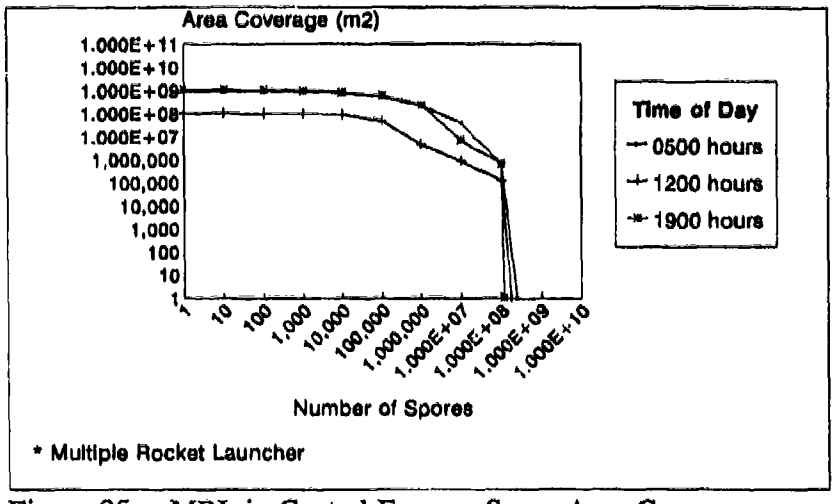

Figure 95. MRL in Central Europe: Spore Area Coverage

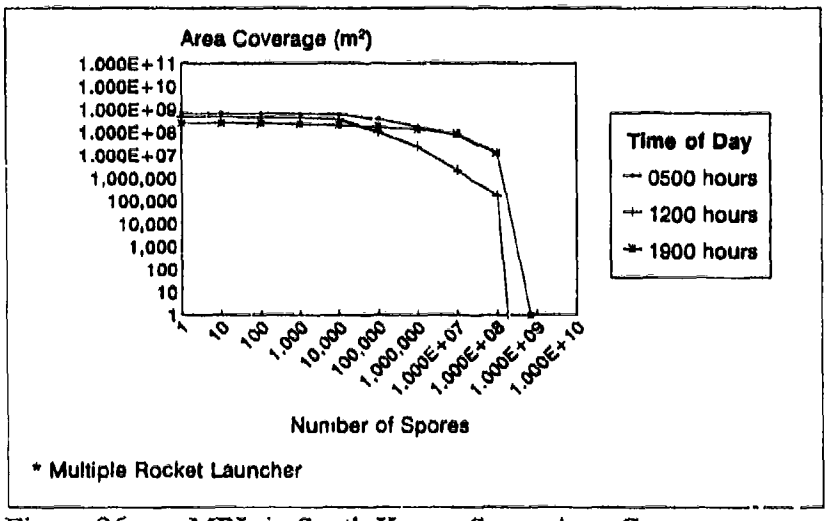

Figure 96. MRL in South Korea: Spore Area Coverage

Figure 97 reflects the casualty area coverage potential of the MRL system for each of the regions. For Central Europe, Southeast Asia and Southwest Asia, the vaccine would reduce the casualty area coverage by approximately three orders of magnitude for the 0500 and 1900 hours releases. For the 1200 hours releases, the reduction would be about four orders of magnitude. For the South Korean winter climate, the medical interventions would be more severely challenged as evidenced also in the footprint and spore area coverage charts. Even with vaccine protection, the area covered by lethal levels of *B. anthracis* would amount to at least 1 km^2. The antibiotic therapy achieves less than an order of magnitude reduction in casualty area coverage in all cases.

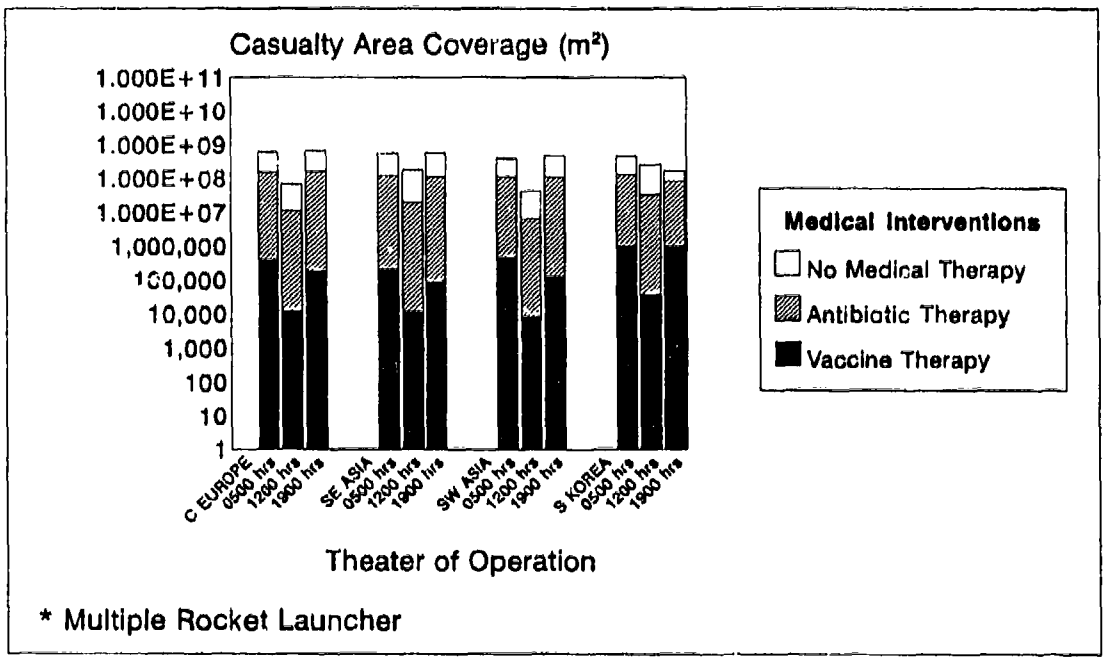

Figure 97. MRL: Casualty Area Coverage

5.5 *BACILLUS ANTHRACIS* DELIVERED BY SPRAY

The spray attacks simulated an aerial release of 1,200 kilograms of dry *B. anthracis* released through a single nozzle for three release times in four climates. An agent release was simulated along a 100 km line, 60 meters above ground, resulting in a flux rate of 12 kg/km. This attack represented a VERY intense hazard. Liquid *B. anthracis* could also be released as a spray.

The hazard footprints (Figures 98-109) show that the quantity of agent disseminated by this system could affect considerable distances downwind which roughly approximate 12 to 20 hours of transport with the 0500, 1200, and 1900 hours releases. The footprint charts also show the unit effectiveness at various points with three potential therapy options. Note that for a unit in MOPP 0, vaccination would be very effective in ensuring survival from this attack. In contrast, a considerable fraction of the spray footprint would represent a threat sufficiently lethal that even prompt use of antibiotic therapy would not prevent unit effectiveness from dropping to 60 percent. This drop in unit effectiveness would represent loss of life rather than the temporary degradation of performance to 63 percent due to the assumption of MOPP 4.

One of the more notable characteristics of the spray attack is the evenness of the hazard level along the line of spray as well as downwind. Note the similarity in unit effectiveness for units assuming MOPP 0 at positions 2 and 3 in the spray footprints. Due to the large extent of hazard, this attack scenario would clearly constitute an attack with a weapon of mass destruction. What is so remarkable is that attacks by weapons with such enormous potential for loss of life could be simply negated through a program of vaccination prior to the outbreak of hostilities.

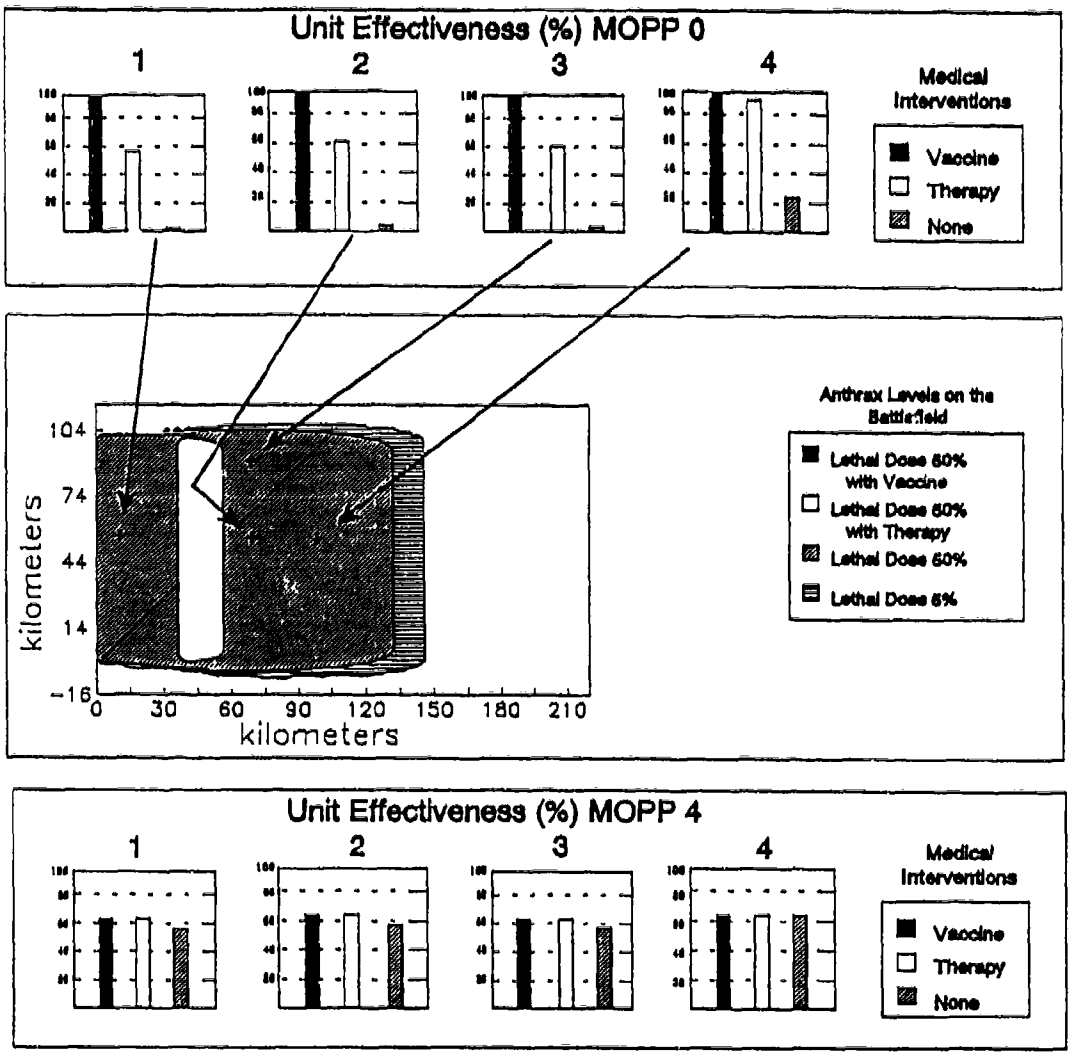

Figure 98. Aerial Spray in Southwest Asia at 0500 Hours: Artillery Unit Effectiveness with Medical Interventions

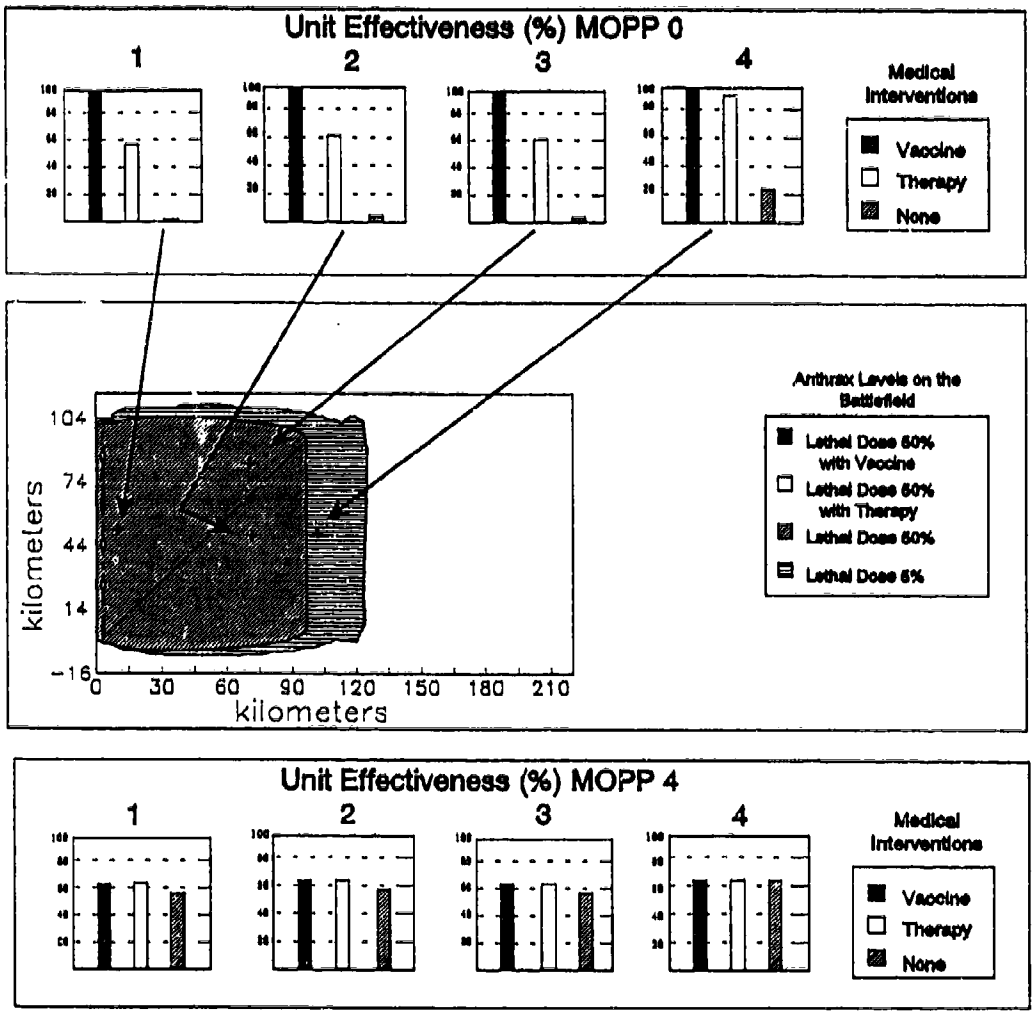

Figure 99. Aerial Spray in Southwest Asia at 1200 Hours: Artillery Unit Effectiveness with Medical Interventions

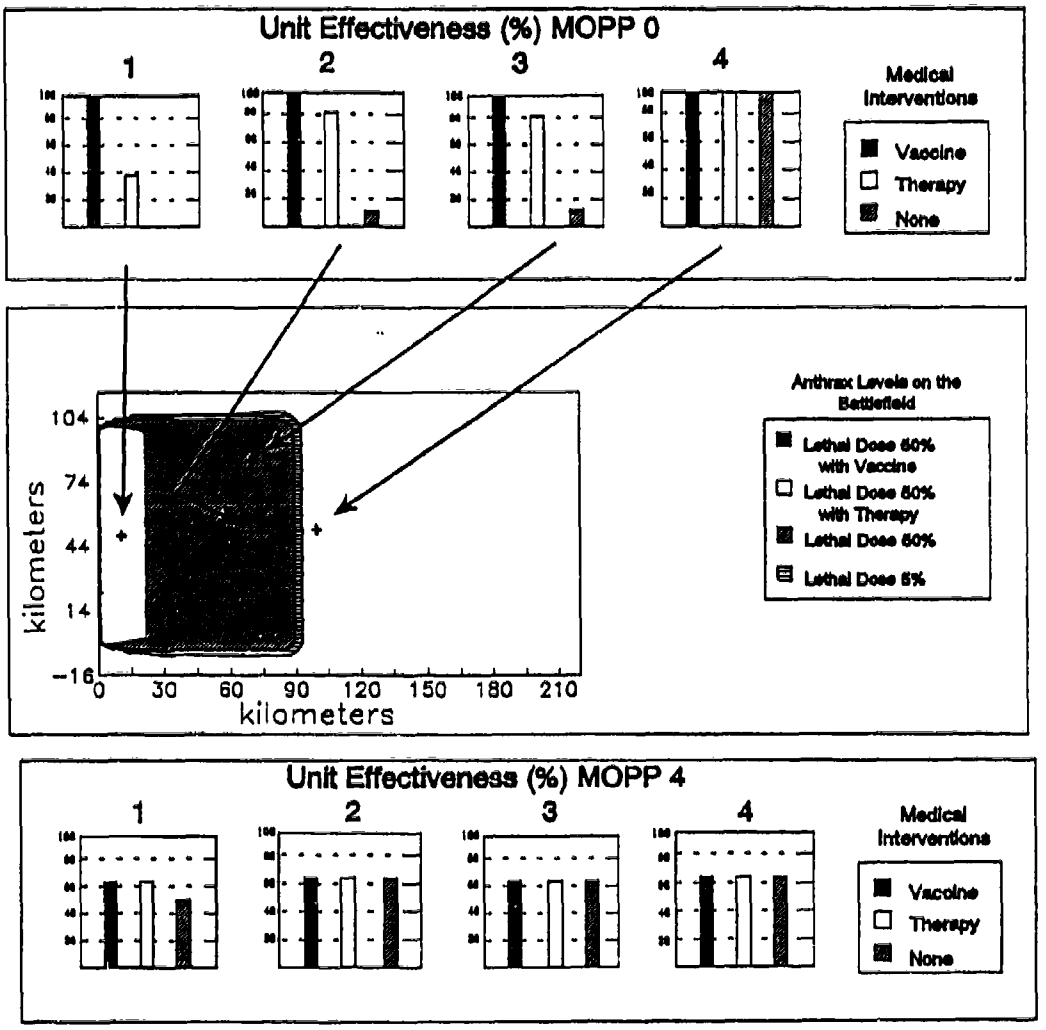

Figure 100. Aerial Spray in Southwest Asia at 1900 Hours: Artillery Unit Effectiveness with Medical Interventions

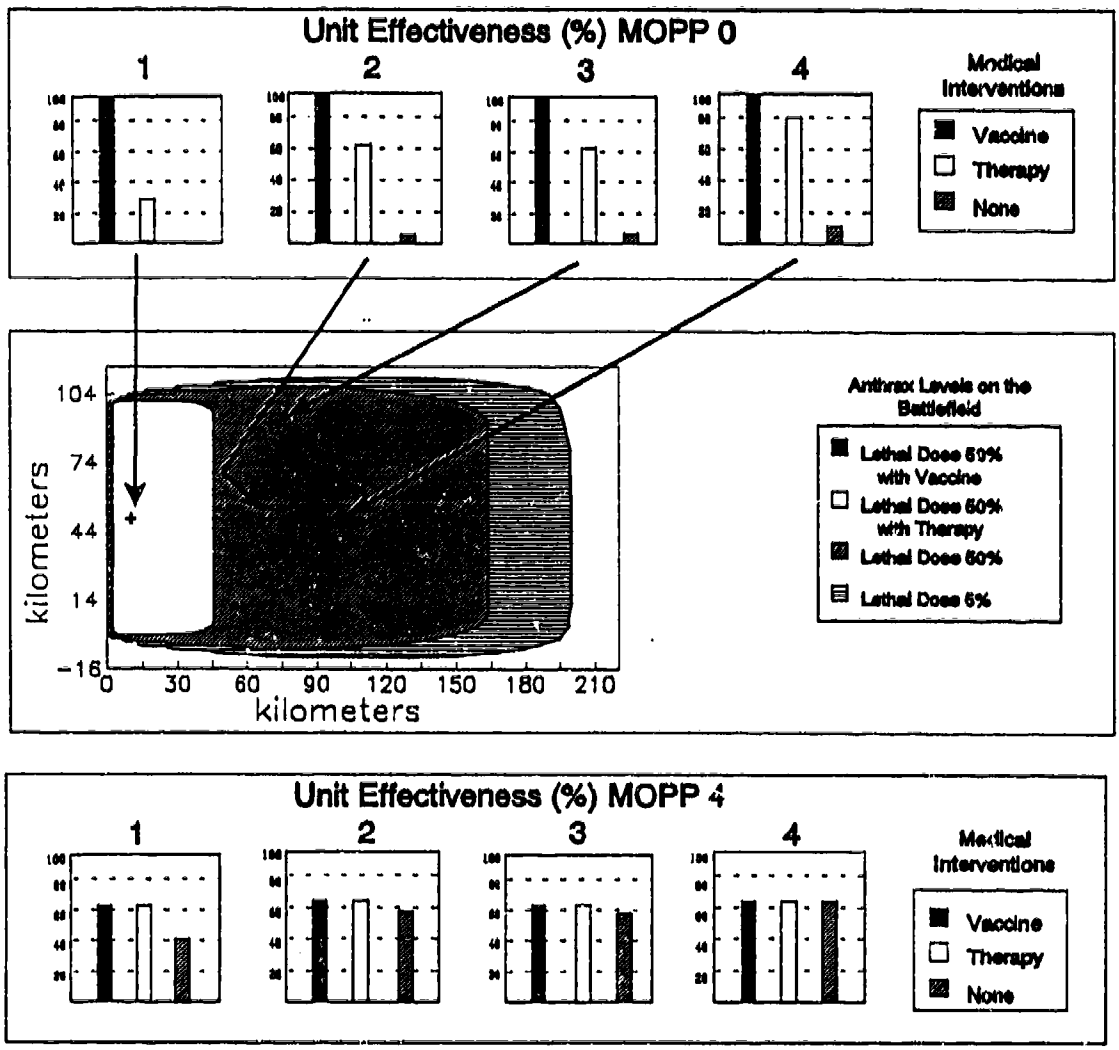

Figure 101. Aerial Spray in Southeast Asia at 0500 Hours: Artillery Unit Effectiveness with Medical Interventions

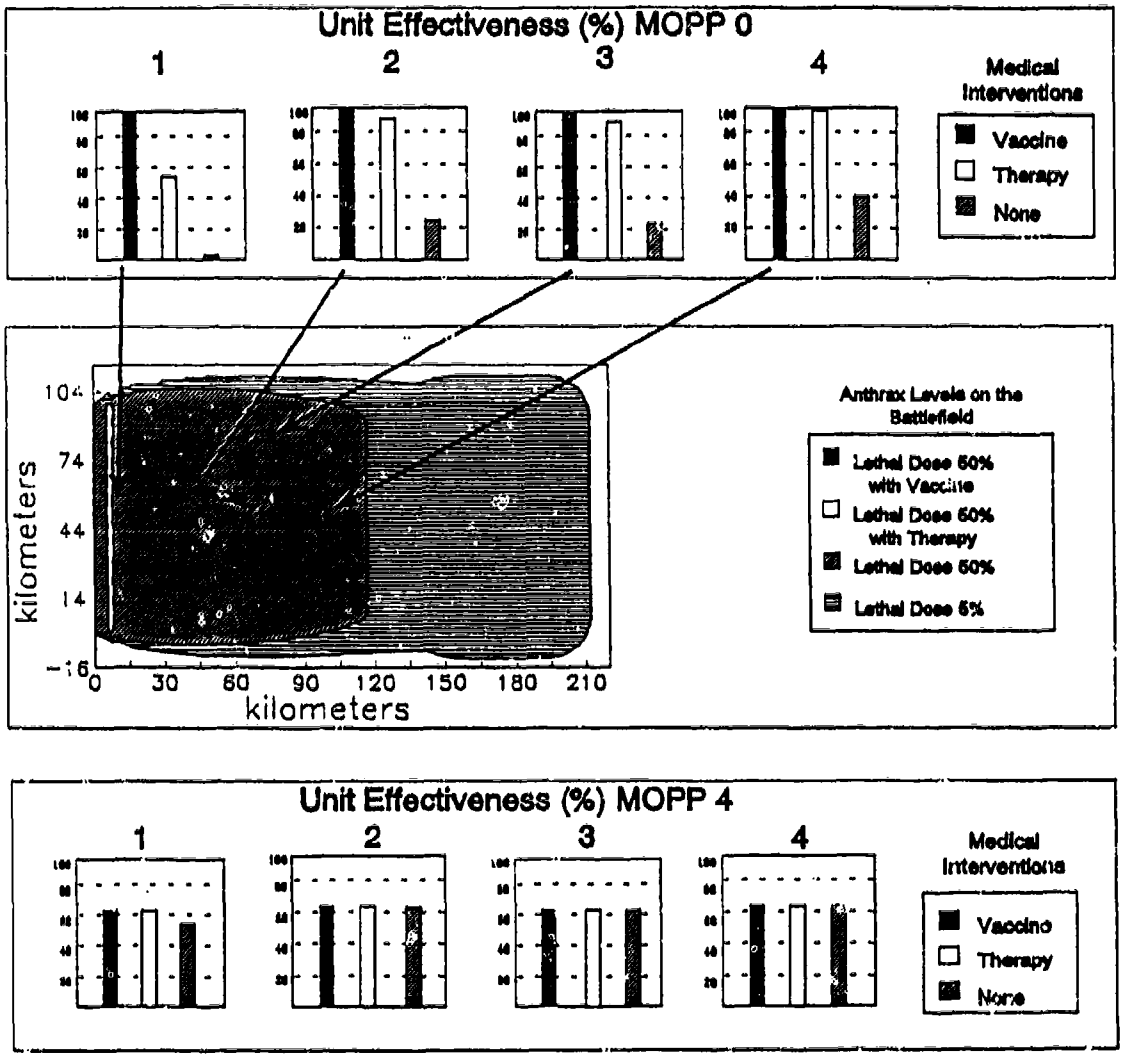

Figure 102. Aerial Spray in Southeast Asia at 1200 Hours: Artillery Unit Effectiveness with Medical Interventions

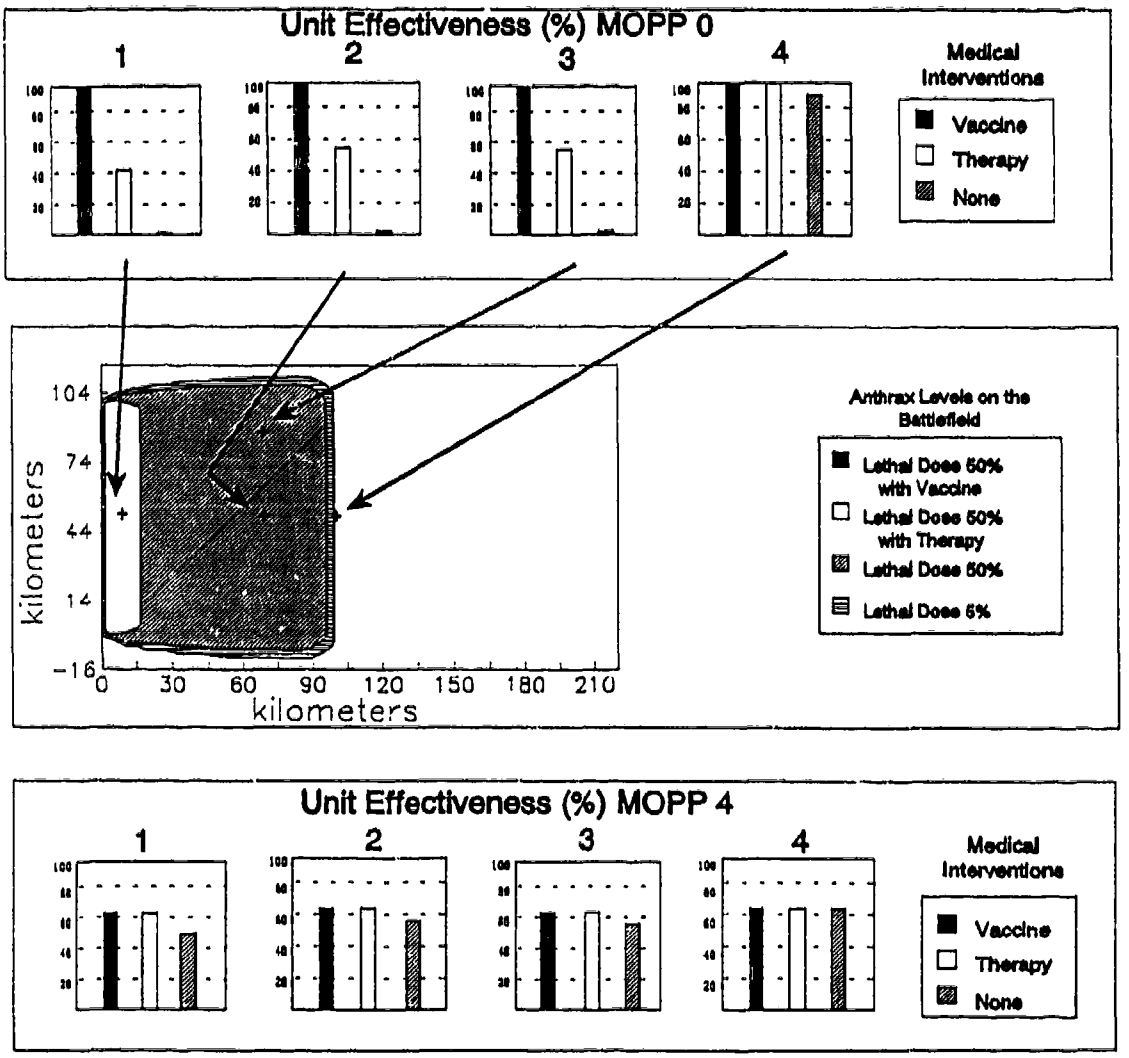

Figure 103. Aerial Spray in Southeast Asia at 1900 Hours: Artillery Unit Effectiveness with Medical Interventions

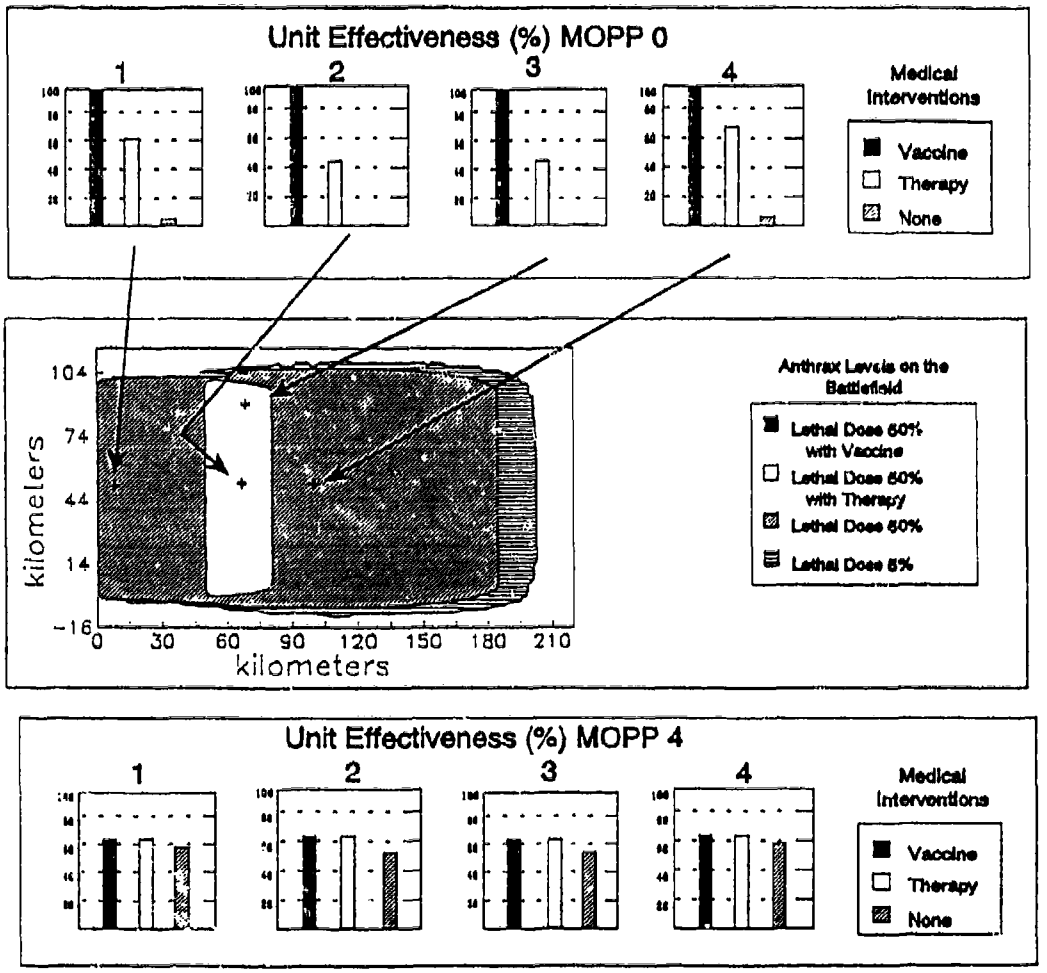

Figure 104. Aerial Spray in Central Europe at 0500 Hours: Artillery Unit Effectiveness with Medical Interventions

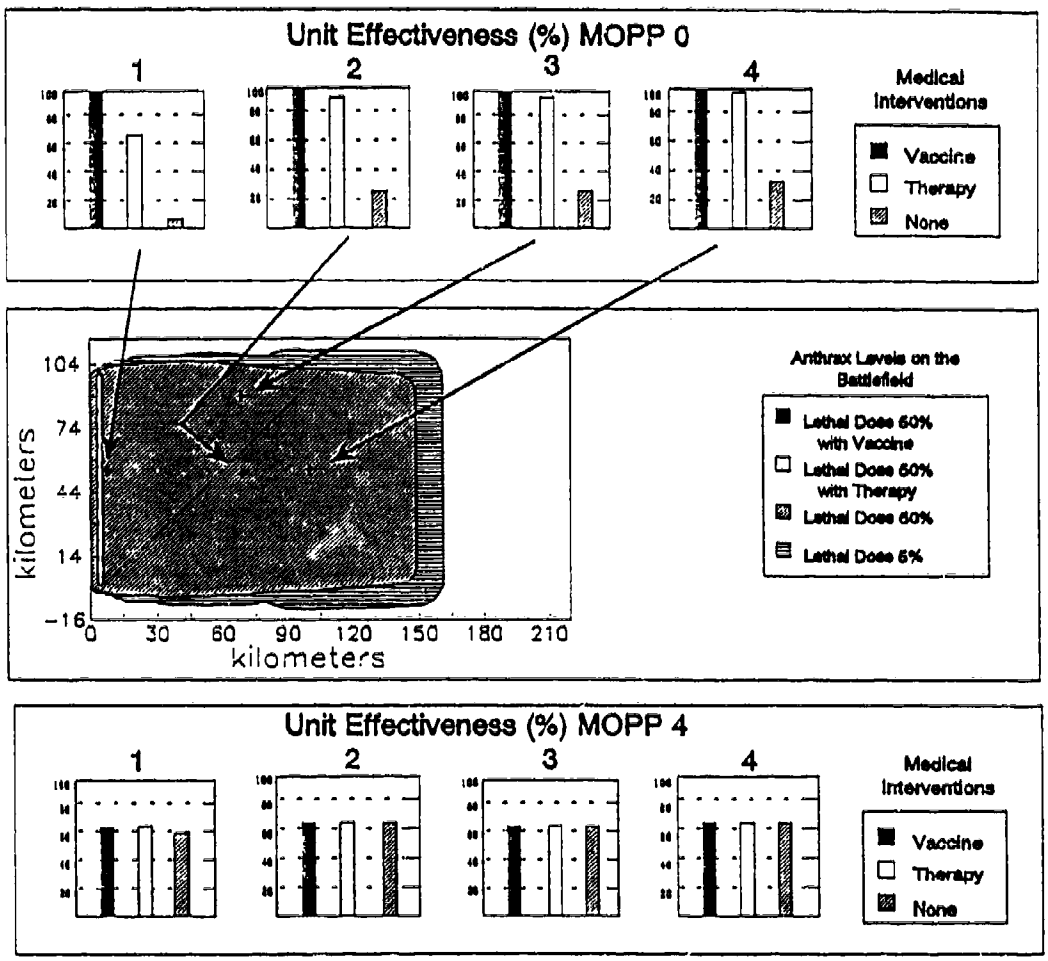

Figure 105. Aerial Spray in Central Europe at 1200 Hours: Artillery Unit Effectiveness with Medical Interventions

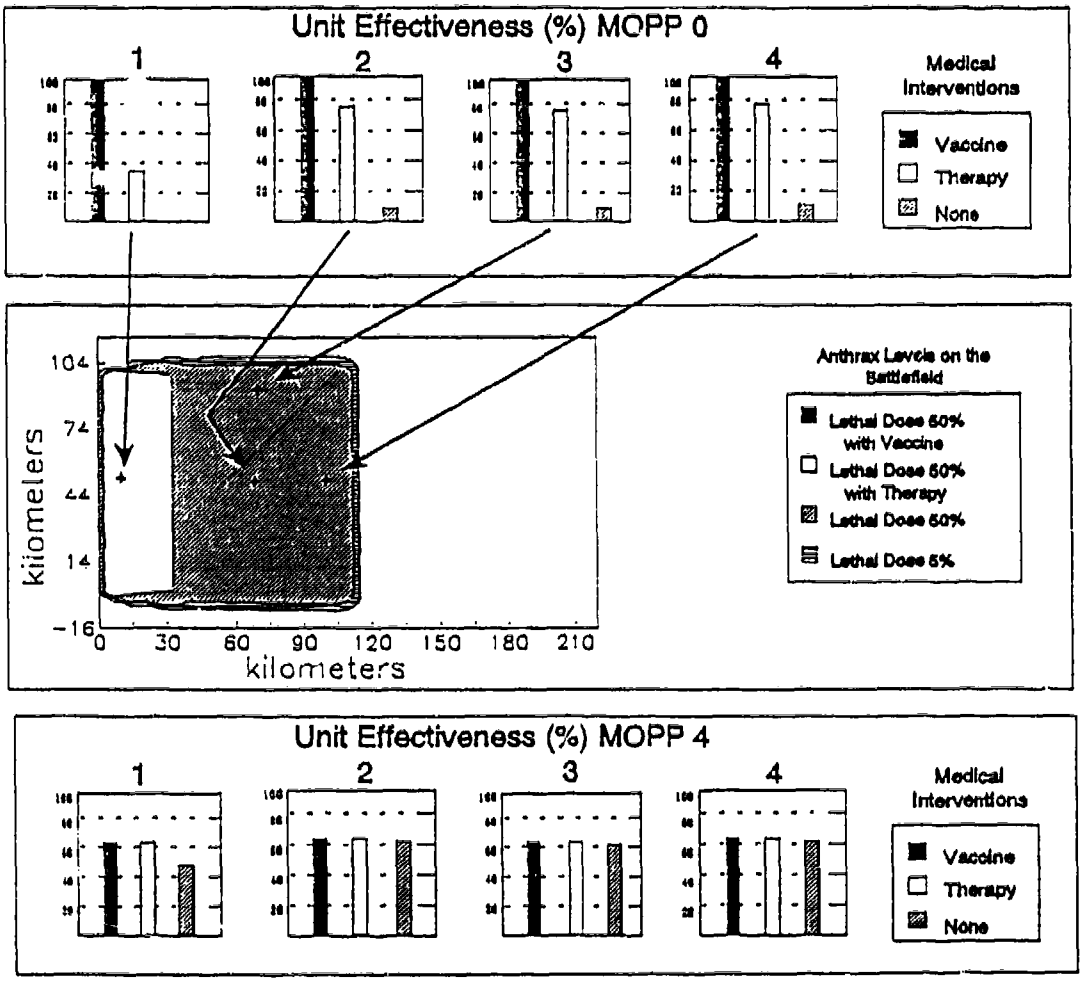

Figure 106. Aerial Spray in Central Europe at 1900 Hours: Artillery Unit Effectiveness with Medical Interventions

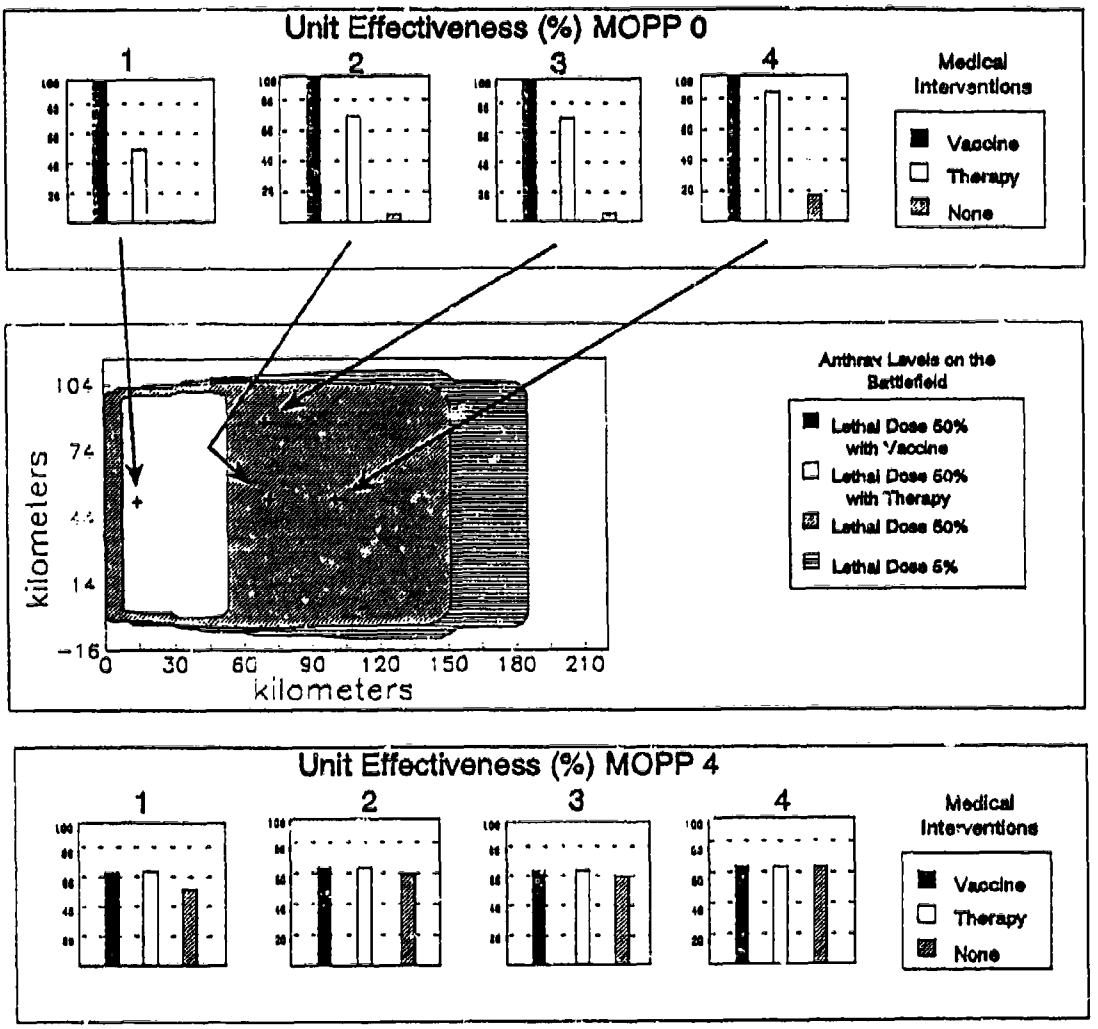

Figure 107. Aerial Spray in South Korea at 0500 Hours: Artillery Unit Effectiveness with Medical Interventions

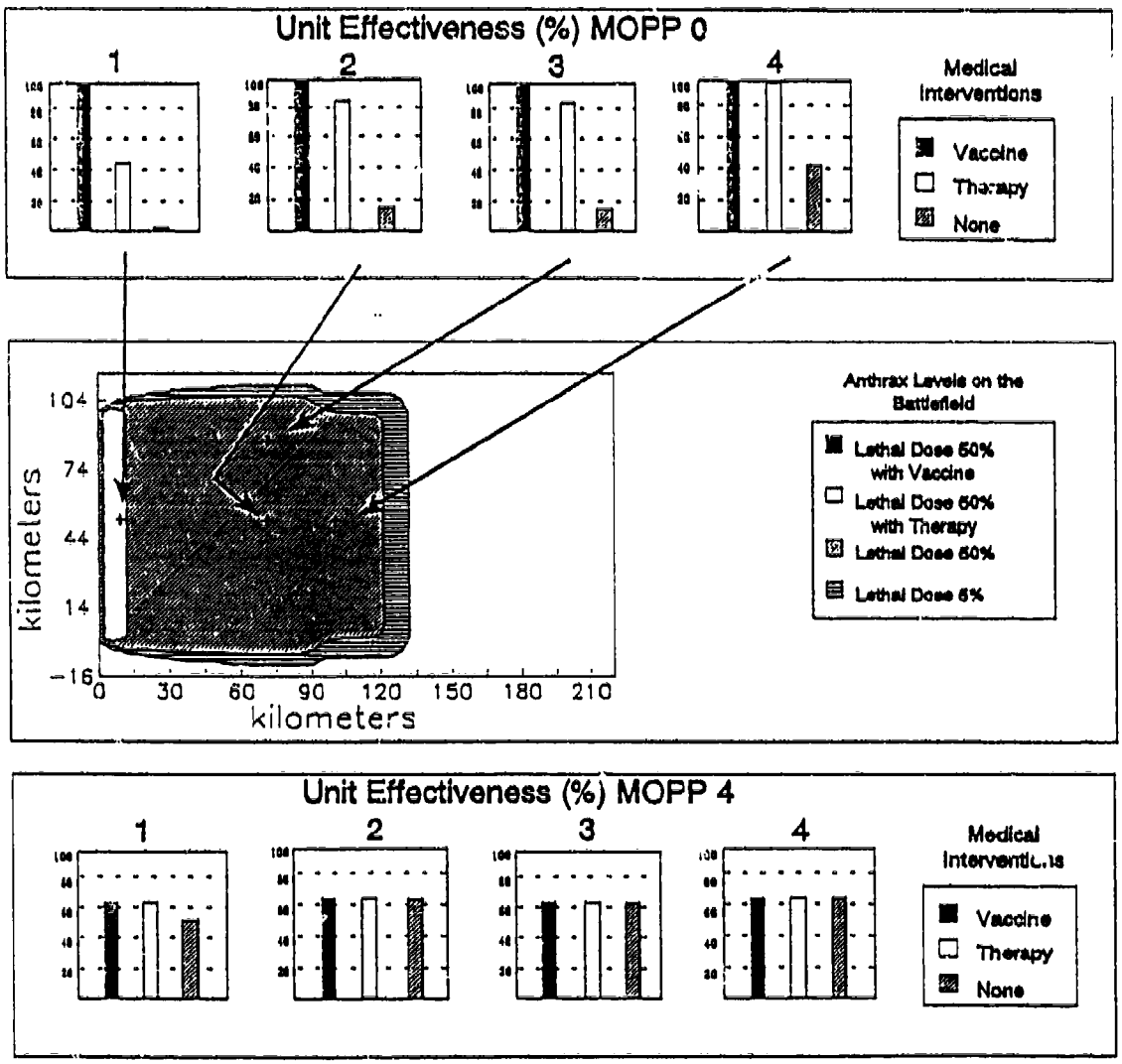

Figure 108. Aerial Spray in South Korea at 1200 Hours: Artillery Unit Effectiveness with Medical Interventions

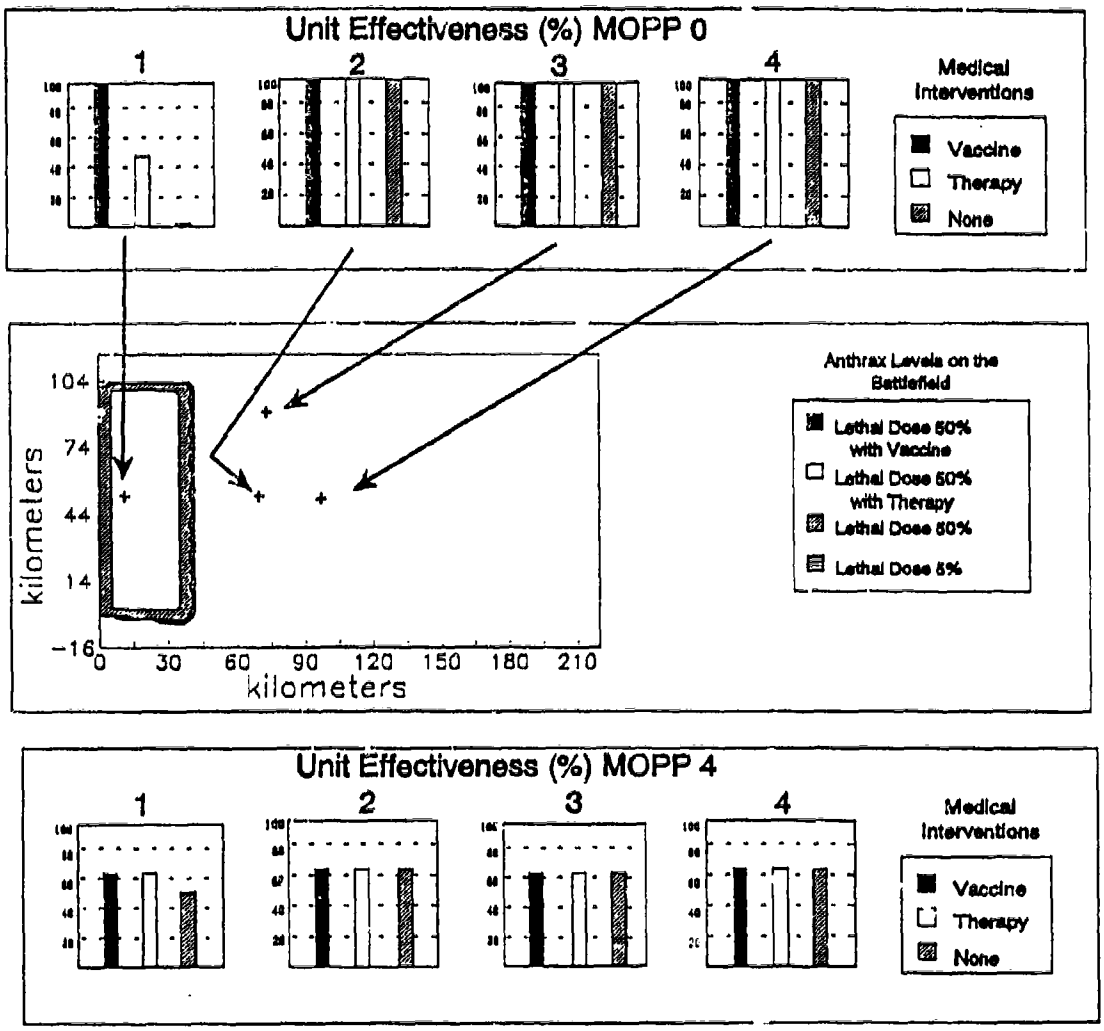

Figure 109. Aerial Spray in South Korea at 1900 Hours: Artillery Unit Effectiveness with Medical Interventions

The Southwest Asian, Southeast Asian, and Central European climates showed no appreciable differences in the area covered by at least one spore. (See Figures 110-113.) Only at very high levels of spores would differences become larger than an order of magnitude based on the time of release. From a military effectiveness point of view, note that there was almost no difference in the capability of the spray release mechanism across the four climatic regions. The spray release was the least sensitive of the six weapon systems simulated relative to regional climatic differences.

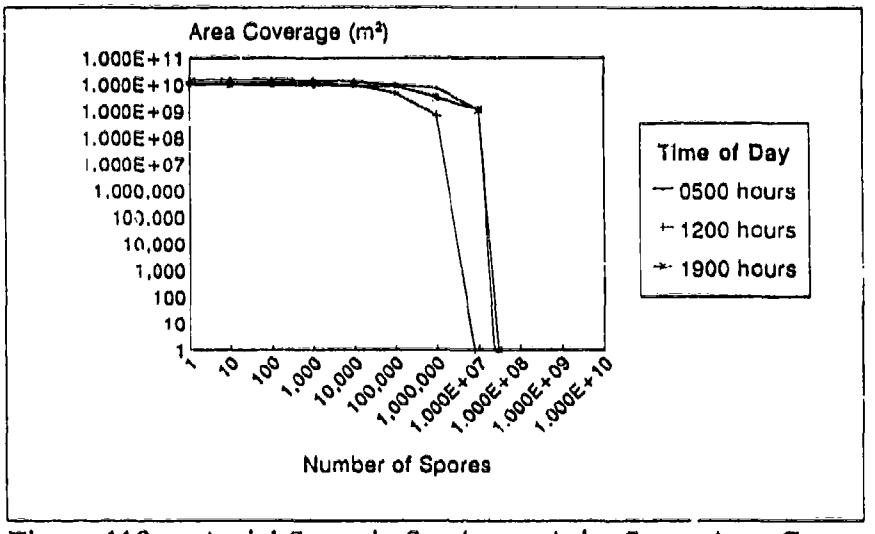

Figure 110. Aerial Spray in Southwest Asia: Spore Area Coverage

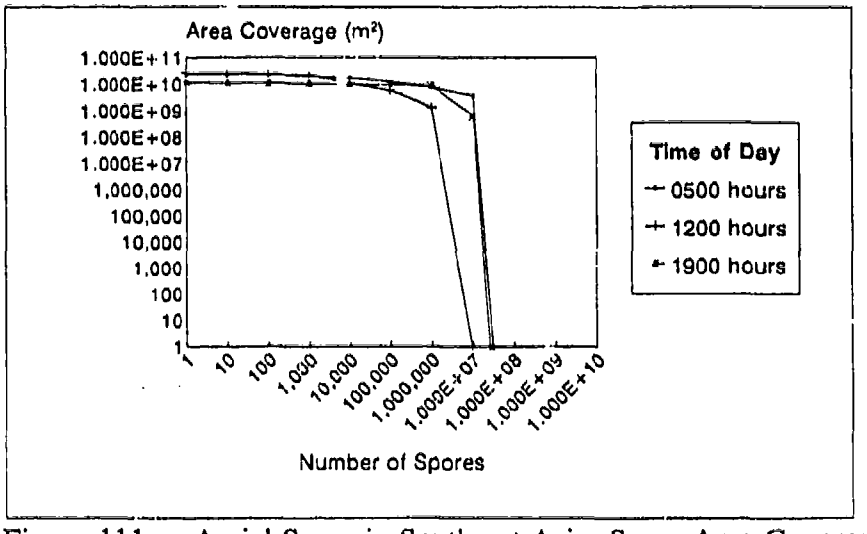

Figure 111. Aerial Spray in Southeast Asia: Spore Area Coverage

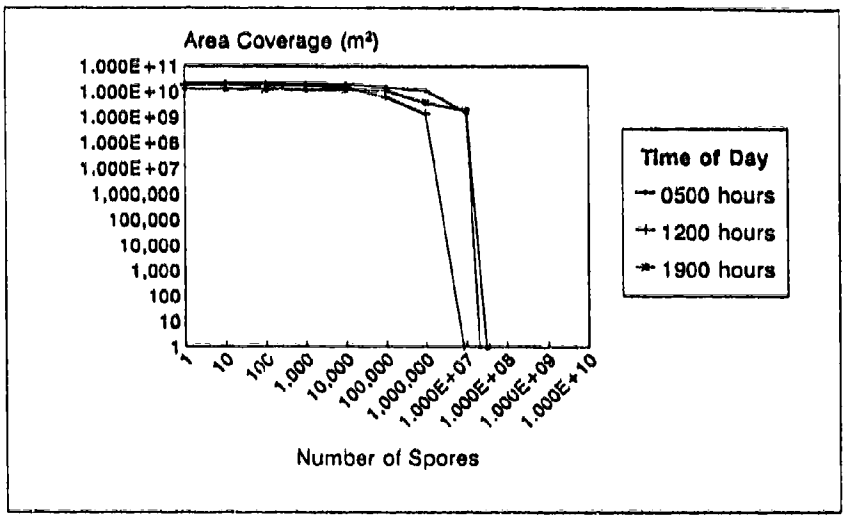

Figure 112. Aerial Spray in Central Europe: Spore Area Coverage

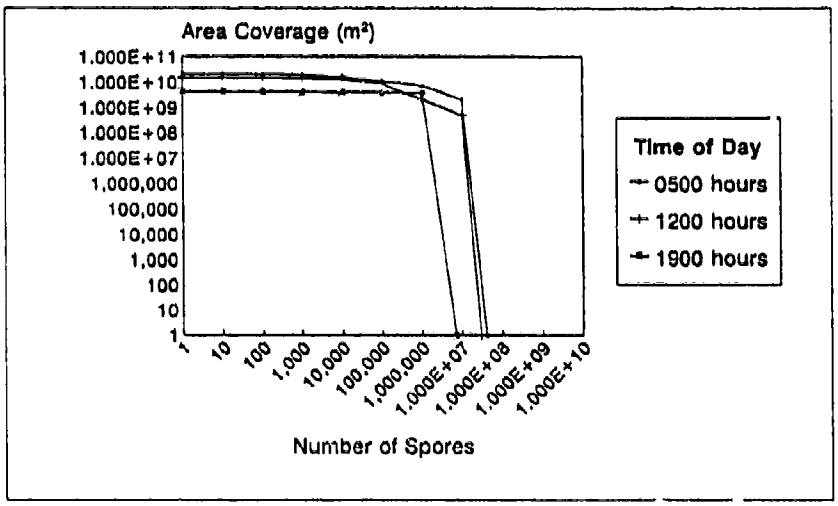

Figure 113. Aerial Spray in South Korea: Spore Area Coverage

Figure 114 illustrates the exceptionally high level of casualty area coverage achievable by spray. This can be attributed to two principal factors: (1) The spray device can achieve dissemination efficiencies in the range of 60 percent, and (2) The total mass of agent released was 1,200 kg, second only to the fill weight of the intercontinental ballistic missile submunitions. As can be seen in the chart, the appropriate use of antibiotic therapy would reduce the probable lethal area by less than one order of magnitude or less than 90 percent. However, the vaccine would reduce the probable casualty area by three to four orders of magnitude. Without medical therapy, close to 10,000 km² would be contaminated with lethal levels. With effective vaccination, the likely lethal area coverage would be between 1 and 10 km² for the 1200 hours releases and between 10 and 100 km² for the 0500 and 1900 hours releases.

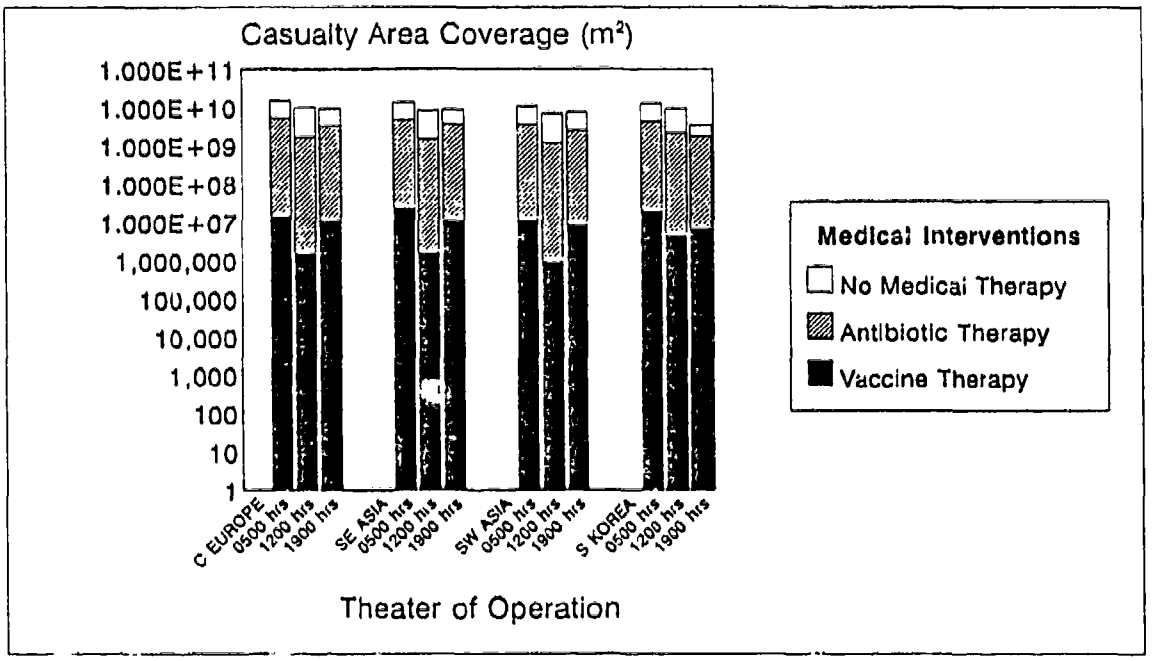

Figure 114. Aerial Spray: Casualty Area Coverage

5.6 INTERCONTINENTAL BALLISTIC MISSILE WITH *B. ANTHRACIS*-FILLED SUBMUNITIONS

A high altitude release of approximately 40,000 submunitions by an intercontinental ballistic missile (ICBM) was simulated for attack scenarios in four regional climates for three release times. Each submunition was modeled to contain just under 39 grams of *B. anthracis*, the same as the submunitions modeled for the tactical ballistic missile scenarios.

Figures 115-126 depict the hazard area footprints and estimates of unit effectiveness for units at four locations within the target area. Although it is unrealistic to think that an ICBM would be targeted against an artillery unit, the ICBM attack scenario represents the impact the use of a weapon of mass destruction in a theater of operations might have on a unit that is generally representative of an average combat unit. As can be seen from the size of the footprint, not only frontline units, but also organizational units deep in the rear areas as well as nearby population centers would be at risk. Results indicate that the vaccine would provide complete protection and maintain unit effectiveness at 100 percent for units in MOPP 0 for all regional climates and times of releases. By comparison, donning of protective equipment (MOPP 4) would reduce unit effectiveness to 63 percent.

The most notable characteristic of the ICBM attack as modeled is its vast area of lethal coverage for units without medical therapy or protective equipment. The ICBM attack, however, lacks the intensity of the hazard levels delivered by the other five weapon systems. Consequently, antibiotic therapy can maintain unit effectiveness at 100 percent following the 1200 hours ICBM releases simulated across the four regions; and for all other release times, it can preserve unit effectiveness at about the 63 percent level afforded by MOPP 4. While the effectiveness levels would seem equivalent, it should be noted that the loss of effectiveness suffered by troops in MOPP 0 relying on antibiotic treatment alone is due to loss of life rather than to the temporary disablement of the protective garments of MOPP 4. Antibiotic therapy would need to be supplemented with the assumption of MOPP 4 in order to preserve life, in which case the unit would return to 100 percent effectiveness once it left the protective posture. Note that a release of submunitions that resulted in a smaller spread of the agent would increase the intensity of the attack, a development that could overwhelm the protection of antibiotic therapy. Operationally this would present a problem: Only masking or vaccination would be left as alternatives. But at what time should soldiers don MOPP 4, and how long should they remain in that posture? Without a means to determine the termination of the threat from a *B. anthracis* attack, units may be in MOPP 4 for extended periods of time. Use of predeployment vaccination would eliminate the uncertainty associated with detection and the protective capabilities of antibiotic therapy as well as prevent the decline in unit effectiveness associated with the assumption of MOPP 4.

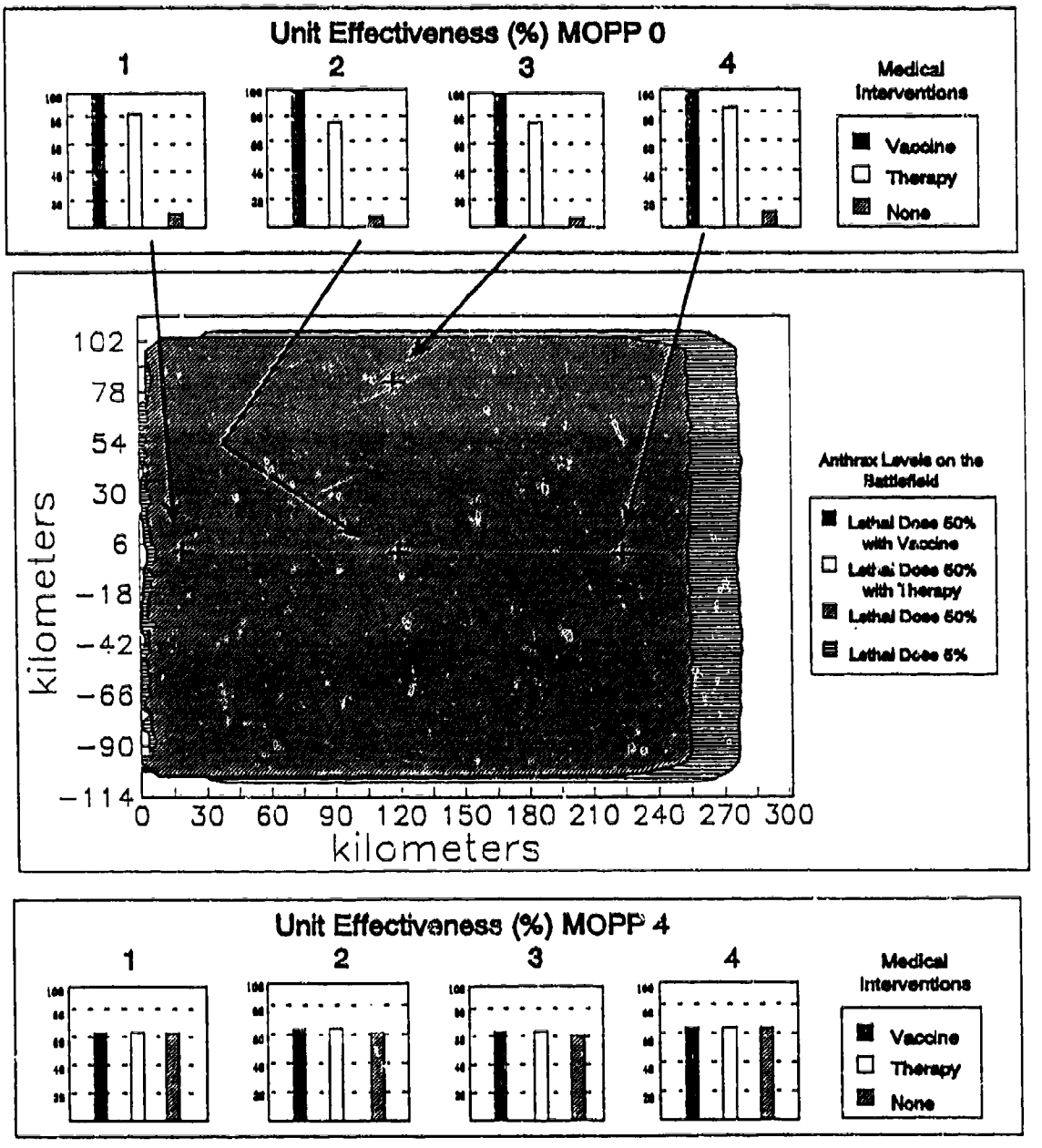

Figure 115. ICBM in Southwest Asia at 0500 Hours: Artillery Unit Effectiveness with Medical Interventions

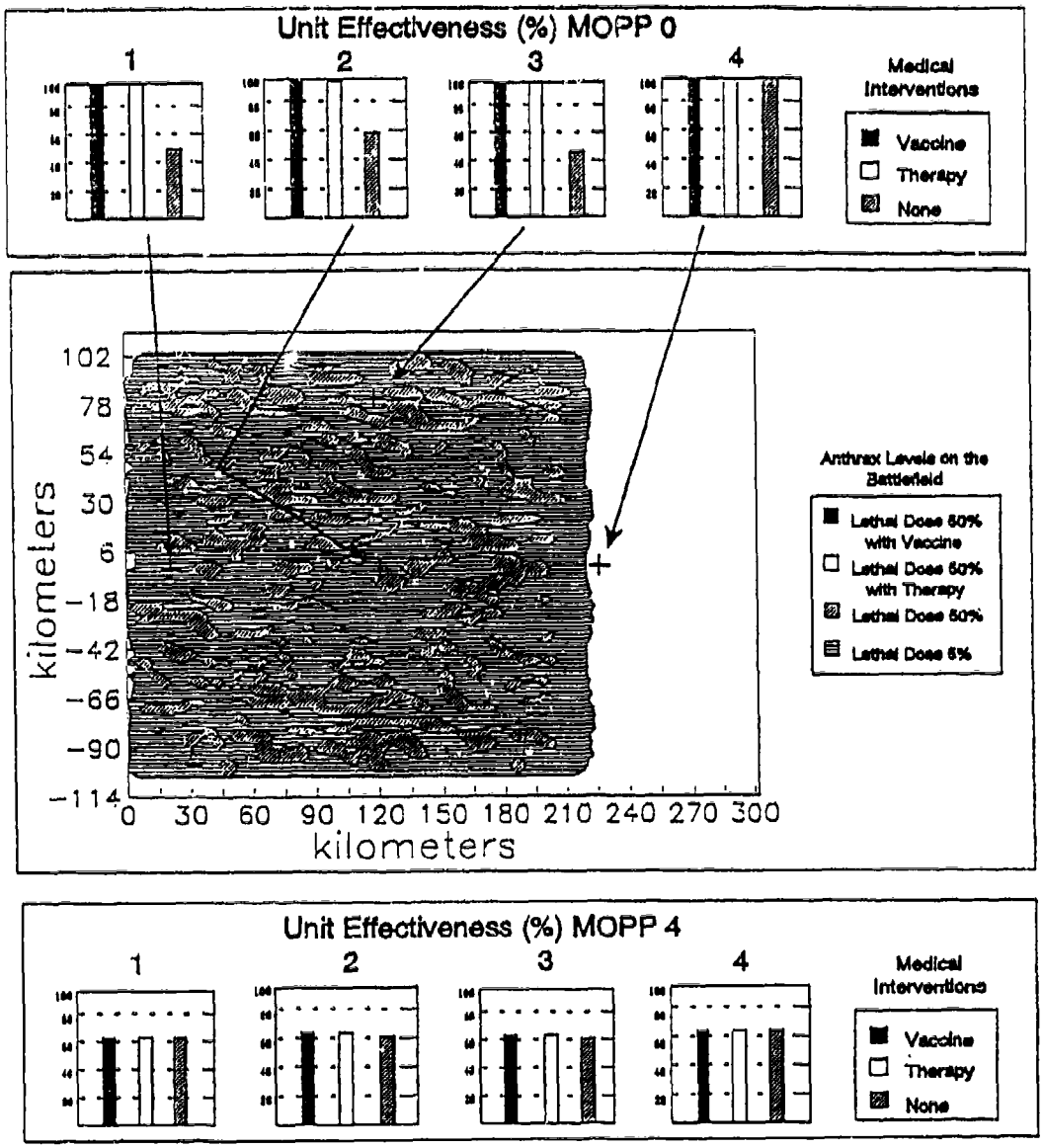

Figure 116. ICBM in Southwest Asia at 1200 Hours: Artillery Unit Effectiveness with Medical Interventions

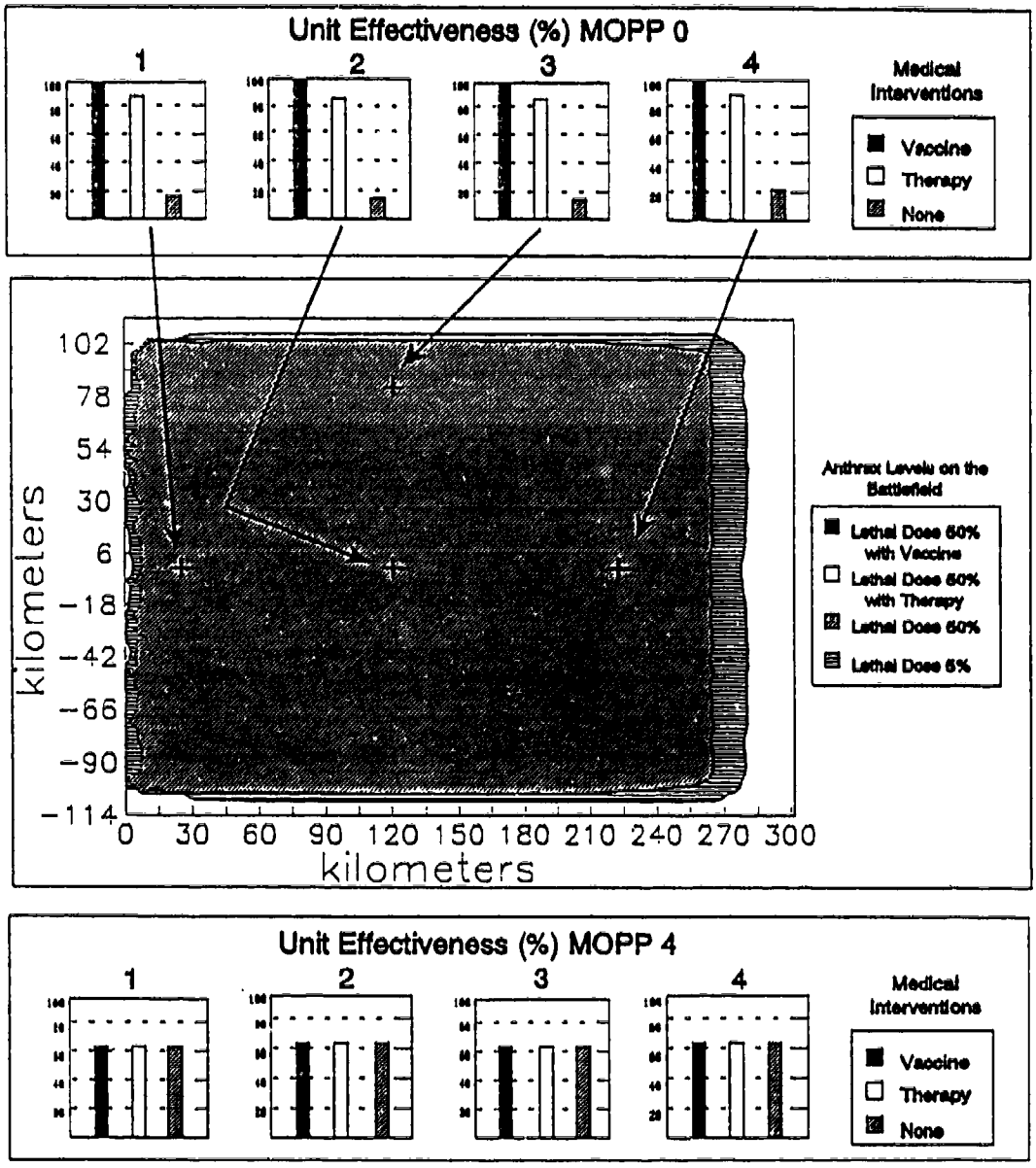

Figure 117. ICBM in Southwest Asia at 1900 Hours: Artillery Unit Effectiveness with Medical Interventions

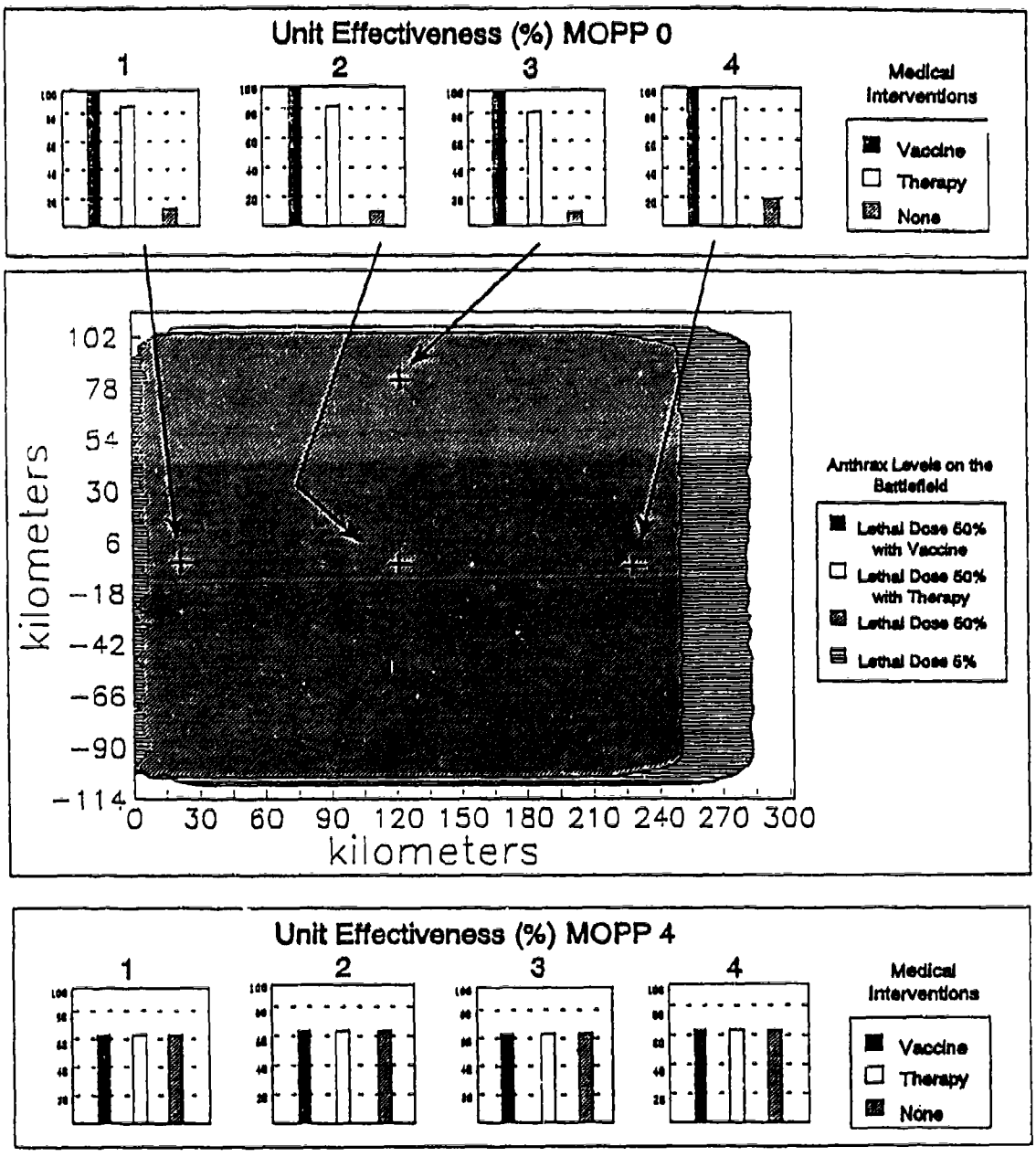

Figure 118. ICBM in Southeast Asia at 0500 Hours: Artillery Unit Effectiveness with Medical Interventions

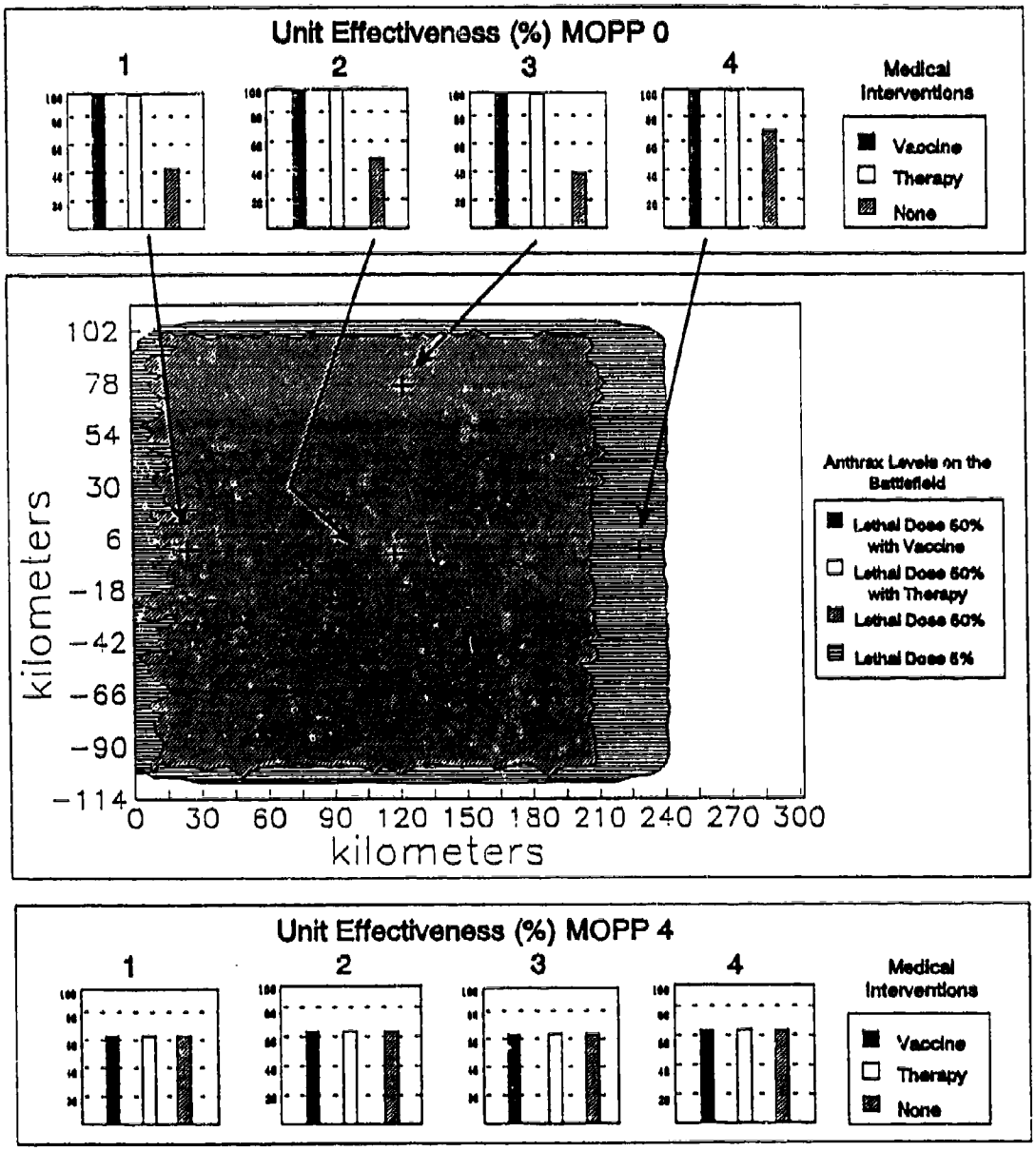

Figure 119. ICBM in Southeast Asia at 1200 Hours: Artillery Unit Effectiveness with Medical Interventions

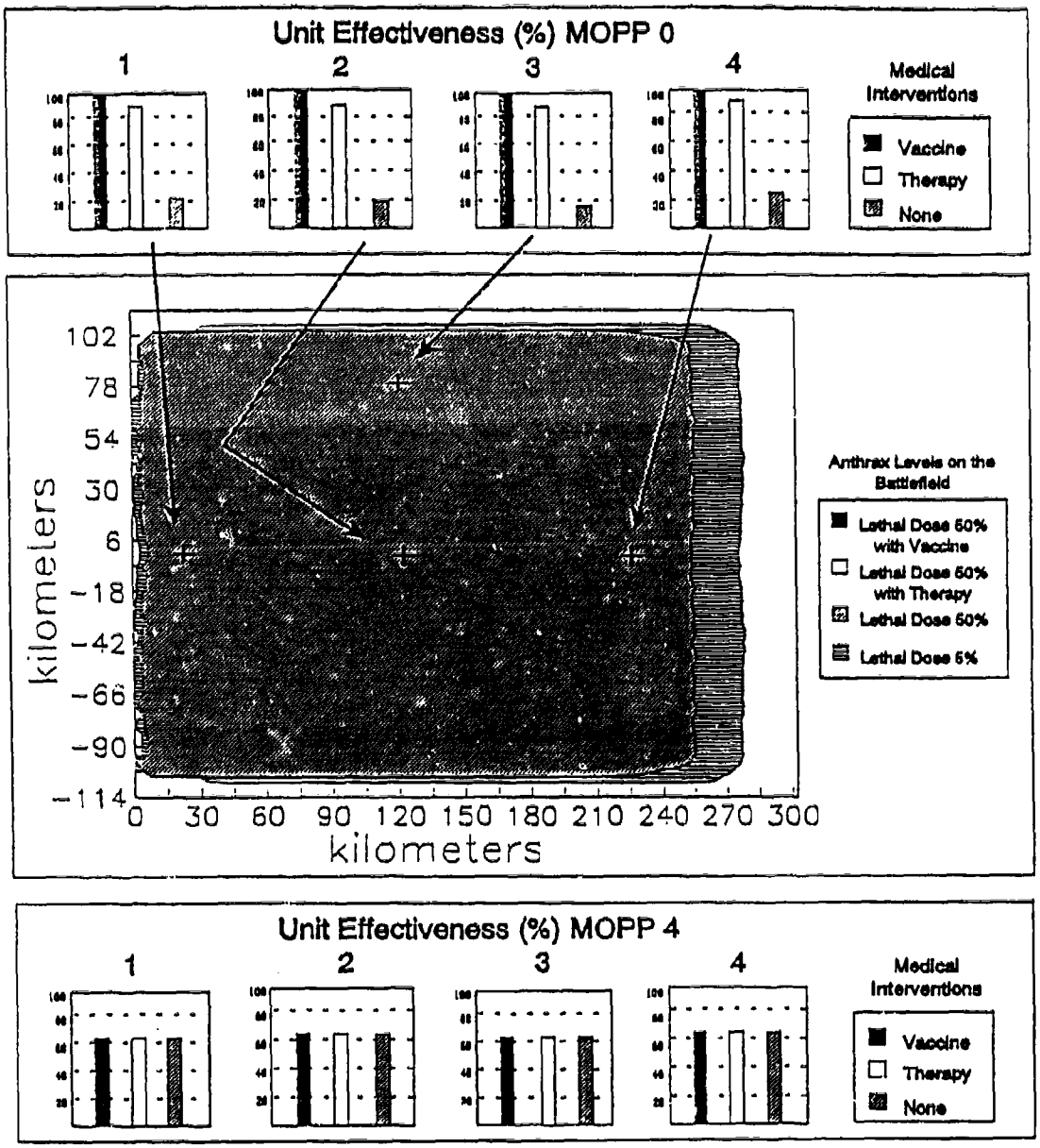

Figure 120. ICBM in Southeast Asia at 1900 Hours: Artillery Unit Effectiveness with Medical Interventions

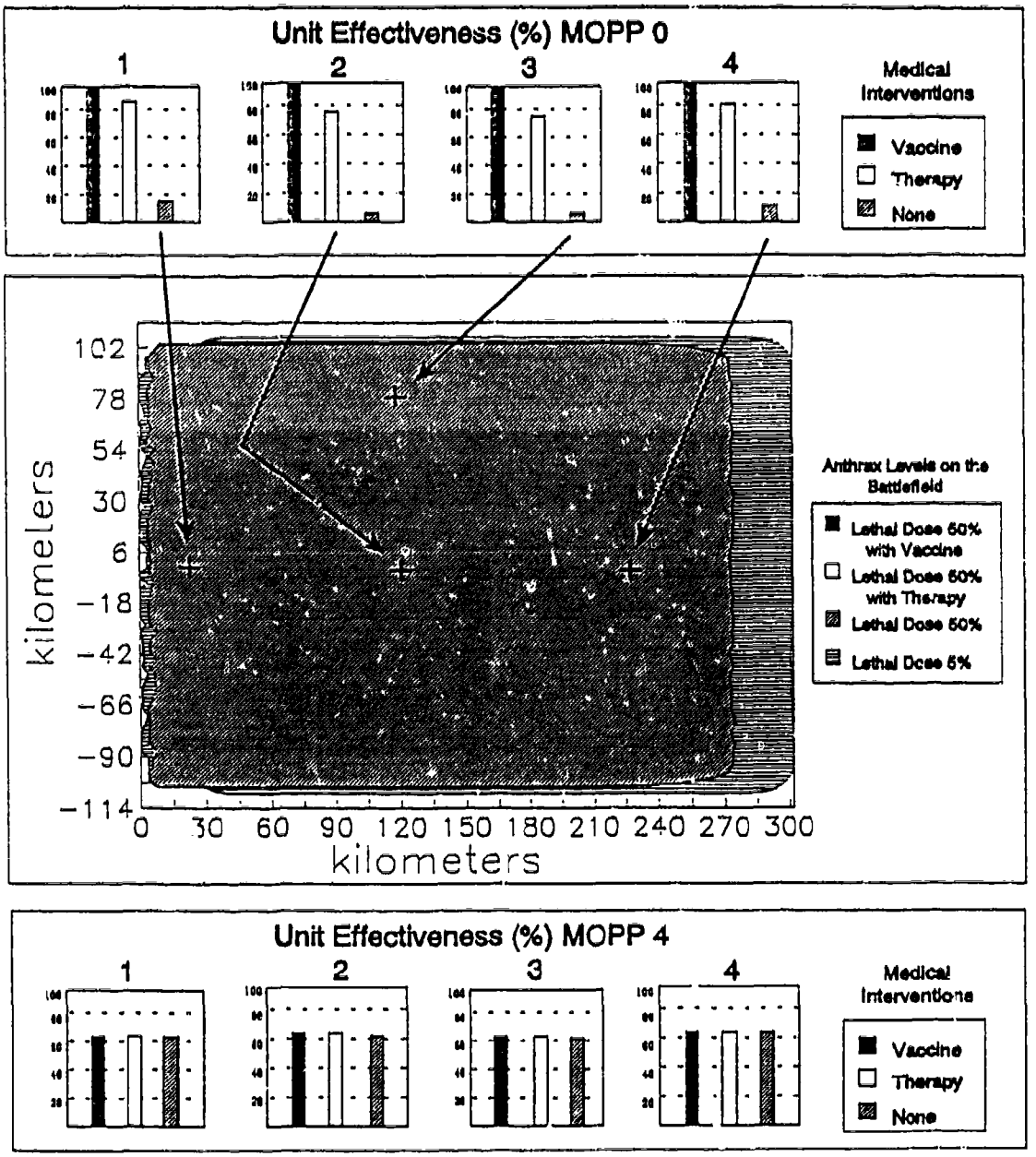

Figure 121. ICBM in Central Europe at 0500 Hours: Artillery Unit Effectiveness with Medical Interventions

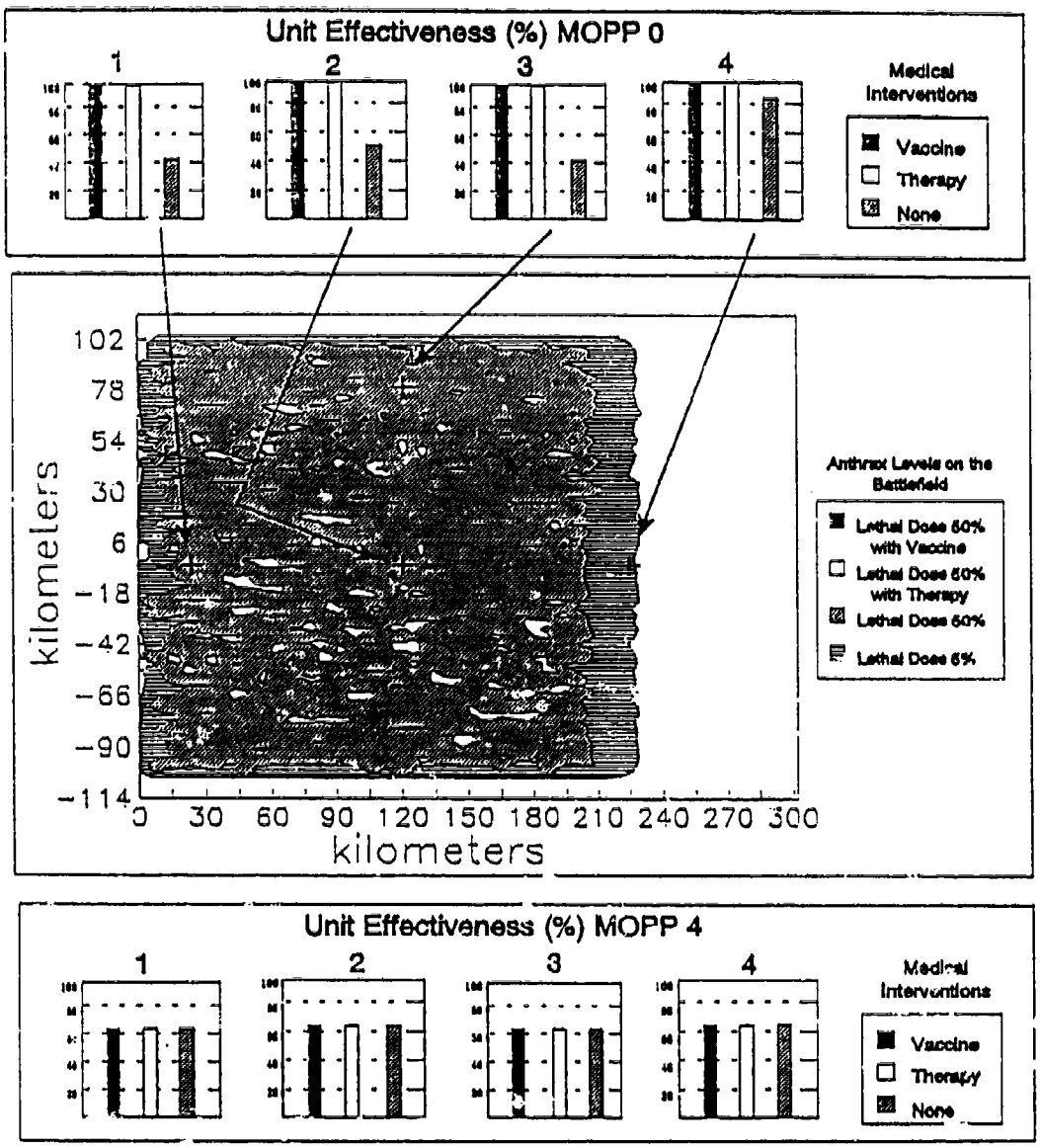

Figure 122. ICBM in Central Europe at 1200 Hours: Artillery Unit Effectiveness with Medical Interventions

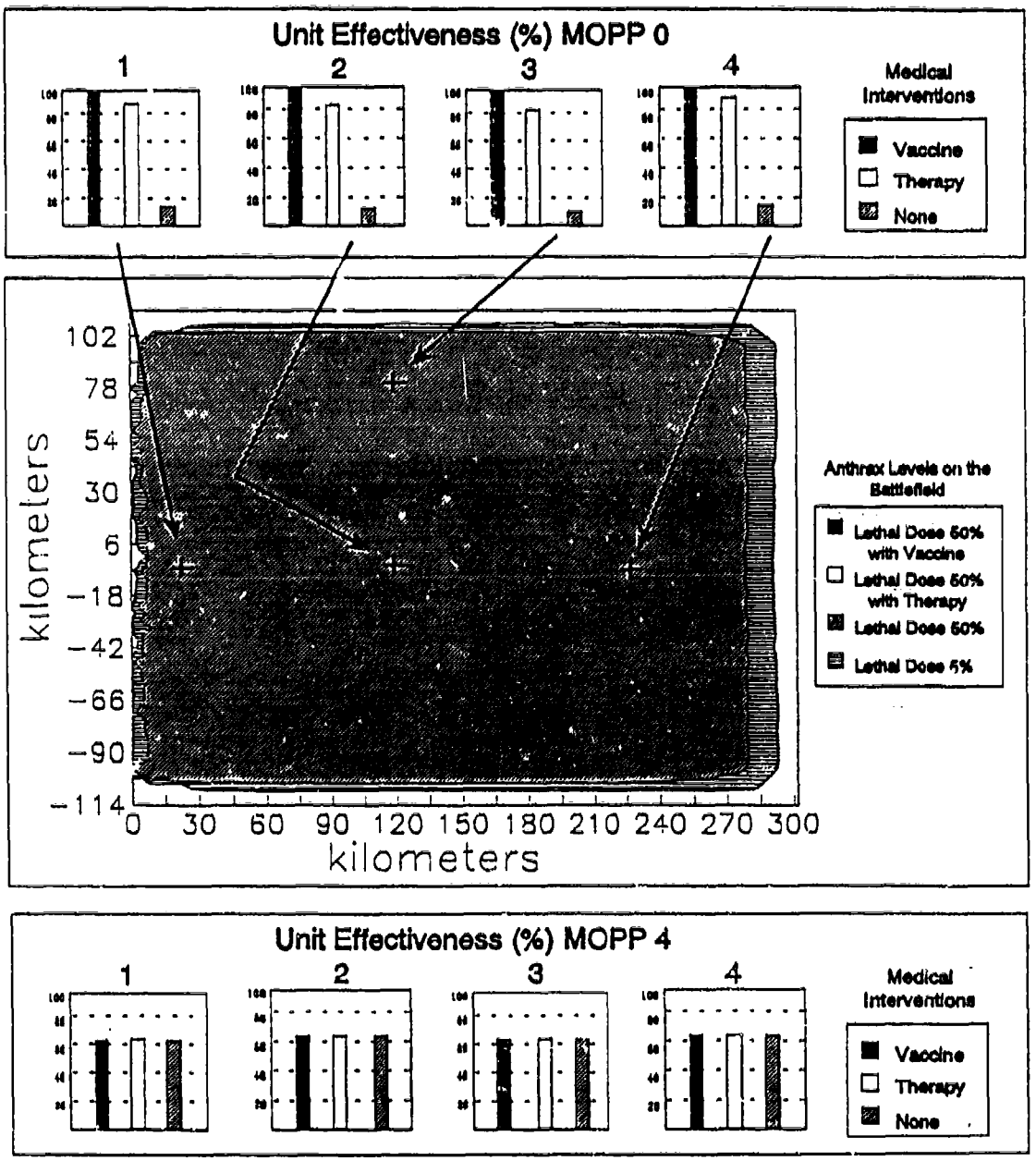

Figure 123. ICBM in Central Europe at 1900 Hours: Artillery Unit Effectiveness with Medical Interventions

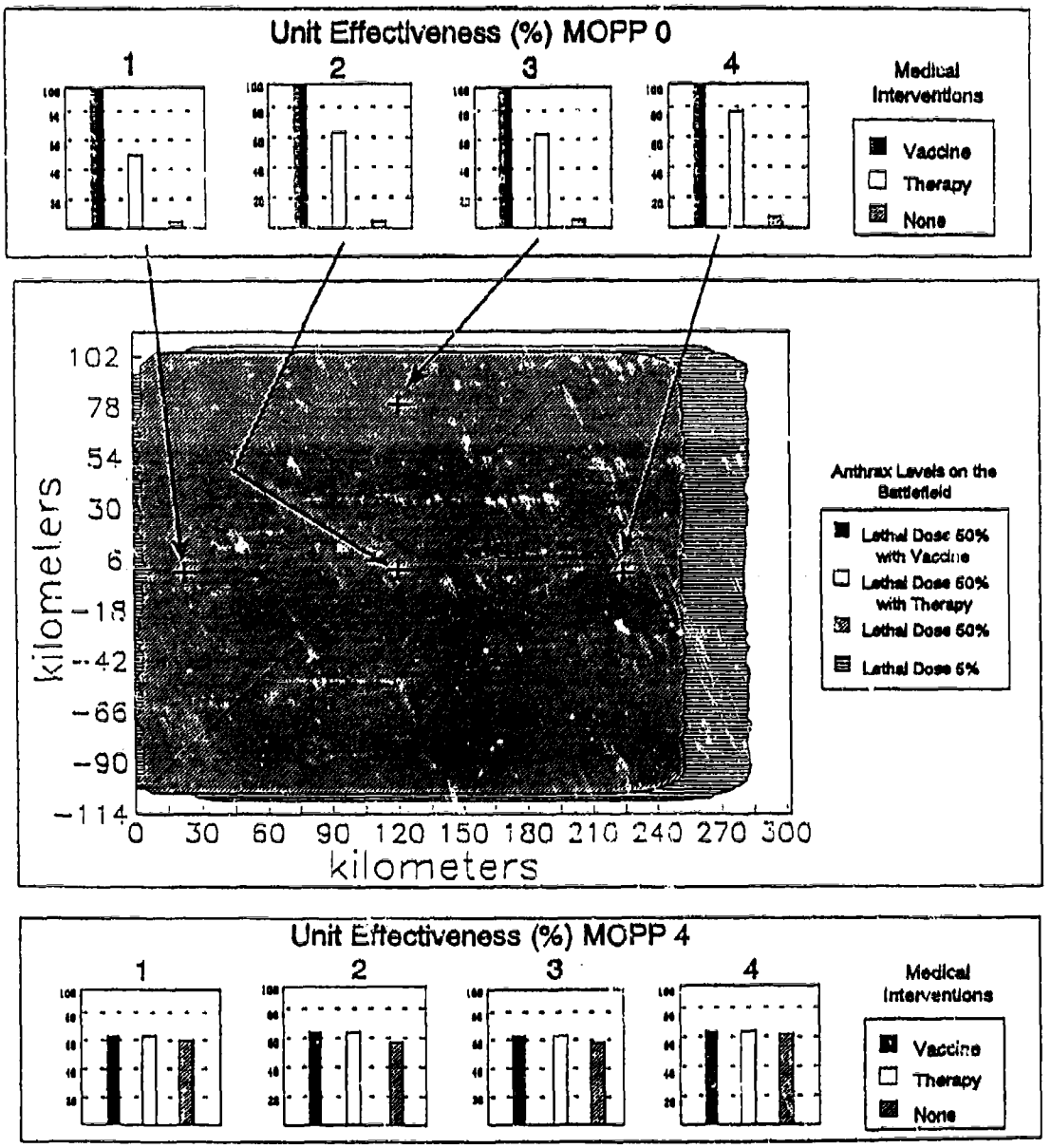

Figure 124. ICBM in South Korea at 0500 Hours: Artillery Unit Effectiveness with Medical Interventions

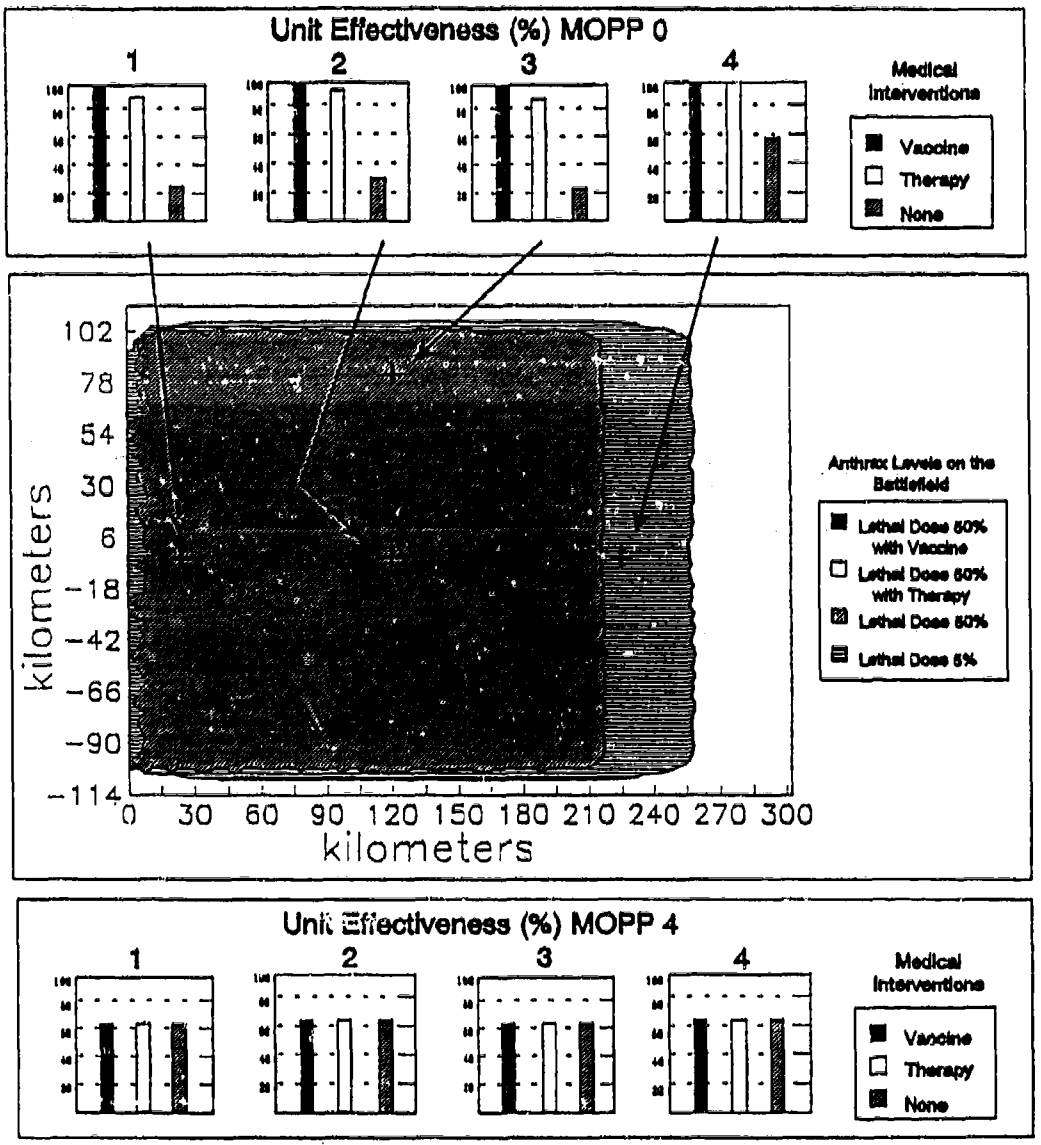

Figure 125. ICBM in South Korea at 1200 Hours: Artillery Unit Effectiveness with Medical Interventions

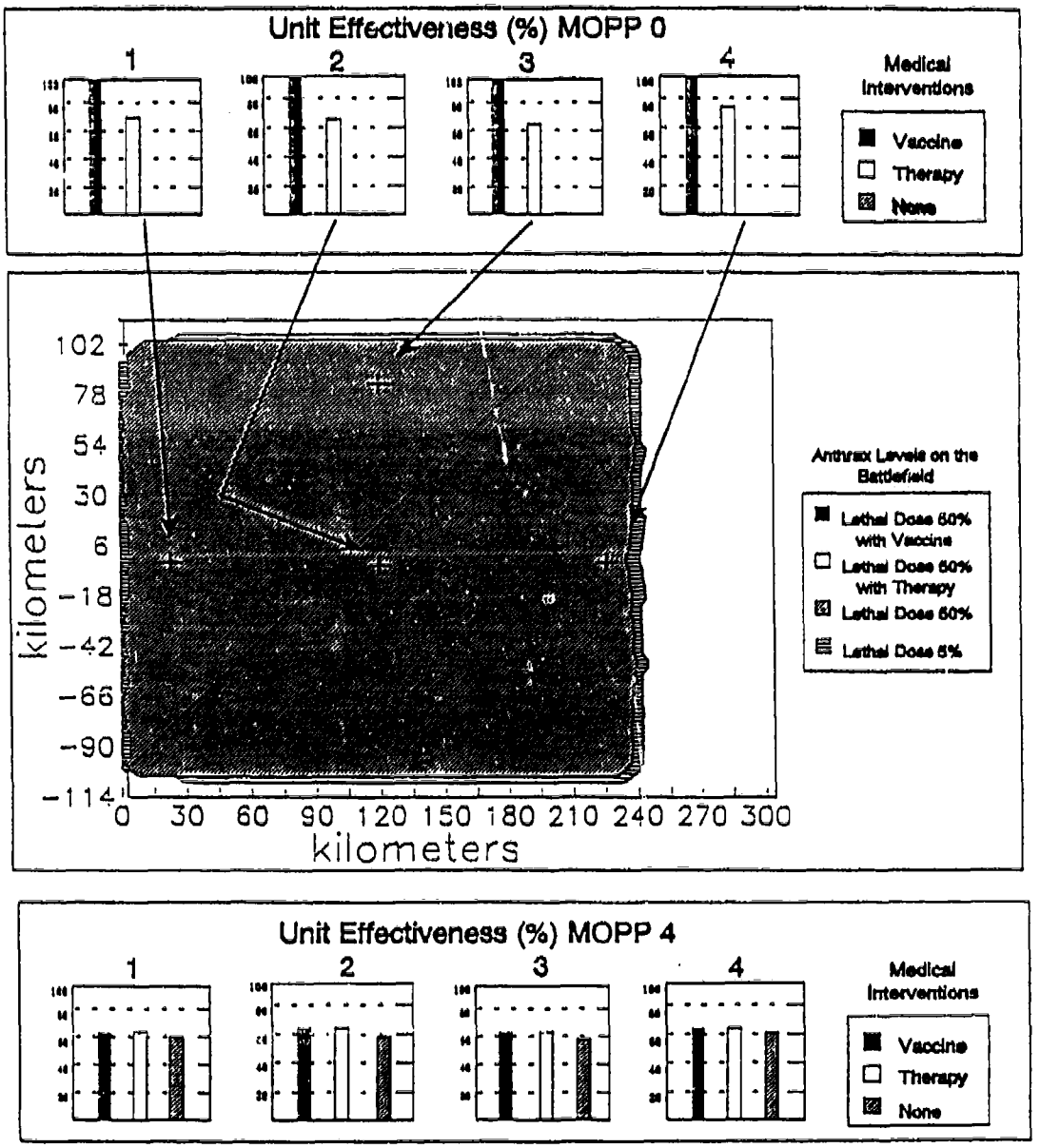

Figure 126. ICBM in South Korea at 1900 Hours: Artillery Unit Effectiveness with Medical Interventions

The extent of the vast area coverage of an ICBM attack can be seen in the spore area coverage charts (Figures 127-130). Note that in every region and for all release times, the area covered by at least one spore per square meter exceeds 10,000 km². The peak numbers of spores achievable is approximately 1-2 million per square meter. This is about an order of magnitude less than that achieved by the tactical ballistic missile attack scenario which used submunitions with the same fill weight, but with a total agent weight equal to one-fifth that of the ICBM attack. This difference can be attributed to the much larger impact area of the ICBM submunitions which spreads the hazard out instead of concentrating it as in the tactical ballistic missile scenarios. Of the six weapon systems studied, the ICBM attack would produce the lowest peak levels of spore coverage.

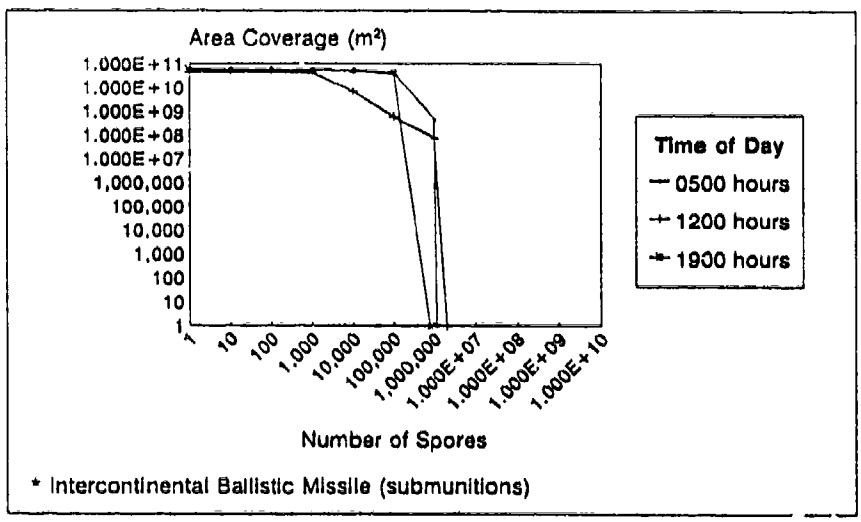

Figure 127. ICBM in Southwest Asia: Spore Area Coverage

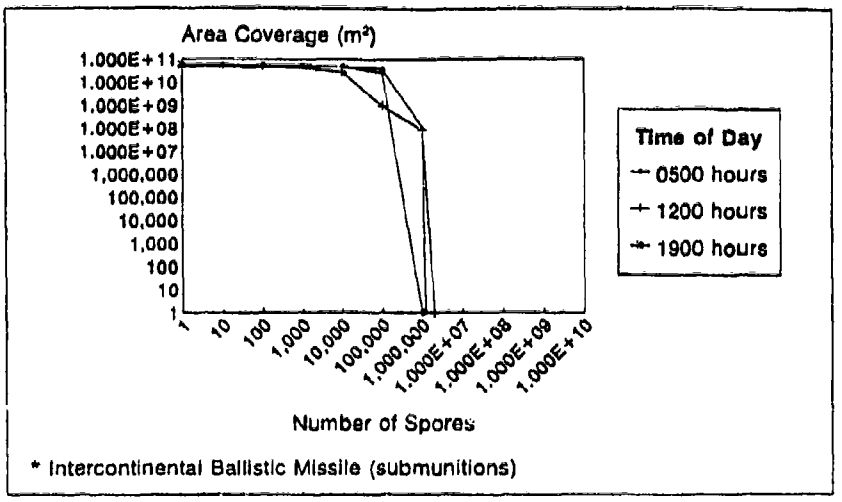

Figure 128. ICBM in Southeast Asia: Spore Area Coverage

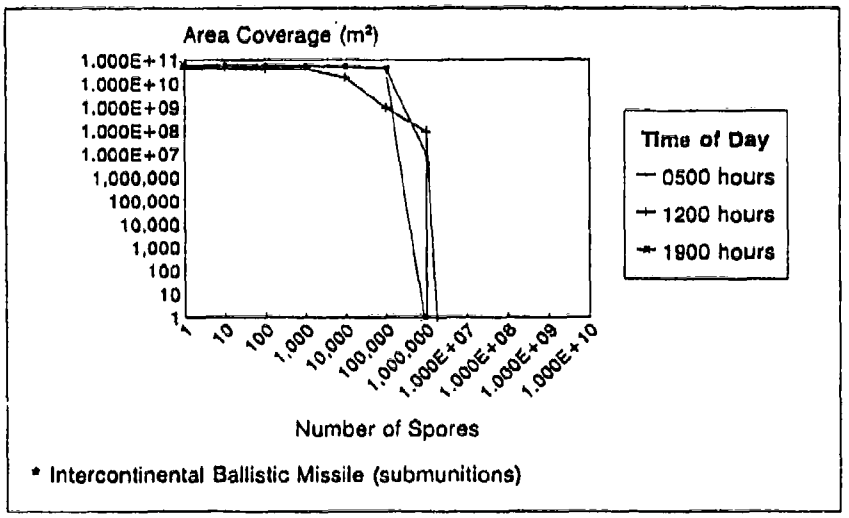

Figure 129. ICBM in Central Europe: Spore Area Coverage

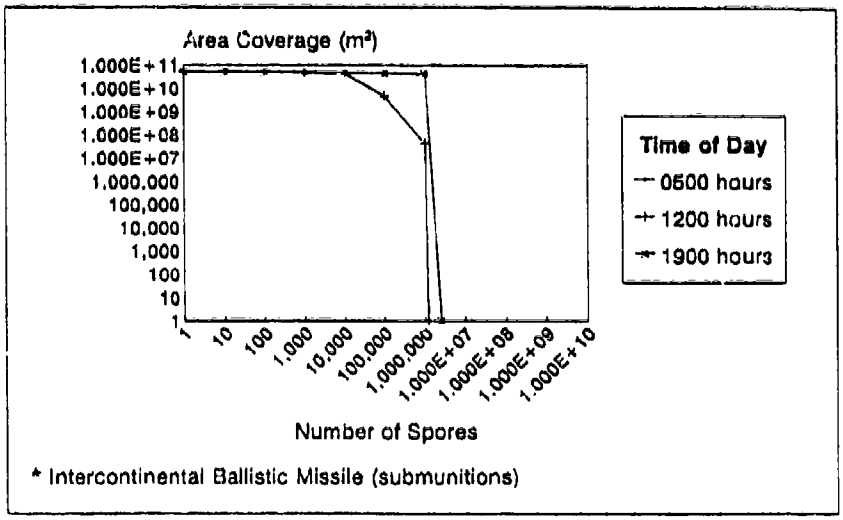

Figure 130. ICBM in South Korea: Spore Area Coverage

The casualty area coverage potential of the ICBM attack simulation for MOPP 0 can be seen in Figure 131. Note that without medical intervention, the casualty area coverage exceeds 10,000 km² except for the Southwest Asian 1200 hours release where it is slightly less. Use of antibiotic therapy reduces the probable lethal area by less than one order of magnitude, or less than 90 percent, for the 0500 and 1900 hours releases while the 1200 hour releases show a reduction in area coverage by about an order of magnitude. The vaccine reduces the probable casualty area by five to six orders of magnitude, except for the 1900 hours release in the Central European and Southwest Asian climate where the vaccine limited casualty area coverage to less than 100,000 m² (0.1 km²).

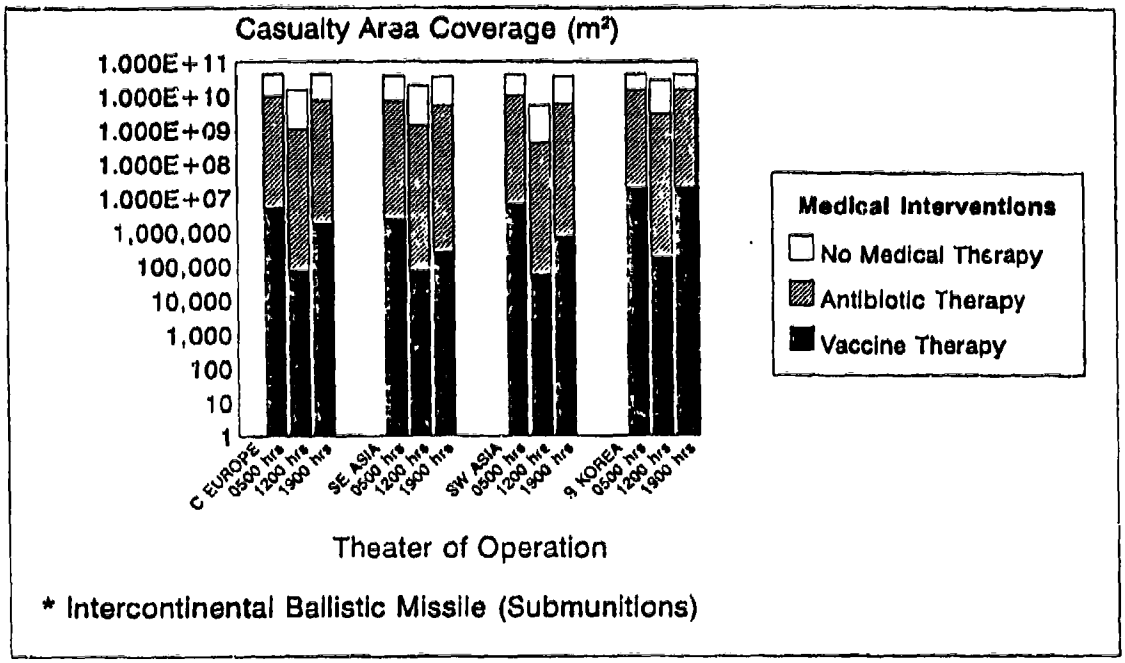

Figure 131. ICBM: Casualty Area Coverage

6.0 CONCLUSIONS

The most significant finding within the context of this study is that unit effectiveness can best be preserved through the use of predeployment vaccination with the fielded MDPH-PA vaccine. For every attack scenario simulated and all release times modeled, unit effectiveness was maintained at or above the 99 percent level in MOPP 0 with the exception of the multi-rocket launcher attack in the Korean winter climate. Even here, unit effectiveness would be maintained at 90 percent.

The use of vaccine to protect against a *B. anthracis* attack can obviate the need for MOPP 4 with its inherent degradation of unit effectiveness. This can be especially important with weapon systems such as an aircraft equipped with a sprayer or an ICBM with submunitions that can create LD_{50} levels over areas as vast as 10,000 km^2. Given knowledge of such an attack, commanders would be faced with the decision of when protective equipment should be donned and for how long. MOPP levels 0 through 4 appear to be optimized for operation in a chemical environment where multiple routes of agent entry are a concern. The principle threat from weaponized *B. anthracis* is through the respiratory system; thus, a mask alone would provide an adequate level of protection without the severe decline in unit effectiveness induced by MOPP 3[3] and MOPP 4, the two postures in which the mask is worn. Doctrinal consideration should be given to promulgation of guidance on a mask-only posture for biological agents whose dominate route of entry is respiratory. It is suggested that the medical community include as a scientific technical objective the determination of which biological agents would minimally require a mask-only posture to provide an effective defense, absent a policy or resources to vaccinate all personnel prior to world-wide deployment, and since vaccine for every foreseeable biological threat is not available.

The ease with which a covert *B. anthracis* attack could be executed via a spray or a terrorist device should be a compelling rationale for a predeployment vaccine regimen since medical personnel might first be alerted to such an attack only through the occurrence of onset of symptoms. Late detection combined with potential logistics difficulties in accessing sufficient quantities of antibiotics could result in loss of life on a catastrophic scale. Even with timely determination of *B. anthracis* exposure, there would be an enormous demand for in-theater medical capabilities due to the wide casualty area coverage potential of the agent. Although antibiotics may maintain unit effectiveness at accepted levels, there would likely be a tethering of operational units to their medical logistics pipelines and facilities, thus restricting unit mobility -- an operational consideration not modeled in this study.

The unit effectiveness charts show that for MOPP 0, there are numerous plausible attack scenarios where antibiotic therapy will not preclude loss of life and the attendant decline in unit effectiveness. Of all the attack scenarios simulated, direct multi-rocket launcher and artillery attacks achieved the highest levels of effectiveness against personnel protected only by

[3]Not modeled in this study, although the results would be equivalent for MOPP 3 and MOPP 4 since the main protection is afforded by the use of the mask to prevent inhalation of the *B. anthracis* spores.

antibiotic therapy. Fireplans for these weapon systems are capable of creating high levels of dosage on small area targets, which can significantly breach the protection afforded by antibiotic therapy. Advance masking can reduce exposure and thereby the dosage received, but this is subject to timely detection and notification of an attack.

As was seen in the survivability excursion in the analysis, MOPP 4, because of the use of the mask, maintained unit survivability levels above 90 percent against a tactical ballistic missile attack even without medical intervention. Although survivability levels could be expected to decline under direct multi-rocket launcher or artillery attacks in winter climates, the point is that it is the mask that is providing this level of protection against the respiratory threat, not the other paraphernalia. However, both the mask and antibiotic therapy suffer from the same critical operational deficiency -- in order to survive, the soldier must either know that a *B. anthracis* attack is underway so that he can mask in time or be aware that exposure has occurred prior to onset of symptoms so that antibiotic therapy can be started in time to be effective.

The sensitivity analysis conducted in the study showed that unit effectiveness was essentially the same for LD_{50} values based on spore levels in the range of 8,000 to 10,000.

Agent decay can significantly reduce the extent of the downwind hazard, especially for attacks during the hours of bright sunlight (high UV levels). There were significant differences in the extent of the downwind hazard when noonday decay rates were varied by a factor of 2.5. However, the increase in decay rates between the USAMRDC and USACRDEC estimates would only account for a difference in hazard levels in the target area of approximately 5 percent of the total agent mass released for those units under *direct* attack. Accordingly, unit effectiveness would be only minimally affected, if at all, based on differences in agent decay rates, and the overall effect of using the lower rates provided by USAMRDC would be to provide a conservative estimate of unit effectiveness for each of the medical interventions modeled.

Finally, there is appreciable uncertainty in some of the data required by the modeling community to conduct analyses and efficacy assessments. This study is no exception. The benefit of this and other studies is not in the absolute values derived from the analysis, but rather in the trends that can be recognized and the broader generalizations that can be made based on the extensive number of simulations underpinning these conclusions.

REFERENCES

AURA was developed by Dr. Terrence Klopcic at the U.S. Army Research Laboratory.

Brachman, Philip S. "Anthrax" in Cecil Textbook of Medicine, Ed., James B. Wyngaarden, M.D., and Lloyd H. Smith, Jr., M.D. Philadelphia: W.B. Saunders Co., 1985.

CASUALTY was developed by Mr. Richard E. McNally of Science Applications International Corporation.

Compton, James A. F. Military Chemical and Biological Agents: Chemical and Toxicological Properties. The Telford Press: New Jersey, 1987, pp. 360-361.

PLUME Version 2.6 is the February 1991 update of the model developed by Mr. Roger Gibbs of the U.S. Naval Surface Warfare Center at Dahlgren, Va.

The Problem of Chemical and Biological Warfare: Vol. II: Weapons Today, SIPRI, New York, 1973.

APPENDIX A

Memo on Technical Input Parameters

DEPARTMENT OF THE ARMY
U.S. ARMY MEDICAL RESEARCH INSTITUTE OF INFECTIOUS DISEASES
FREDERICK, MARYLAND 21702-5011

REPLY TO ATTENTION OF:

SGRD-UIM (70) 16 January 1992

MEMORANDUM THRU

Commander, U.S. Army Medical Research Institute of Infectious Diseases, ATTN: SGRD-UIM (LTC Maria Sjogren), Fort Detrick, Frederick, MD 21702-5011

Commander, U.S. Army Medical Research Institute of Infectious Diseases, Fort Detrick, Frederick, MD 21702-5011

FOR Commander, Walter Reed Army Institute of Research, ATTN: SGRD-UWI (LTC Steven R. Hursh), Project Manager, Anthrax Computer Modeling Study, Division of Neuropsychiatry, Washington, DC 20307-5100

SUBJECT: Answers to Technical Questions, Battlefield Levels of Anthrax Computer Modeling Project

1. The enclosed document provides the technical input you requested for the Battlefield Levels of Anthrax Computer Modeling Study. Answers were derived from discussions with COL Arthur Friedlander, literature sources, and input provided by Mr. William Patrick. Please call if you have any questions concerning this information.

2. Point of contact for this memorandum is LTC Eitzen at DSN 343-7655 or Commercial (301) 663-7655.

Encl

EDWARD M. EITZEN, JR.
LTC, MC
Chief, Operational Medicine

BATTLEFIELD LEVELS OF ANTHRAX COMPUTER MODELING PROJECT

This project is a joint project of Walter Reed Army Institute of Research (WRAIR) and Science Applications International Corporation (SAIC) of Joppatowne, Maryland to try to assess the potential impact of a biological attack by enemy forces on U.S. Army units. The project manager and a representative of SAIC met on 9 January 1992 with COL Charles Bailey, COL Arthur Friedlander, LTC Edward Eitzen, and MAJ Lester Caudle of USAMRIID to brief USAMRIID personnel on the modeling project and to ask for assistance in obtaining answers to several technical questions which might be provided from data generated by USAMRIID's medical defensive program against biological threat agents. These answers are needed for inclusion in the computer model which will be used to simulate performance degradation of Army units which might occur due to enemy use of biological agents. The answers to the questions below have been developed in consultations between COL Friedlander, LTC Eitzen, and MAJ Caudle, as well as by Mr. Patrick in his capacity as a USAMRIID consultant.

Answers to Technical Questions

1. What is the uncertainty of the toxicological values for exposure to Anthrax aerosols disseminated by enemy forces?

ID_{50} 8,000-10,000 cells

The infectious dose for pulmonary anthrax in 50% of animals is essentially the same as the lethal dose 50 (LD_{50}). This is because pulmonary anthrax is almost uniformly fatal in unvaccinated and untreated animals. Old data from experiments at USAMRIID on small rhesus monkeys show a mean LD_{50} of 8,689 total inhaled anthrax spores. This estimate of 8,000-10,000 is therefore fairly accurate for the animals studied. How this data extrapolates to humans is uncertain, but it is the best estimate we have.

ID_{50} 0.000523 mg-min/m^3
ID_{90} 0.00415 mg-min/m^3
ID_5 0.000036 mg-min/m^3

These values are less useful because of the units in which they are presented. They should be changed to spores or LD_{50}'s instead of milligrams as a unit.

2. **Should the computer model focus on simulated wet or dry dissemination by a hostile force? What is a reasonable dissemination efficiency?**

The question of whether to focus our medical defensive effort on wet or dry dissemination depends on the adversary involved and should be answered by the intelligence community. A sophisticated adversary such as the former USSR would probably concentrate on use of dry agents because: they are more concentrated, they do not change physically at temperatures above freezing, and they provide a higher aerosol recovery or disseminating efficiency. They are more difficult to produce; the drying process requires a high level of sophistication. The safety aspects of handling dry agents are also more difficult. Advanced countries could produce dry agents; State supported terrorist groups could potentially do so as well with support from a sophisticated country. Less sophisticated countries or terrorists with limited resources would only be able to produce liquid agents which are unstable above freezing and are more difficult to disseminate efficiently.

A reasonable dissemination efficiency for the release of the threat agent anthrax by a hostile force depends on the type of weapon or device being used to disseminate the agent in addition to whether the agent is in liquid or dry form:

	Bomblets explosive	Bomblets gaseous	Line Source single nozzle	Line Source 2 fluid nozzle	Line Source dry agent
Dry Anthrax	5%	20%	NA	NA	60%
Liquid Anthrax	3%	5%	10%	30%	NA

3. **What are current medical interventions?**

Current interventions include the physical protection provided by protective mask, antibiotics such as doxycycline and ciprofloxacin, and anthrax vaccine.

a. **What level of protection does vaccination provide?**

Vaccine provided prophylactically to rhesus monkeys (2 doses given 2 weeks apart) provides protection against the inhalation of 500 LD_{50}'s of spores, or against approximately 4,000,000 inhaled spores. This is protection against pulmonary anthrax. Cutaneous anthrax cases have occurred, however, in workers given only 2 vaccinations.

b. **When must antibiotic therapy start to be effective?**

Ciprofloxacin or doxycycline started 1 day after inhalation exposure and continued for 30 days was protective against 10 inhaled LD_{50}'s in 8 of 9 rhesus monkeys in the ciprofloxacin group, and in 9 of 10 monkeys in the doxycycline group. Postexposure anthrax vaccine plus doxycycline protected 9 out of 9 experimental animals. There is no data as to whether antibiotics started on day 2 or 3 would protect; however, it is felt that some protection might be provided although the percentage protected would be lower.

c. **Will personnel be incapacitated during therapy?**

Whether a soldier or sailor is 'incapacitated' by adverse effects depends on his/her job (i.e., pilot versus infantryman). However, the incidence of side effects can be included in the model. For doxycycline, 5 to 10 percent will have an exaggerated response to UV light, called photosensitivity. Under the right circumstances this could incapacitate a soldier if he/she were to receive a severe sunburn. About the same percentage will have gastrointestinal symptoms (nausea, abdominal discomfort, or diarrhea). Ciprofloxacin causes these gastrointestinal symptoms in 3 to 6 percent of individuals; central nervous system symptoms such as headache, dizziness, agitation, or sleep disturbance occur in 1 to 4 percent; allergic reactions such as rash or pruritus occur in 0.5 to 2 percent; other adverse effects such as seizures, hallucinations, fever, urticaria, or anaphylaxis are rare.

True incapacitation in one limb from anthrax vaccine is very rare, occurring in 1 of 2,231 patients (0.05%). At USAMRIID, anthrax vaccine has been shown to cause local swelling, induration, or tenderness in 4.0% of patients, and systemic symptoms such as headache, fever, or nausea in 1.0% of recipients.

4. What is the time distribution of symptom onset after an enemy BW attack and is this distribution sensitive to exposure levels?

The onset of illness after exposure in animal experiments varies somewhat with the dose of spores to which they are exposed. Onset varies from approximately 1 to 5.5 days after exposure, with the shorter time to onset occurring after higher inhaled doses. Onset of symptoms generally precedes death in untreated animals by about 2 days, or 48 hours. Some older data in the literature shows that animals receiving less than 500,000 spores had mean time to death (TTD) of 7.5 days while animals receiving greater than 500,000 spores had mean a mean TTD of 3 days. More recent data from USAMRIID experiments showed no

difference in TTD (5 days) between animals exposed to 1,200,000 spores versus those exposed to 2,000,000 spores. This limited data is all that is available concerning this question.

5. What is the duration of incapacitation for survivors?

This question is best answered by saying that the only incapacitation in survivors would be in treated patients from the side effects of treatment (see #3 above). In animal studies of pulmonary anthrax, with an infecting dose, all untreated animals die, and treated animals who survive do quite well. In cases of natural human pulmonary anthrax in humans in this century, 16 of 18 were fatal.

6. What factors/intensity levels are associated with agent decay?

Temperature Sensitivity

	ST50: Survival Time, 50 Percent, in Days		
	-30° C	4° C	20° C
Dry Anthrax	indefinite	indefinite	indefinite
Liquid Anthrax	indefinite	indefinite	indefinite

Nighttime decay of an anthrax aerosol in percent decay per minute is 0.1 percent per minute decay at 75° F at any humidity condition, either low or high. Below freezing temperatures such as in an arctic environment, there is no decay of an aerosol.

Radiation Sensitivity

Sunlight causes less than 1 percent per minute decay of an anthrax aerosol. Other radiation sensitivity is minimal under normal ambient conditions.

Desiccation Sensitivity

Liquid and dry anthrax are not sensitive to desiccation.

Chemical Sensitivity

Liquid and dry anthrax are not sensitive to any common environmental chemicals. Anthrax spores are killed by a decontaminant solution of 0.5 percent sodium hypochlorite (bleach solution).

Other Sensitivities

None.

APPENDIX B

Environmental Conditions

Southwest Asia Environmental Conditions
(Summer)

Hour of Day	Wind Speed (k/hr)	Stability Category	Agent Decay Rate (%/min.)	Surface Type
0000	7	5	.1	2
0100	7	5	.1	2
0200	7	5	.1	2
0300	7	5	.1	2
0400	7	5	.1	2
0500	7	5	.1	2
0600	7	5	.1	2
0700	11	4	1	2
0800	11	4	1	2
0900	13	3	1	2
1000	15	2	1	2
1100	16	1	1	2
1200	16	1	1	2
1300	16	1	1	2
1400	16	1	1	2
1500	16	2	1	2
1600	15	2	1	2
1700	14	3	1	2
1800	13	3	1	2
1900	11	4	1	2
2000	11	4	1	2
2100	7	5	.1	2
2200	7	5	.1	2
2300	7	5	.1	2

Pasquill Stability Categories
1 = A (very unstable)
2 = B (unstable)
3 = C (slightly unstable)
4 = D (neutral)
5 = E (slightly stable)
6 = F (stable)
7 = G (very stable)

Surface
1 = Water
2 = Sand
3 = Barren
4 = Grass
5 = Forest
6 = Town

Southeast Asia Environmental Conditions
(Tropical)

Hour of Day	Wind Speed (k/hr)	Stability Category	Agent Decay Rate (%/min.)	Surface Type
0000	6	5	.1	5
0100	6	5	.1	5
0200	6	5	.1	5
0300	6	5	.1	5
0400	6	5	.1	5
0500	6	5	.5	5
0600	6	5	.5	5
0700	8	4	1	5
0800	8	4	1	5
0900	9	3	1	5
1000	9	3	1	5
1100	9	2	1	5
1200	9	2	1	5
1300	9	2	1	5
1400	9	2	1	5
1500	9	2	1	5
1600	9	2	1	5
1700	9	3	1	5
1800	9	3	.5	5
1900	8	4	.5	5
2000	8	4	.1	5
2100	6	5	.1	5
2200	6	5	.1	5
2300	6	5	.1	5

Pasquill Stability Categories
1 = A (very unstable)
2 = B (unstable)
3 = C (slightly unstable)
4 = D (neutral)
5 = E (slightly stable)
6 = F (stable)
7 = G (very stable)

Surface
1 = Water
2 = Sand
3 = Barren
4 = Grass
5 = Forest
6 = Town

Central Europe Environmental Conditions
(Spring)

Hour of Day	Wind Speed (k/hr)	Stability Category	Agent Decay Rate (%/min.)	Surface Type
0000	9	5	.1	3
0100	9	5	.1	3
0200	9	5	.1	3
0300	9	5	.1	3
0400	9	5	.1	3
0500	9	5	.1	3
0600	9	5	.1	3
0700	11	4	.3	3
0800	11	4	.3	3
0900	13	3	.5	3
1000	13	3	.5	3
1100	14	2	1	3
1200	14	2	1	3
1300	14	2	1	3
1400	14	2	1	3
1500	14	2	1	3
1600	14	2	1	3
1700	13	3	.5	3
1800	13	3	.5	3
1900	11	4	.3	3
2000	11	4	.3	3
2100	9	5	.1	3
2200	9	5	.1	3
2300	9	5	.1	3

Pasquill Stability Categories
1 = A (very unstable)
2 = B (unstable)
3 = C (slightly unstable)
4 = D (neutral)
5 = E (slightly stable)
6 = F (stable)
7 = G (very stable)

Surface
1 = Water
2 = Sand
3 = Barren
4 = Grass
5 = Forest
6 = Town

South Korea Environmental Conditions
(Winter)

Hour of Day	Wind Speed (k/hr)	Stability Category	Agent Decay Rate (%/min.)	Surface Type
0000	3	5	.1	3
0100	3	5	.1	3
0200	3	5	.1	3
0300	3	5	.1	3
0400	3	5	.1	3
0500	3	5	.1	3
0600	3	5	.1	3
0700	3	5	.1	3
0800	3	5	.1	3
0900	6	4	.3	3
1000	6	4	.3	3
1100	9	3	.3	3
1200	9	3	.5	3
1300	12	2	1	3
1400	12	2	1	3
1500	12	2	.5	3
1600	9	3	.5	3
1700	9	3	.3	3
1800	6	4	.3	3
1900	3	5	.1	3
2000	3	5	.1	3
2100	3	5	.1	3
2200	3	5	.1	3
2300	3	5	.1	3

Pasquill Stability Categories
1 = A (very unstable)
2 = B (unstable)
3 = C (slightly unstable)
4 = D (neutral)
5 = E (slightly stable)
6 = F (stable)
7 = G (very stable)

Surface
1 = Water
2 = Sand
3 = Barren
4 = Grass
5 = Forest
6 = Town

APPENDIX C

Excursions in Delayed Onset of Agent Decay and Increased Toxicity

Undocumented sources have suggested that decay can be prevented for the first 2 hours following a release of *B. anthracis* and that the actual toxicity may be 100 times the levels determined by USAMRDC. This Appendix addresses these issues by providing examples of the results that would be achieved by following these assumptions.

Based on the lower decay rates used in the current study, which range from 0.1 percent/minute in darkness to 1 percent/minute in bright sunlight, the effect of a 2 hour delay in decay would be to conserve between 12 and 30 percent of the agent total mass that would be expected to decay in the first 120 minutes after dissemination. However, on a target such as an airfield attacked at night, the agent would clear the associated 4 km diameter area in about 1 hour or less, assuming winds ranging from 3 to 9 km per hour. In this airfield attack case, the absence of decay in the first hour would only conserve about 6 percent of the total agent mass.

To assess the operational implications of the increased hazard represented by these assumptions, sensitivity analysis was conducted to assess implications of a 100 fold increase in the toxicity level of *B. anthracis* and the effects of a two hour delay in the onset of agent decay following release. The sensitivity of the unit effectiveness for an artillery unit for vaccine prophylaxis, antibiotic therapy and no medical interventions was examined for two theaters of operation and two weapon systems. Attacks were simulated first for a tactical ballistic missile with submunitions and then for release by a spray device. The climates used to examine each attack scenario were Central European and Southwest Asian conditions. The bottom line was that the protective capacity of the vaccine was robust enough to maintain unit effectiveness above 85 percent in all cases without the protection of masking. However, antibiotic therapy could be decisively overwhelmed for areas as large as 15,000 km^2 for a spray attack at 0500 hours in Central Europe. For a unit assuming MOPP 4 prior to the attack, antibiotic therapy would have been required to sustain unit effectiveness at 63 percent -- the expected degradation for an artillery unit in MOPP 4. Without antibiotic therapy, however, the protective ability of masking (MOPP 3 or MOPP 4) would have been overwhelmed.

If one does indeed believe that the toxicity of *B. anthracis* is 100 times greater than the level estimated by USAMRDC, then there is an unequivocal case for a vaccine policy that immunized personnel prior to deployment, or at least in-theater prior to exposure, although the latter still requires some unfortunate risk in timing.

More specifically, Figures C.1-C.24 depict the results of the sensitivity study. Figures C.1-C.4 illustrate the expected spore area coverage that would result from *B. anthracis* attacks using "normal" toxicity rates with decay beginning immediately after release versus "high" toxicity estimates with decay delayed for two hours after release. Simulated TBM attacks for Southwest Asia and Central Europe and spray attacks for Southwest Asia and Central Europe show only a barely perceptible change in spore area coverage due to assessments regarding the toxicity of a spore and differences related to a 2-hour delay in decay.

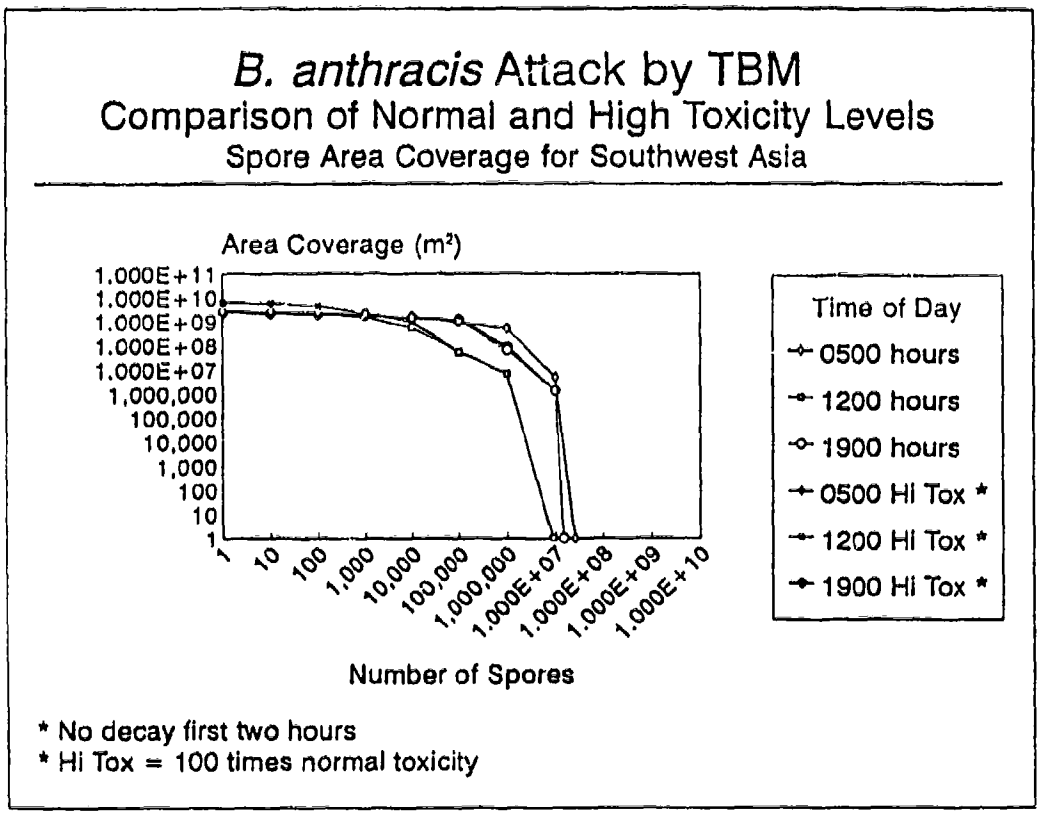

Figure C.1 TBM in Southwest Asia: Spore Area Coverage

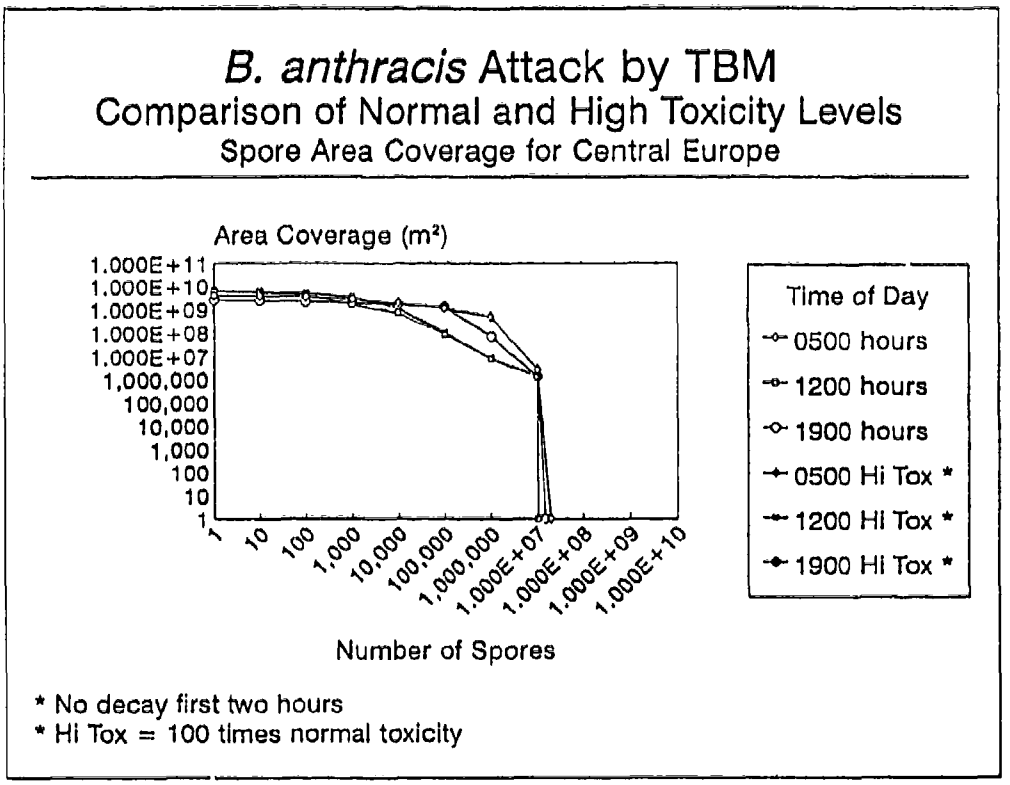

Figure C.2 TBM in Central Europe: Spore Area Coverage

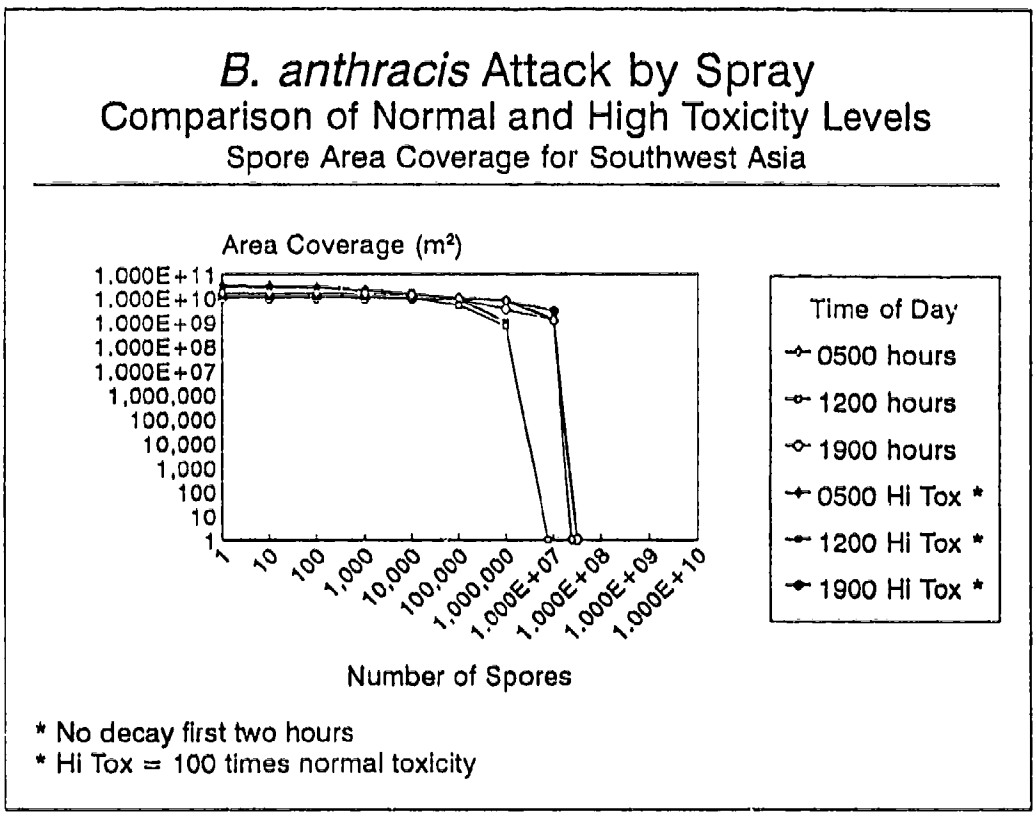

Figure C.3 Aerial Spray in Southwest Asia: Spore Area Coverage

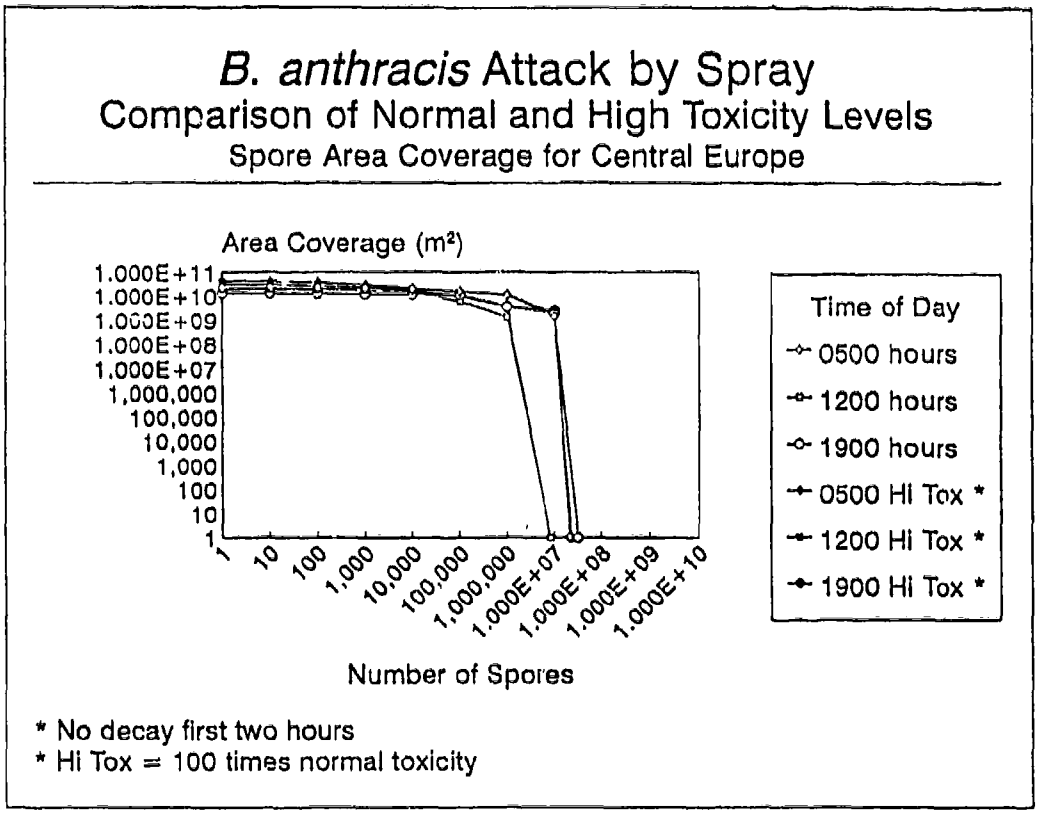

Figure C.4 Aerial Spray in Central Europe: Spore Area Coverage

The implications for casualty area coverage and the resulting levels of *B. anthracis* on the battlefield as depicted in the footprints is quite significant. Predicted casualty area coverage is depicted in Figures C.5-C.12 first for the TBM scenarios and then for the spray scenarios. For each weapon system, results for Southwest Asian conditions were included first and then Central European conditions. The scenarios for each climate were examined both for MOPP 0 and MOPP 4 assumed prior to the simulated attacks. For each of the scenarios examined in the sensitivity study, a comparison of casualty area coverage was made using the study assumptions of decay rate and toxicity as the baseline, represented by the "normal" stackbars. Comparisons are made against the "normal" baseline and results assuming a 2-hour delay in decay, then against the combination of delayed decay and increased toxicity. For all the scenarios, there is no perceptible difference between "normal" and delayed decay. However, a combined delay in decay and a 100-fold increase in toxicity would consistently present an increased challenge to units with antibictic or vaccine protection.

In considering the MOPP 0 scenarios and vaccine as a defense, a 100-fold increase in toxicity resulted in an increase of up to two orders of magnitude in casualty area coverage, representing approximately a 450 km^2 increase in expected lethal area coverage. The overall casualty area coverage with antibiotic therapy was nearly the same as with no medical therapy for MOPP 0, indicating that antibiotic therapy would not be very effective against a 100-fold increase in toxicity. Even assuming that personnel would be in MOPP 4 at the time of the simulated attacks, the high toxicity excursion would produce casualty area coverage against vaccinated personnel ranging from 1,000 m^2 to 1 km^2.

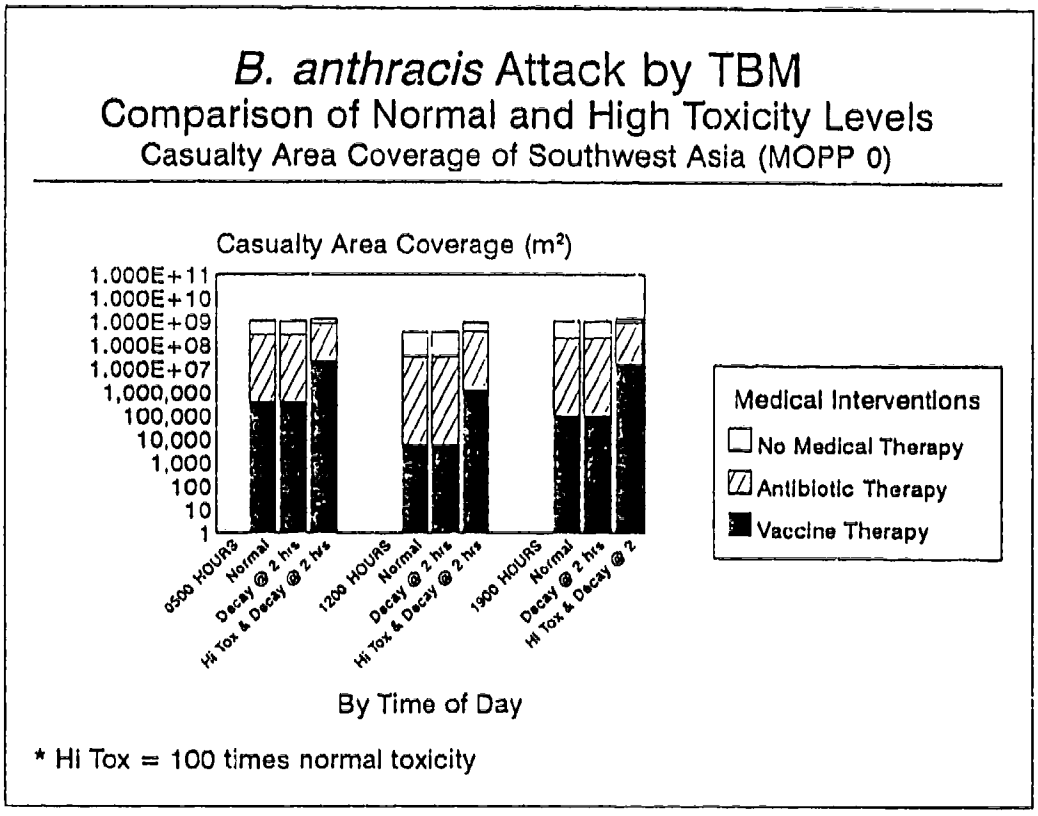

Figure C.5 TBM in Southwest Asia: Casualty Area Coverage (MOPP 0)

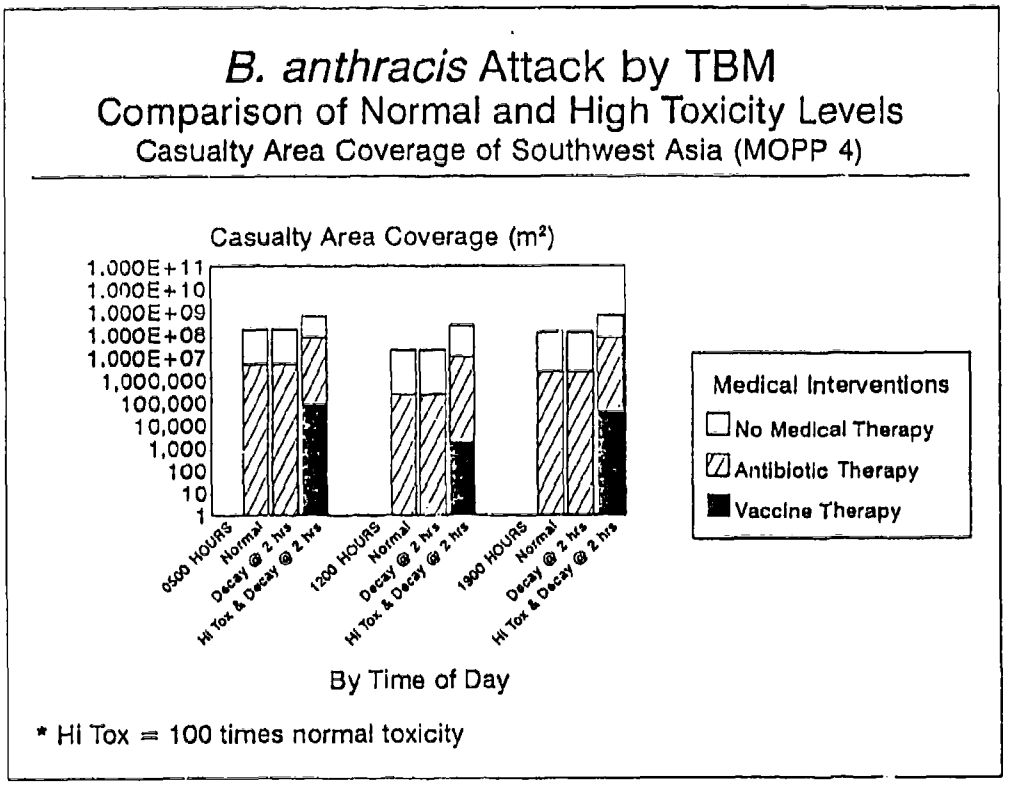

Figure C.6 TBM in Southwest Asia: Casualty Area Coverage (MOPP 4)

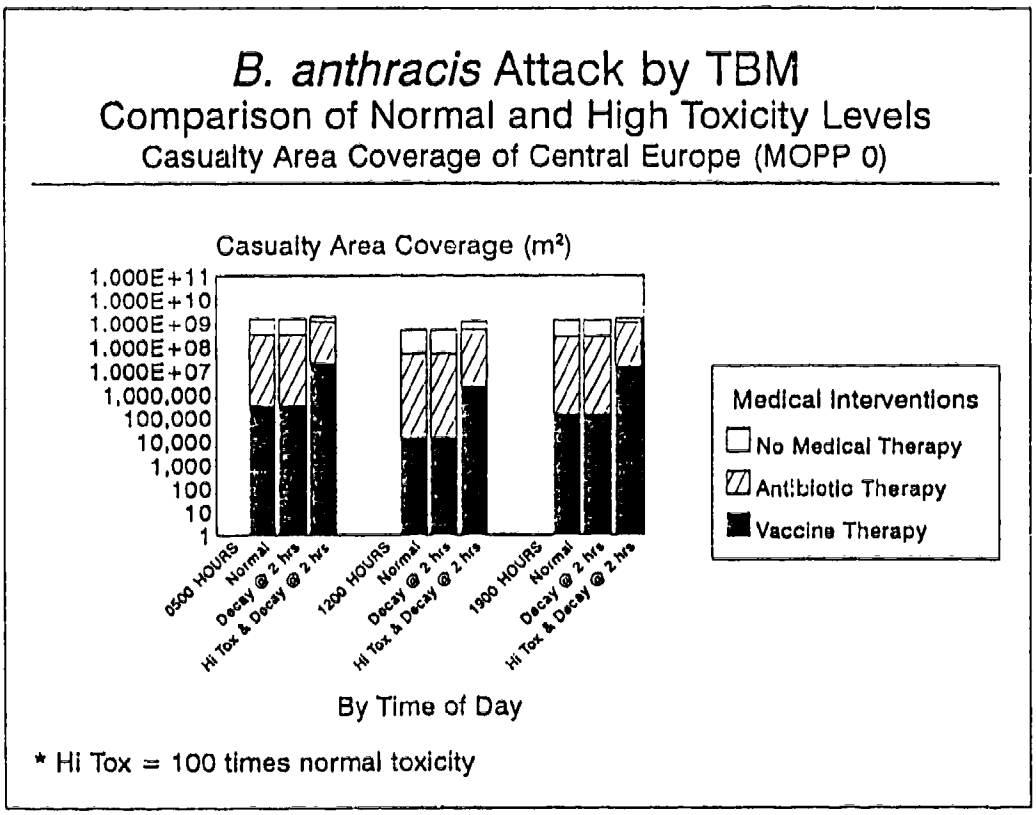

Figure C.7 TBM in Central Europe: Casualty Area Coverage (MOPP 0)

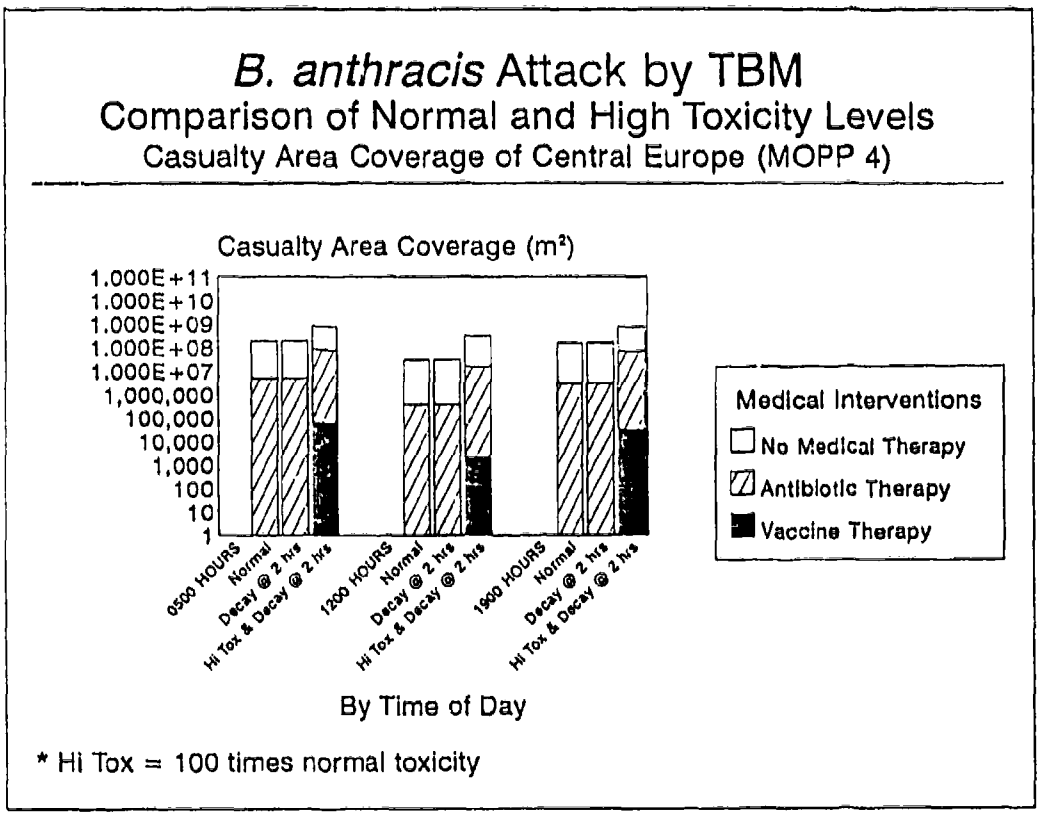

Figure C.8 TBM in Central Europe: Casualty Area Coverage (MOPP 4)

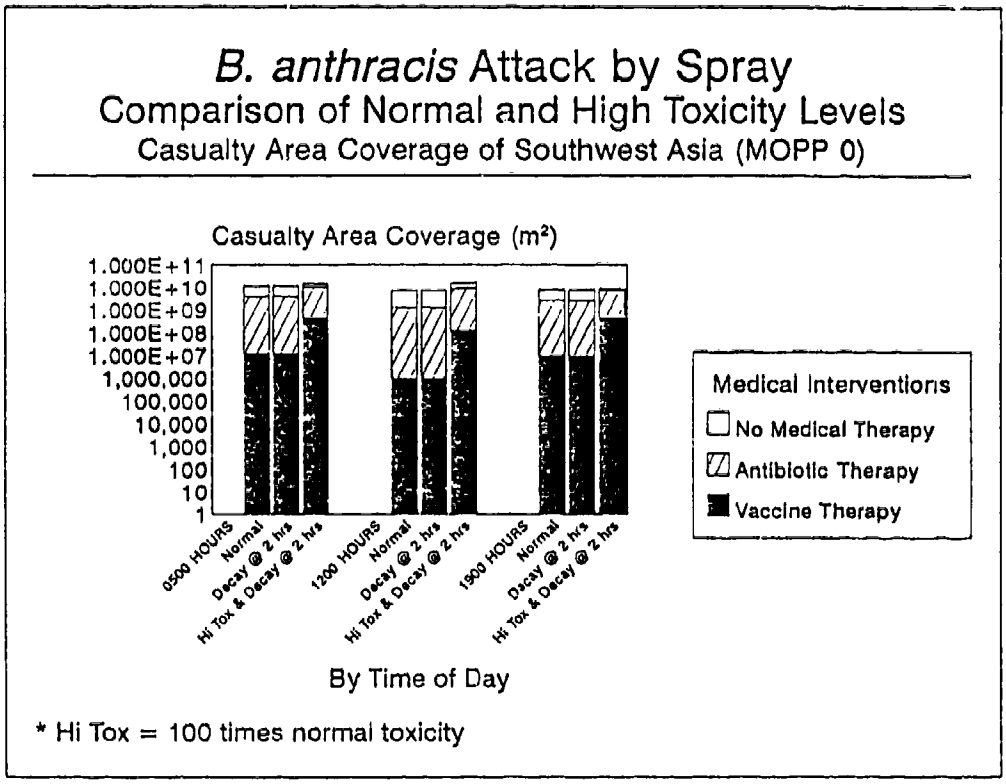

Figure C.9 Aerial Spray in Southwest Asia: Casualty Area Coverage (MOPP 0)

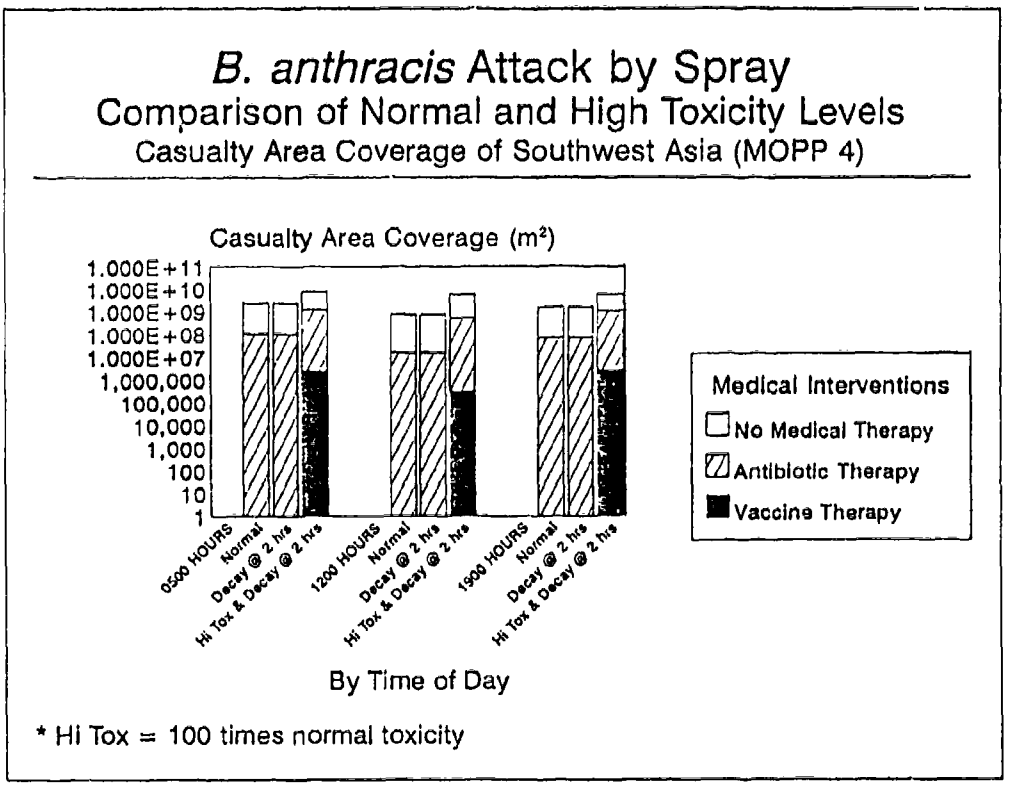

Figure C.10 Aerial Spray in Southwest Asia: Casualty Area Coverage (MOPP 4)

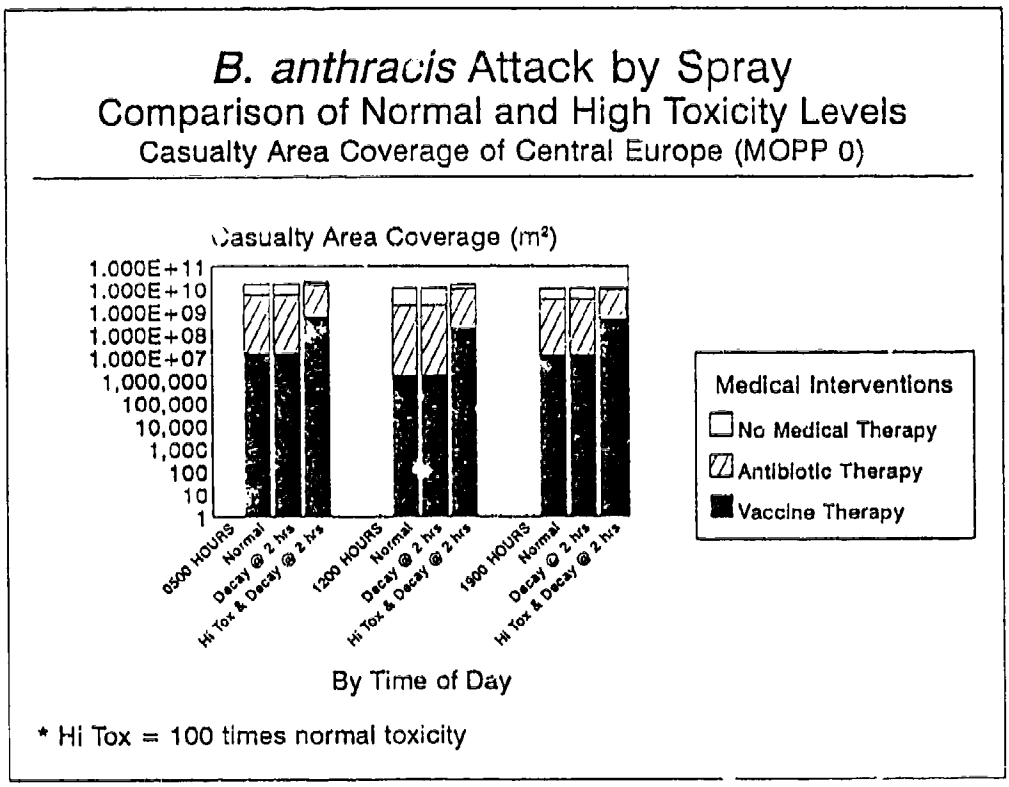

Figure C.11 Aerial Spray in Central Europe: Casualty Area Coverage (MOPP 0)

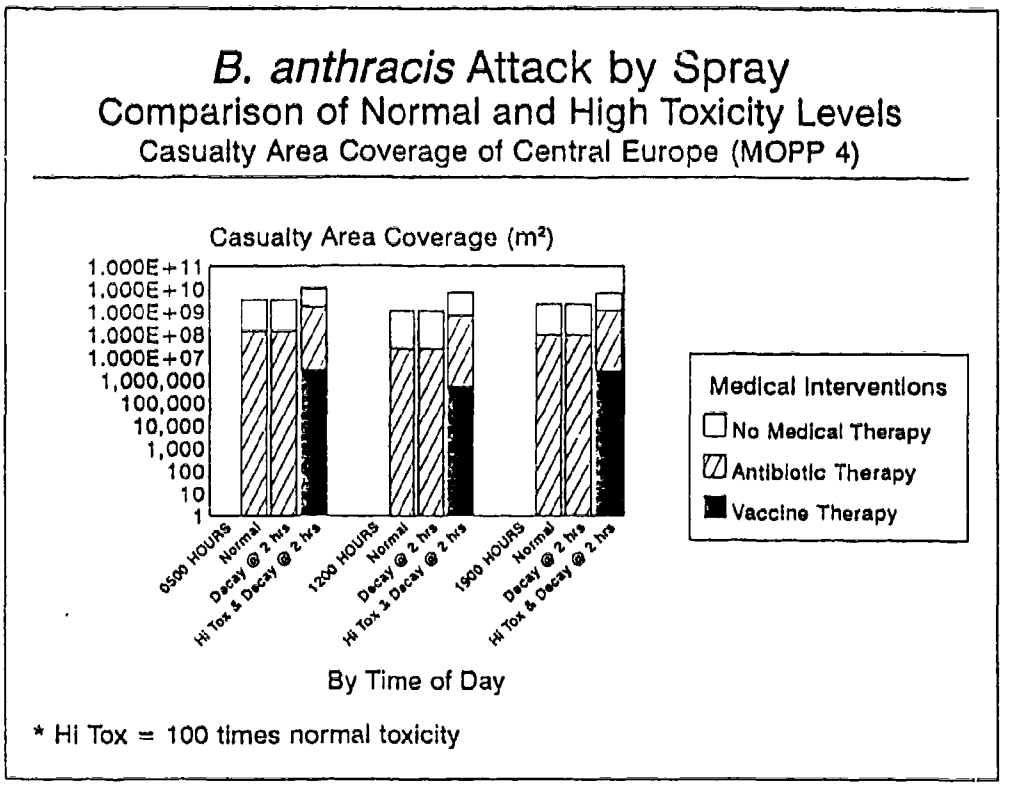

Figure C.12 Aerial Spray in Central Europe: Casualty Area Coverage (MOPP 4)

Figures C.13-C.24 depict the associated hazard area footprints and resultant unit effectiveness for the 100-fold increase in toxicity and the 2-hour delay in decay. As can be seen, the increased toxicity assumption significantly increases the extent of the contours for 50 percent population response with no medical intervention or with antibiotic therapy. In *no* case did the attack scenarios produce areas where there would be 50 percent expected casualties in MOPP 0 when personnel were protected by vaccine. The high level of effectiveness of the vaccine also translated into high levels of unit effectiveness for the artillery unit modeled. In most cases, unit effectiveness was sustained at 100 percent with only slight degradation in effectiveness to about 90 percent.

Without vaccine and sole reliance on antibiotic therapy, the medical workload would increase dramatically as evidenced by the steep decline in unit effectiveness caused by casualties.

The conclusion drawn from this sensitivity analysis was that a vaccine policy that immunizes personnel prior to exposure, preferably prior to deployment, is vital. Dependence on antibiotic therapy alone would result in significant levels of casualties and the resulting degradation in unit effectiveness and attendant heavy medical workloads. Based on the scenarios studied, predeployment vaccination could effectively maintain combat effectiveness and avoid unnecessary illness and loss of life.

Footprints are shown first for TBM scenarios for Southwest Asia and Central Europe at 0500, 1200 and 1900 hours, and then for spray attacks for the same climates and times of day.

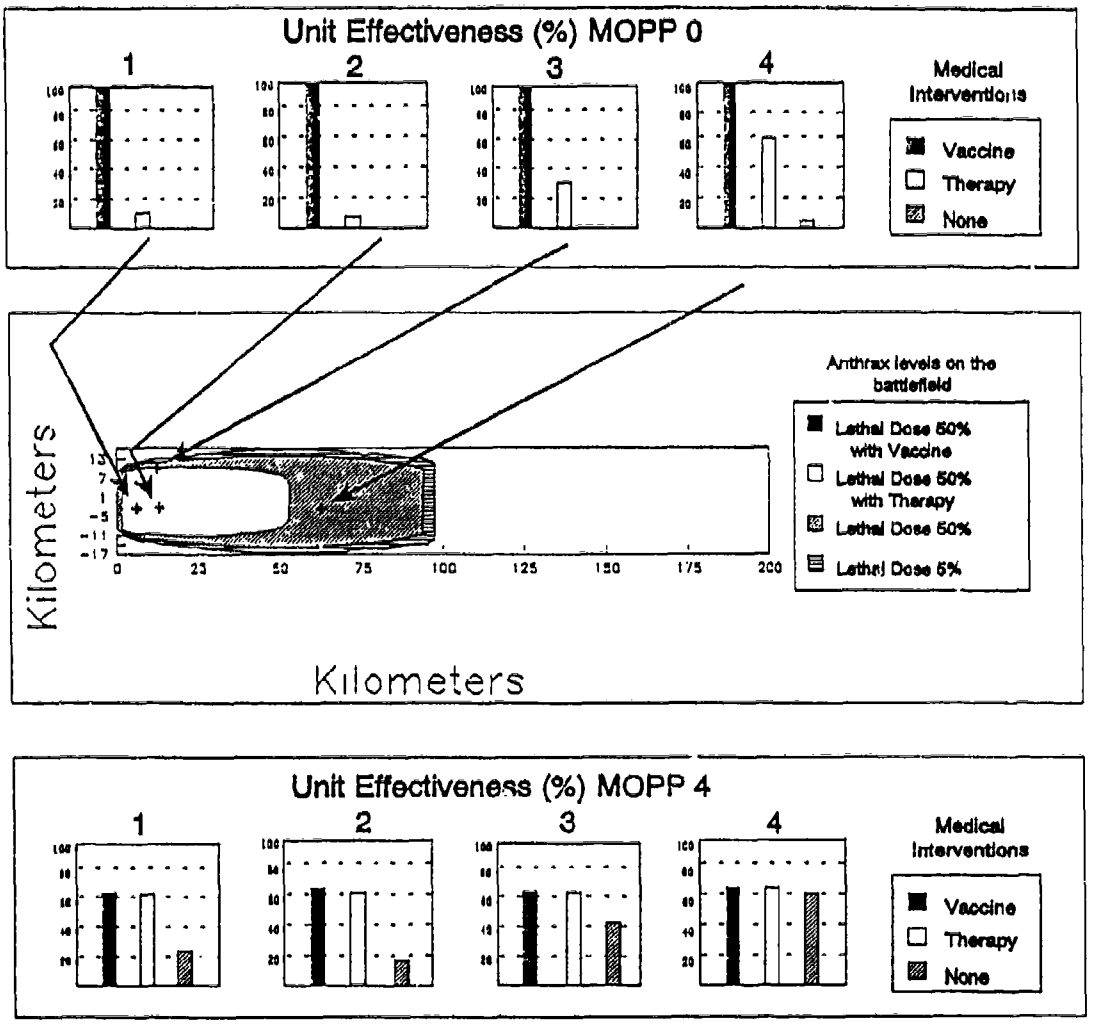

Figure C.13 TBM with Submunitions in Southwest Asia at 0500 Hours: Artillery Unit 100 Times Normal Toxicity Level, No Decay First Two Hours

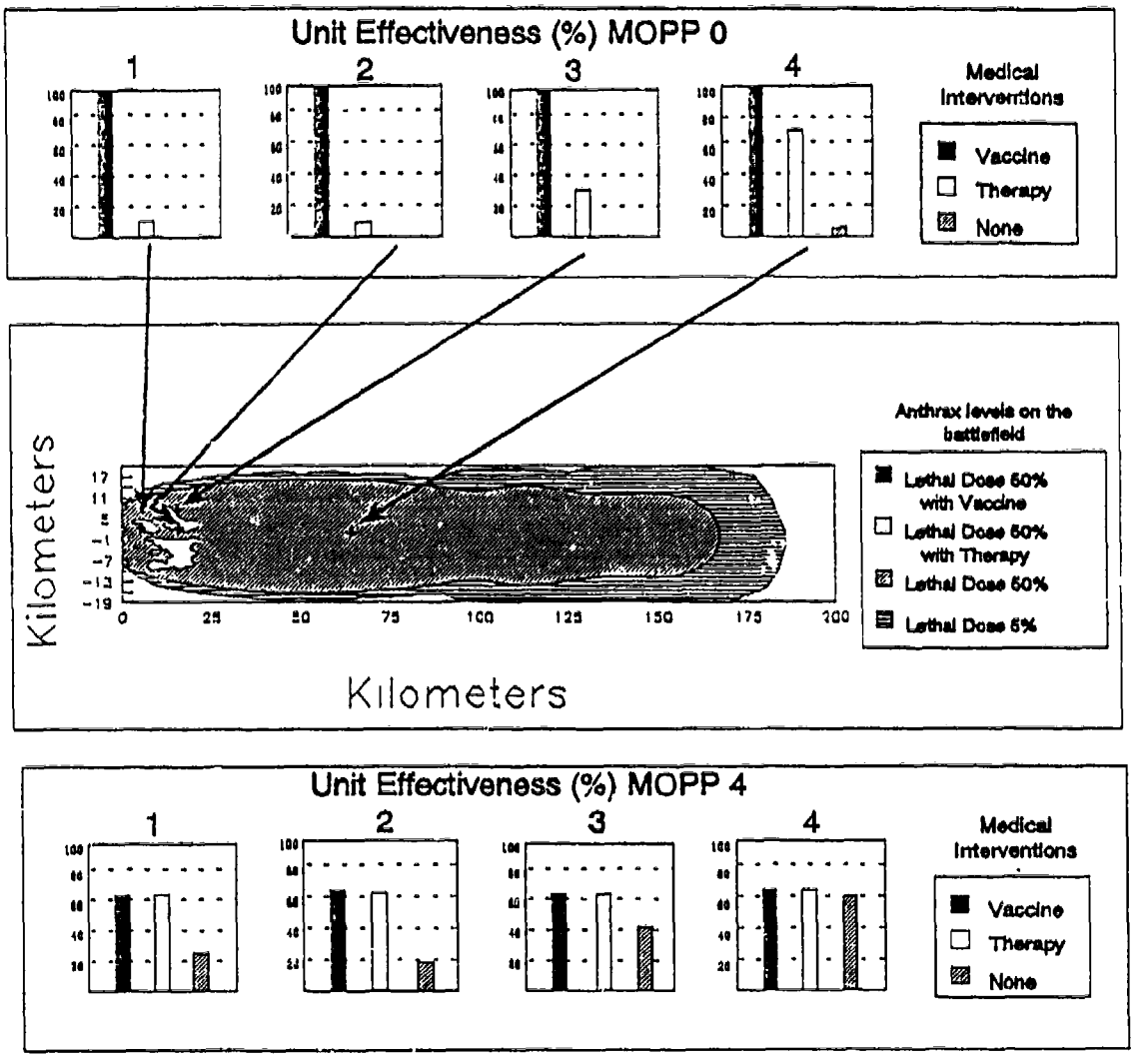

Figure C.14 TBM with Submunitions in Southwest Asia at 1200 Hours: Artillery Unit 100 Times Normal Toxicity Level, No Decay First Two Hours

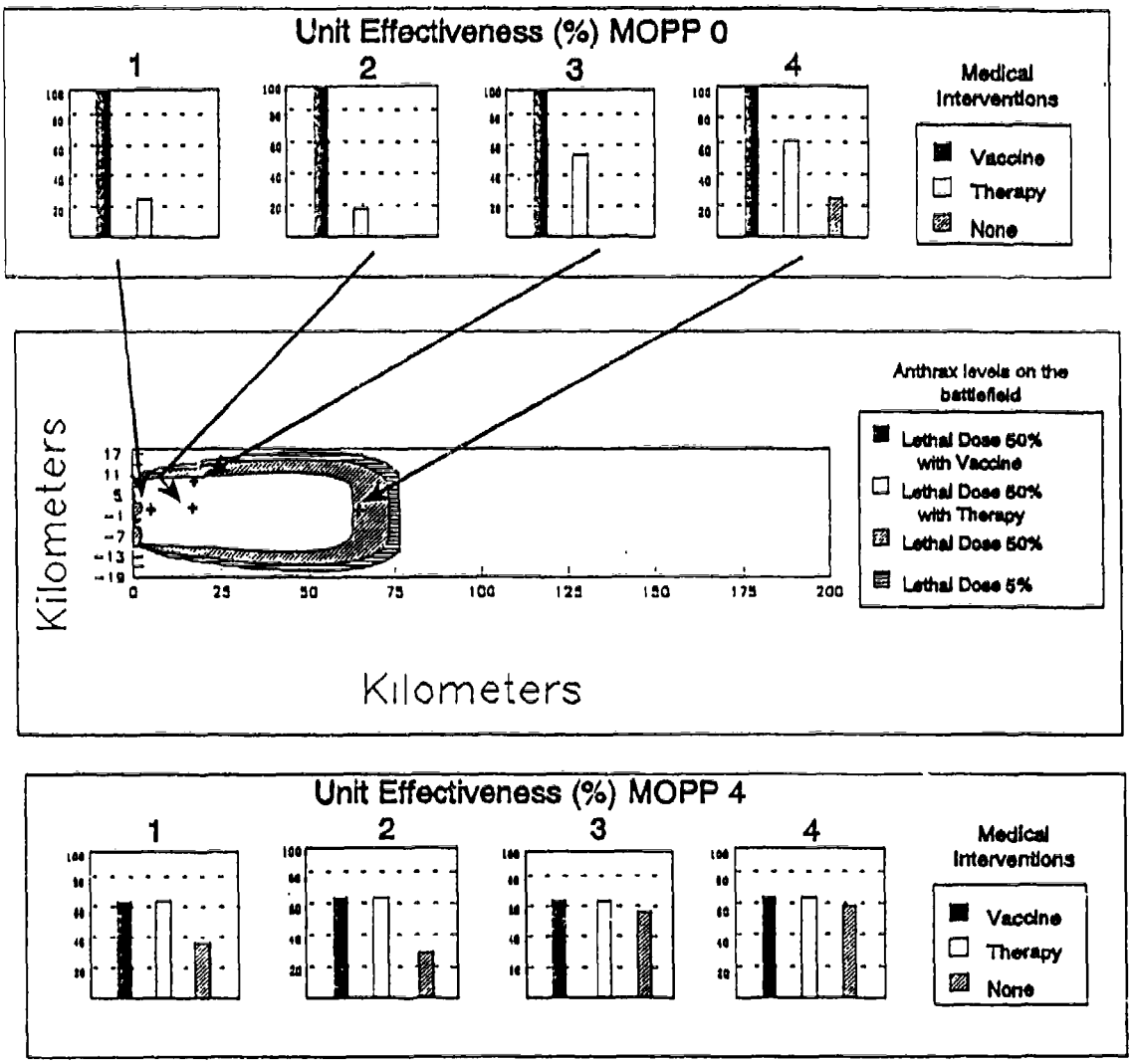

Figure C.15 TBM with Submunitions in Southwest Asia at 1900 Hours: Artillery Unit 100 Times Normal Toxicity Level, No Decay First Two Hours

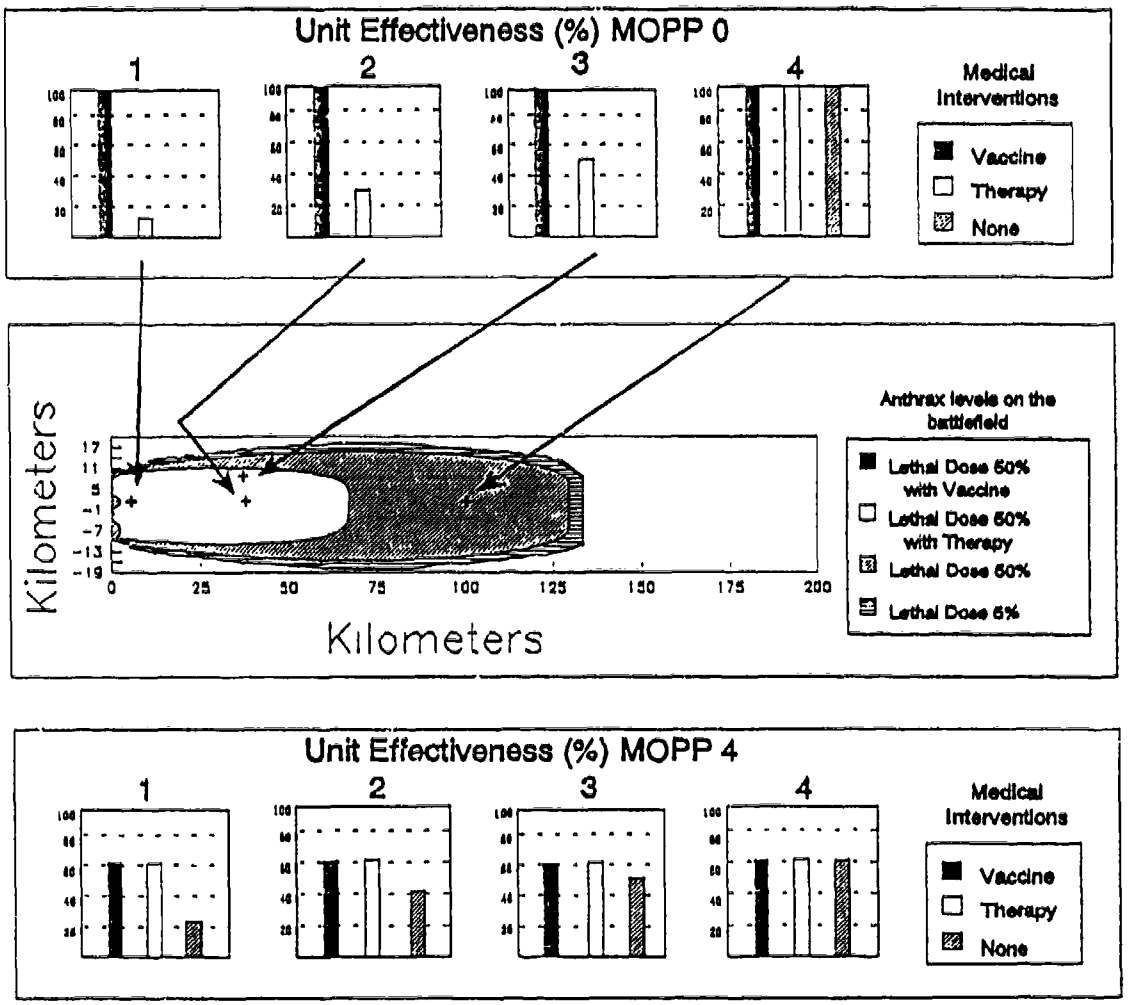

Figure C.16 TBM with Submunitions in Central Europe at 0500 Hours: Artillery Unit 100 Times Normal Toxicity Level, No Decay First Two Hours

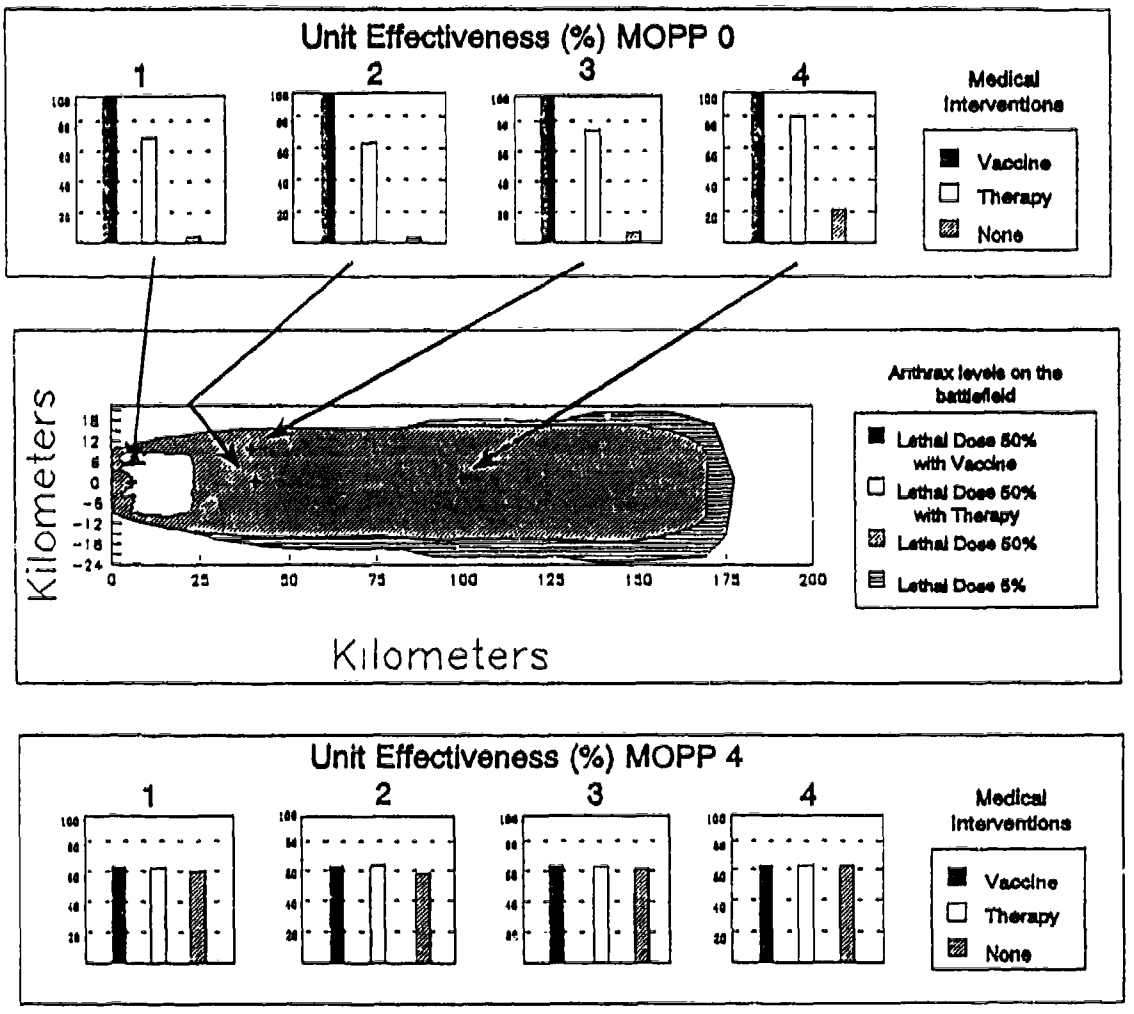

Figure C.17 TBM with Submunitions in Central Europe at 1200 Hours: Artillery Unit 100 Times Normal Toxicity Level, No Decay First Two Hours

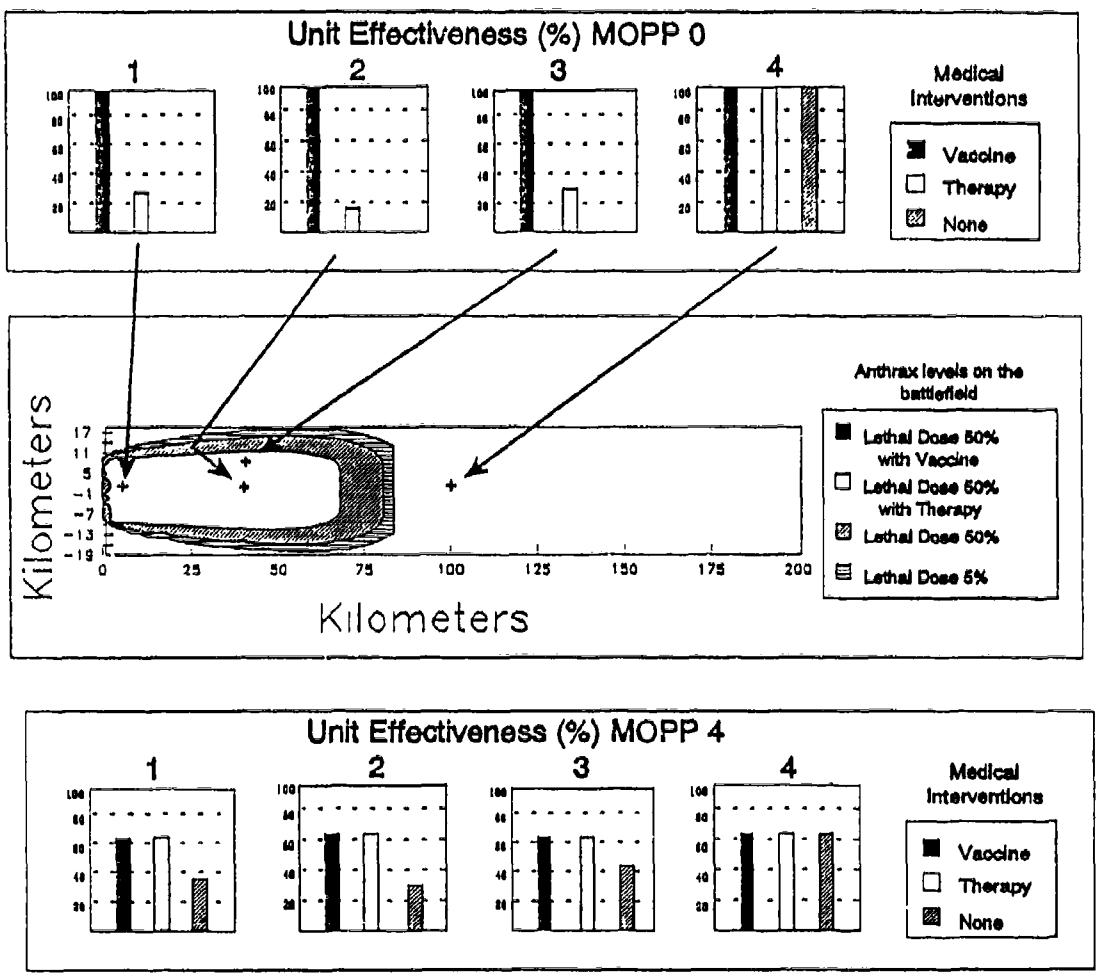

Figure C.18 TBM with Submunitions in Central Europe at 1900 Hours: Artillery Unit 100 Times Normal Toxicity Level, No Decay First Two Hours

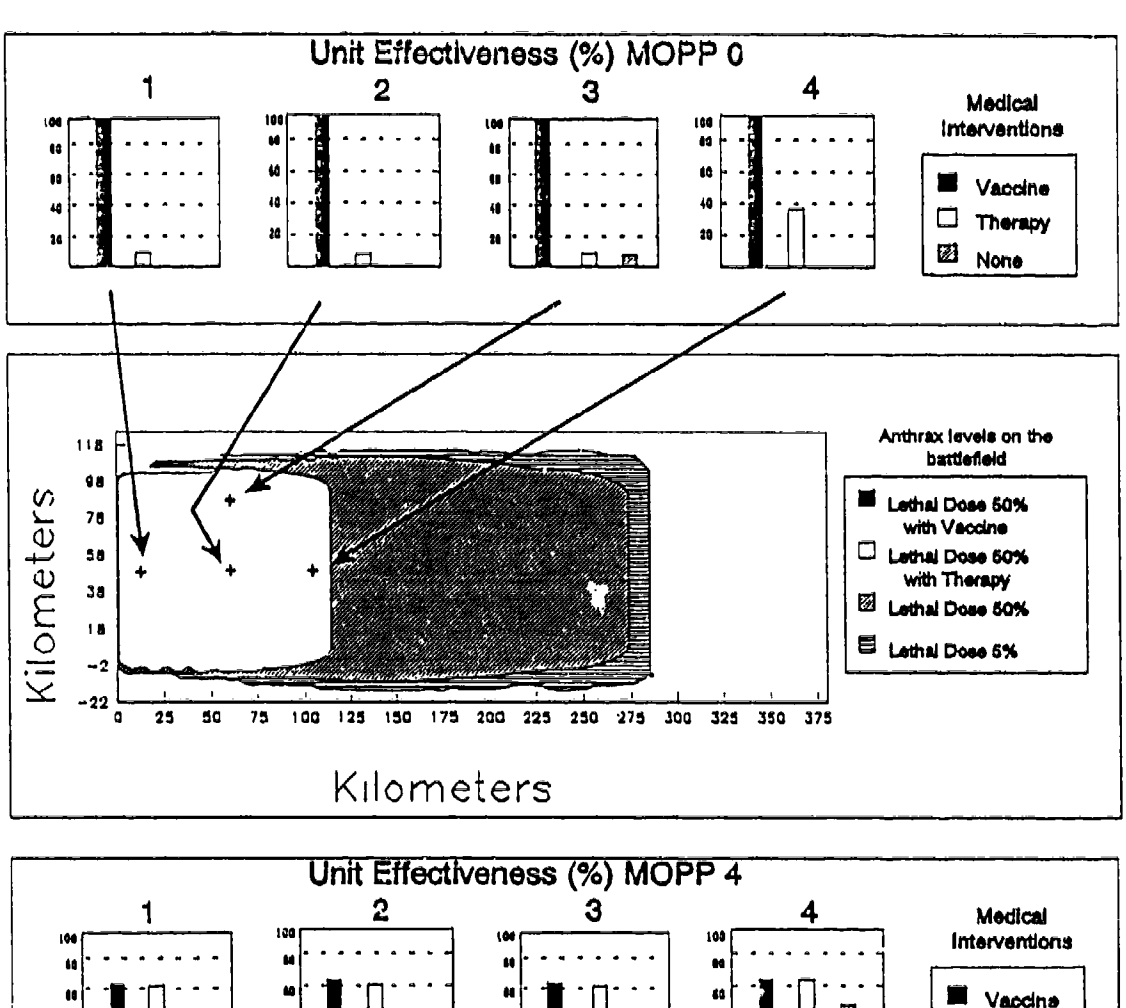

Figure C.19 Aerial Spray in Southwest Asia at 0500 Hours: Artillery Unit 100 Times Normal Toxicity Level, No Decay First Two Hours

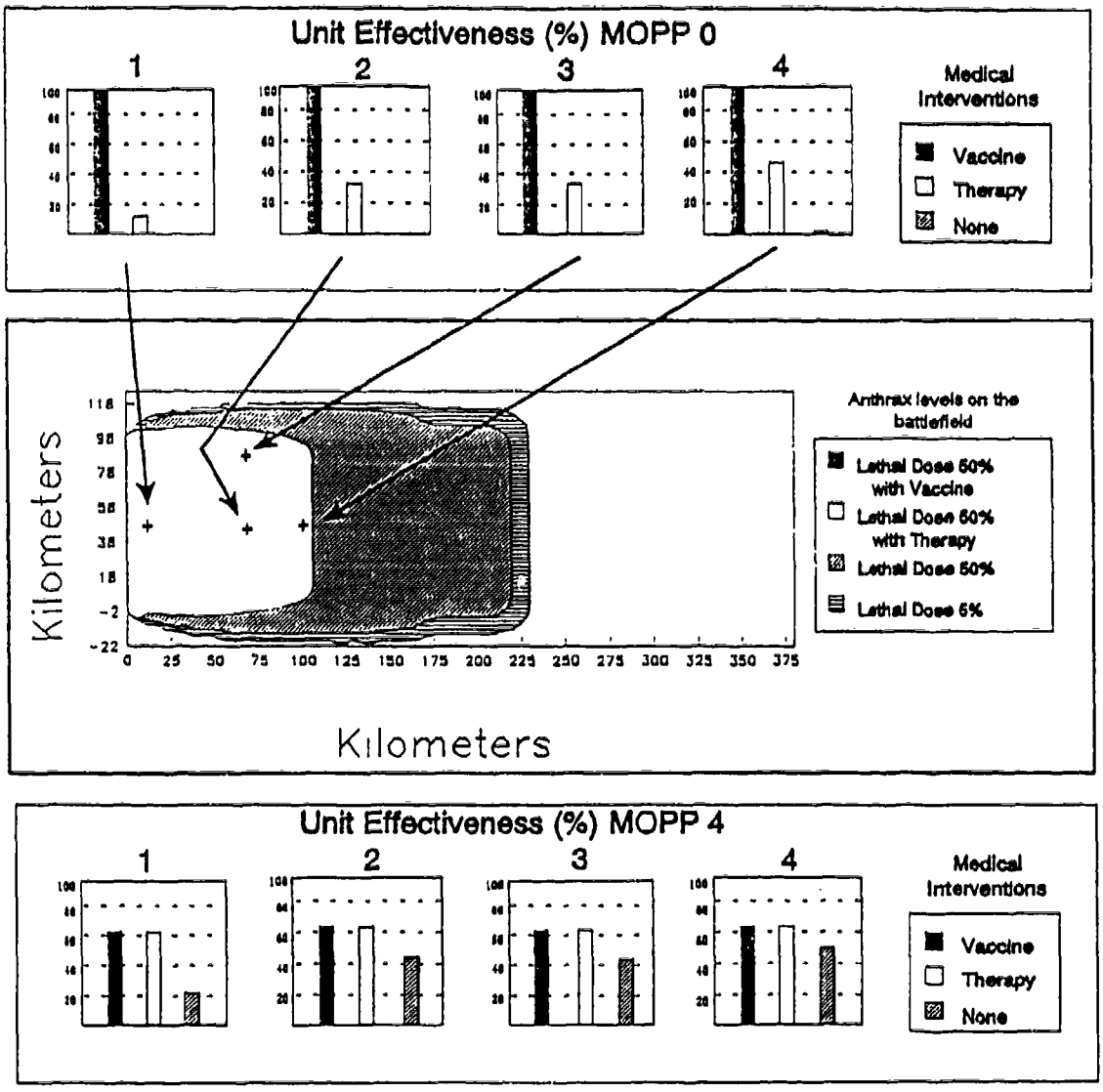

Figure C.20 Aerial Spray in Southwest Asia at 1200 Hours: Artillery Unit 100 Times Normal Toxicity Level, No Decay First Two Hours

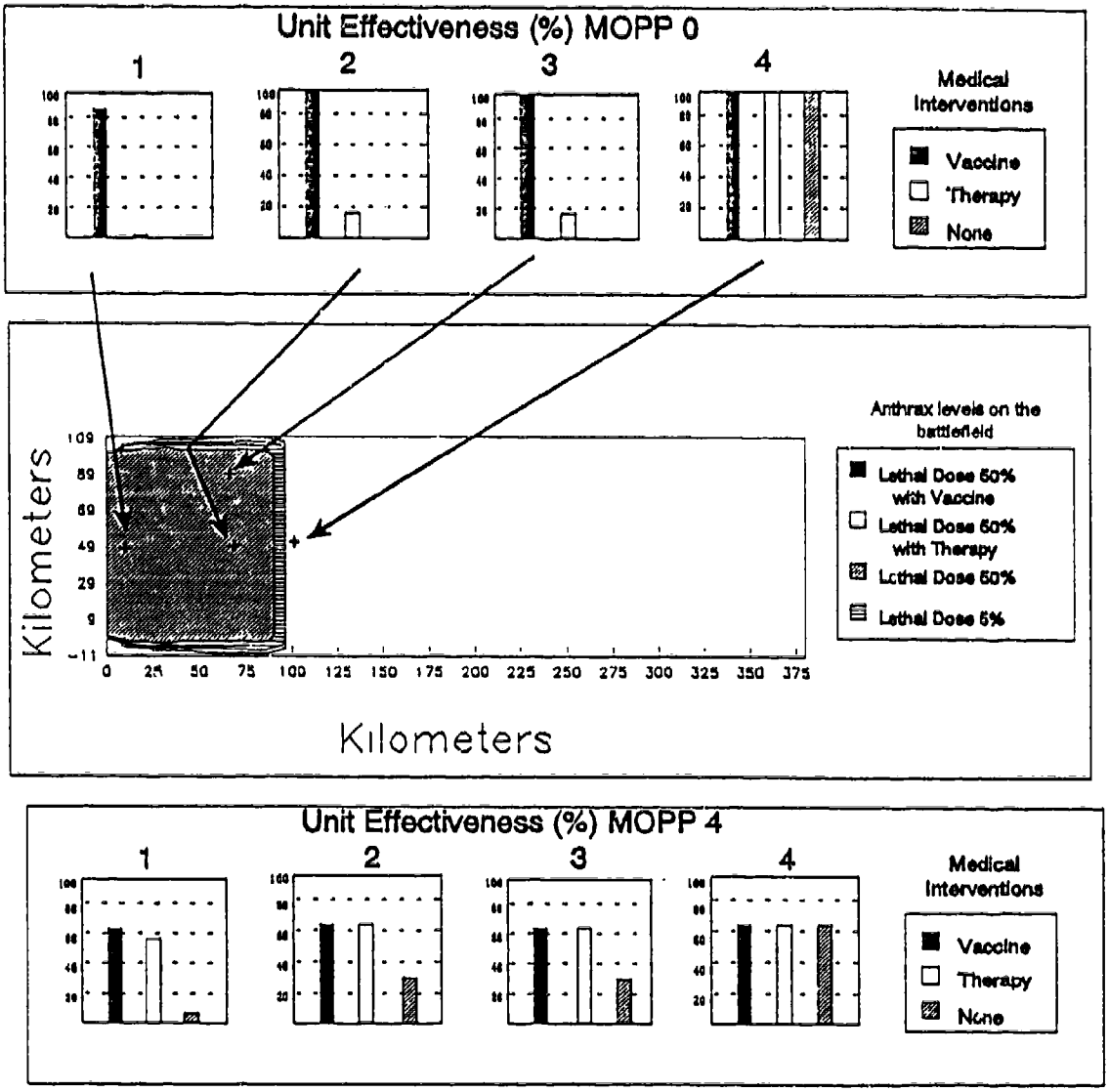

Figure C.21 Aerial Spray in Southwest Asia at 1900 Hours: Artillery Unit 100 Times Normal Toxicity Level, No Decay First Two Hours

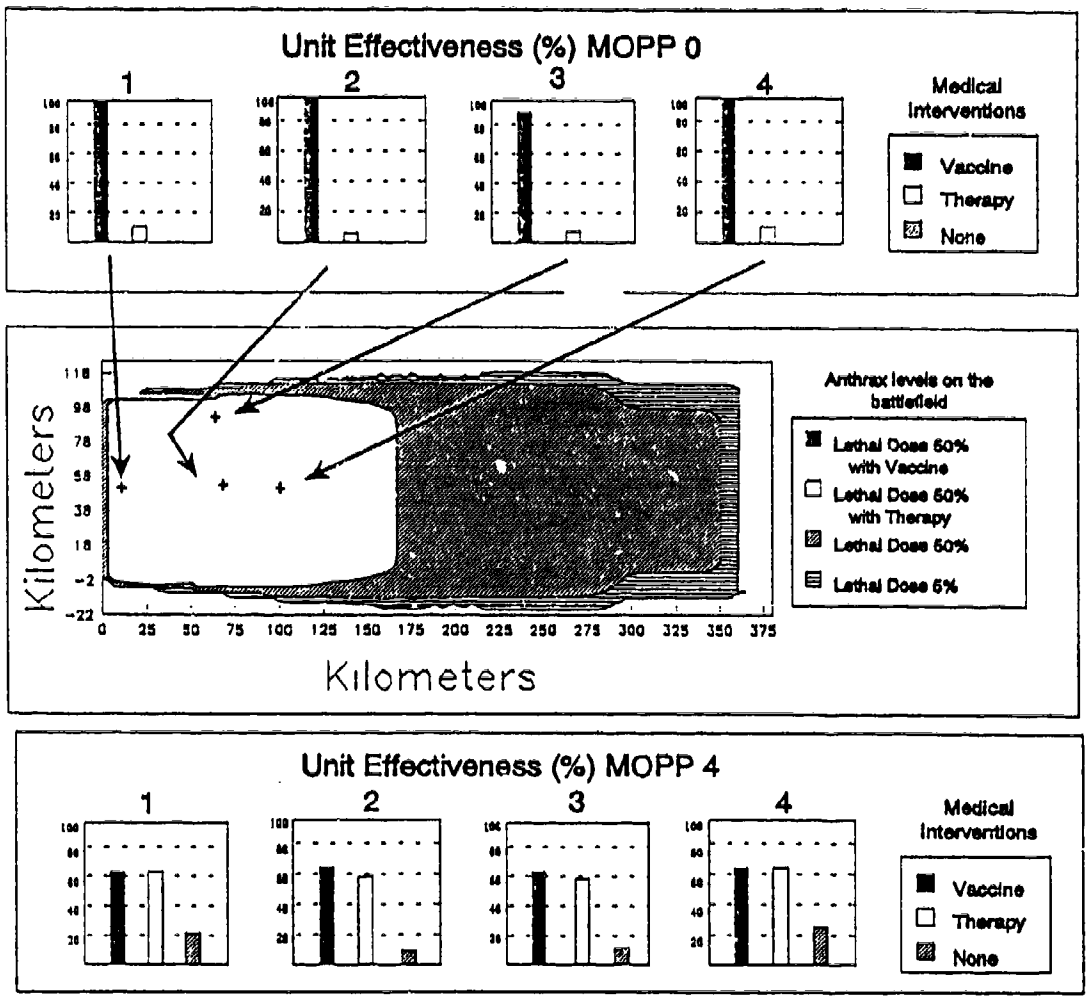

Figure C.22 Aerial Spray in Central Europe at 0500 Hours: Artillery Unit 100 Times Normal Toxicity Level, No Decay First Two Hours

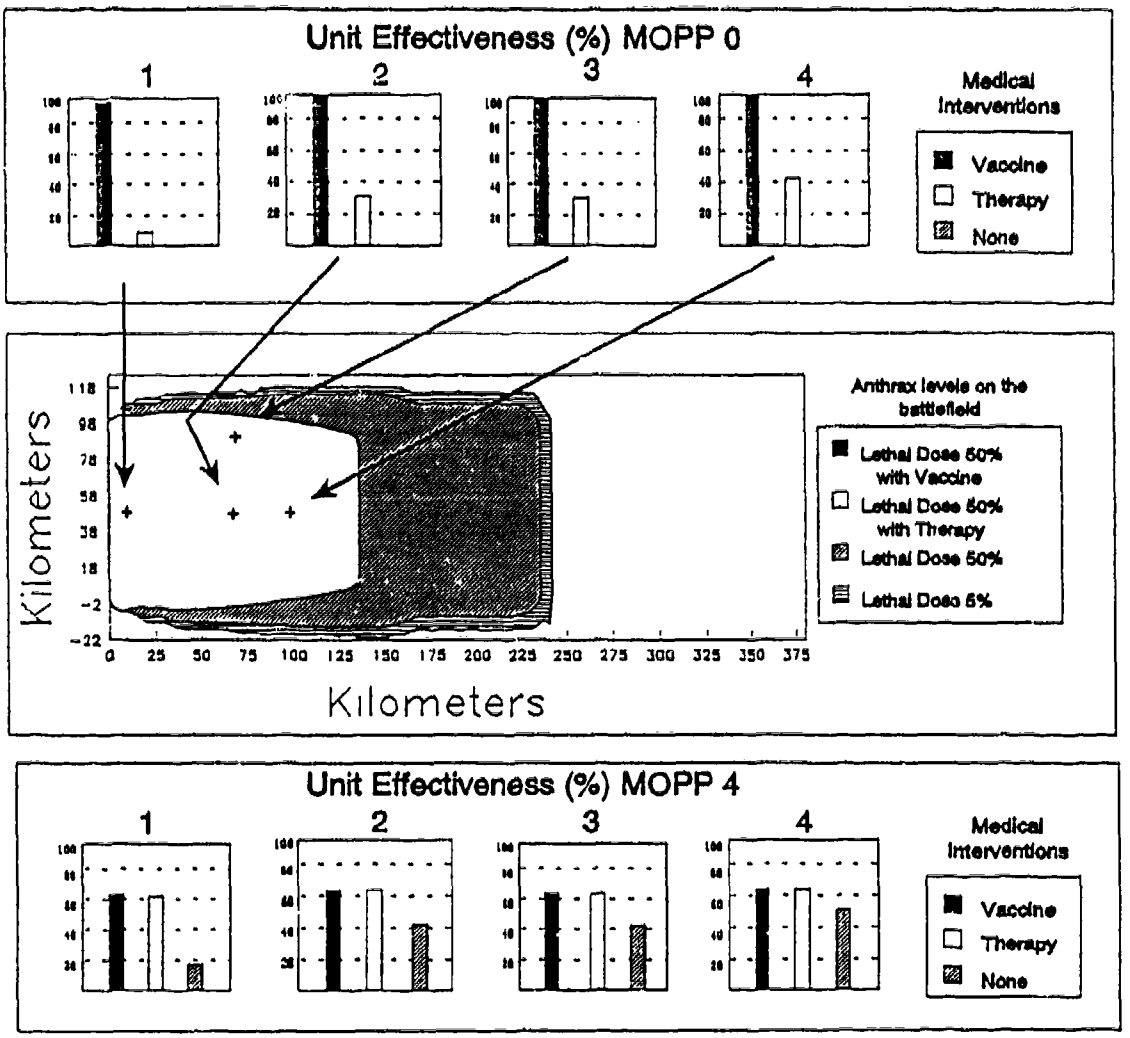

Figure C.23 Aerial Spray in Central Europe at 1200 Hours: Artillery Unit 100 Times Normal Toxicity Level, No Decay First Two Hours

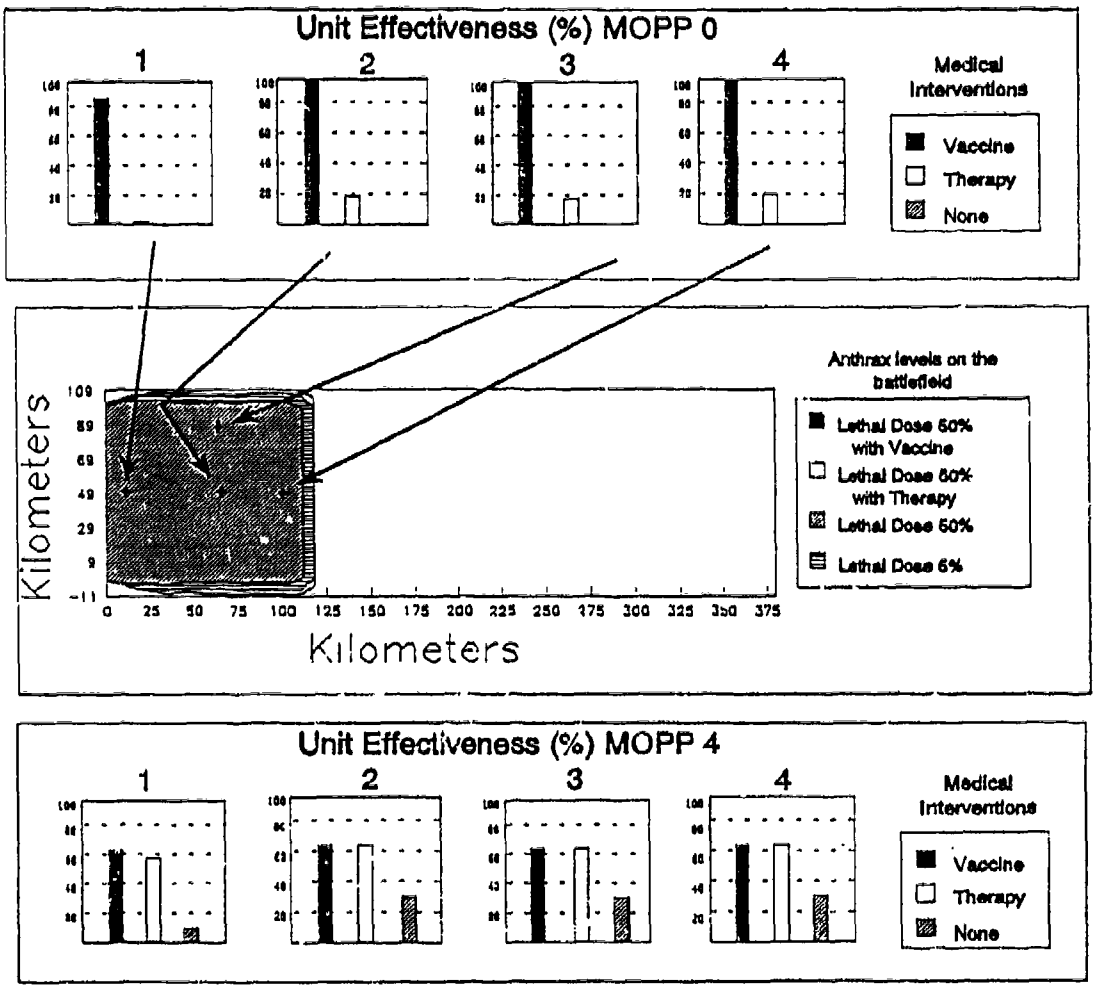

Figure C.24 Aerial Spray in Central Europe at 1900 Hours: Artillery Unit 100 Times Normal Toxicity Level, No Decay First Two Hours

APPENDIX D

Reading the Hazard Footprint Graphs

Reading the Hazard Footprint Graphs:

B. anthracis footprint maps, combined with unit effectiveness bar graphs, show the comparative impact of vaccine and antibiotic therapy as a defense against the expected levels of *B. anthracis* on the battlefield. The Y-axis on the footprint map indicates the crosswind extent of the hazard cloud on the battlefield, and the X-axis indicates the downwind extent. Since the primary route of entry for *B. anthracis* is inhalation, the footprints represent exposure levels across a plane at 1.67 meters off the ground, or nose level. Contours are based on the *B. anthracis* dosage that results in 5 percent and 50 percent population response (deaths) with no medical intervention, 50 percent population response with antibiotic therapy started in the first day of exposure, and contours representing 50 percent population response with vaccinated personnel. It should be noted that the vaccine's protection ratio was great enough to preclude an LD_{50} level in any of the scenarios simulated for this study with vaccinated personnel.

On each footprint map, unit effectiveness was represented for units at four positions within the hazard area (noted by black dots). The resulting unit effectiveness for each unit was then expressed using bar graphs to compare the beneficial effects of vaccine and antibiotic therapy with results for units with no medical therapy. The bar graphs above the footprint represent results for units without physical protection (MOPP 0), and the graphs below the footprint represent corresponding results for units assuming MOPP 4 prior to the attack. It should be noted that while protective gear (particularly masking) is highly effective in preventing the contraction of inhalation anthrax, there is a trade-off in unit effectiveness.

General trends relative to *B. anthracis* footprints:

- Environmental sensitivities (see Appendix B) include UV exposure, atmospheric stability and wind speed, factors which affect the extent of the hazard. Footprints for 1200 hours, therefore, are typically smaller than for other times of day as result of generally higher decay rates and wind speeds as well as unstable atmospheric conditions. Agent transport is controlled by the wind speed profile, and diffusion is controlled by atmospheric turbulence. Unstable (or lapse) conditions tend to dissipate agent concentrations faster than either neutral or stable conditions.

- The more stable atmospheric conditions and lower wind speeds of S. Korean winter produced a relatively more severe hazard compared to the other climates modeled.