PLANNING OF MEDICAL SUPPORT FOR A THREATENED OR ACTUAL BIOLOGICAL ENVIRONMENT. PRINCIPLES, POLICIES AND PROCEDURES

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Summary: Suitable approaches for planning medical support for German Armed Forces out-of-area-operations in a threatened or actual BW environment have not as yet been available. Therefore, appropriate principles, policies and procedures for the medical management of BW casualties and for creating a computerized planning system have now been developed. The latter will enable the user to estimate the probable numbers and rate of casualty intake and to calculate the resources required for level A to C medical support in different BW scenarios and on the basis of different planning assumptions. The system includes models for simulating BW scenarios after an assumed exposure of units varying in size, level of physical NBC protection and effectiveness of medical countermeasures (e.g. immuno- and/or chemoprophylaxis) against aerosols of potential biological warfare agents. Unique incidence and epidemic models have been elaborated with the help of which explosive epidemics and the cumulative percentage or absolute numbers of BW casualties over a period of time can be calculated. Based on clinical, epidemiological and logistical aspects, possible clinical syndromes after inhalation of biological agents are reduced to four grades of severity depending on the agent and the percentage distribution of casualties. Policies governing personnel and materiel requirements for decontamination, evacuation and treatment at each role of the medical evacuation chain are formulated.

Key words: NBC, biological warfare environment, medical support planning, principles, policies, categories of severity, medical evacuation, decontamination, beds, treatment, procedures, casualty estimation, incidence model, epidemic model

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1. Introduction

Since 1990, the security environment has fundamentally changed. Growing socioeconomic, religious and ethnic differences within and beyond Europe's borders have manifested themselves in local military conflicts that are fought with almost all means available and the utmost relentlessness. At the same time, terrorism would seem to be developing a new dimension in that terrorists have no qualms about employing nuclear, chemical or biological weapons. These trends are exemplified by the sarin attack launched by the Aum Shinrikyo in 1995, the ongoing proliferation of biological technologies, the experience of allied forces in "Desert Storm" and the subsequently uncovered biological weapons program in Iraq. Biological warfare (BW) agents are today easily available and may be used everywhere and at any time during overt or clandestine military operations or terrorist actions.

It is therefore legitimate for military thinking to include BW threats which German Armed Forces might encounter during missions in the framework of international crisis management. As a result, the medical service is facing a growing challenge, for it must also be able to provide optimum medical support in a BW environment. Suitable approaches for planning biological medical readiness in out-of-area missions have so far not been available. The possibility of future multinational missions in the face of a BW threat, however, will necessitate biological medical planning based on the best practicable health standards.

Therefore, in 1994 a study was initiated by the Federal Armed Forces Medical Service which included the following objectives:

- to define appropriate principles, policies and procedures for the planning of medical care as well as support in the fields of hygiene and anti-epidemic measures;
- to establish qualitative and quantitative medical requirements for defense, contingency, and mission planning;
- to calculate possible levels of BW casualties and required medical resources based on the epidemiological, infection-related and clinical parameters of biological attacks;
- to ensure compatibility with existing national and NATO policies, guidelines and procedures for biological medical defense and medical support planning at the various roles of the medical evacuation chain;
- to provide expert data and options for the development of a computer-aided NBC Medical Planning System (NBCMedPlanS) for the efficient organization of medical support under variable BW threats and BW environments.

In this presentation, a number of medical and scientific baselines of the NBCMedPlanS bio-module will be provided. The medical planning concept will not make any attempt to assess the probability of BW attacks against German troops in crisis management missions. The resulting policies and procedures will be used solely for the generic planning of

biological medical defense readiness and prediction of BW contingency requirements for medical personnel, materiel and capabilities for decontamination, isolation, evacuation, specific and symptomatic treatment, supportive care and prophylaxis.

2. Baselines

Biological weapons are weapons of mass destruction using pathogens or toxins to cause death or incapacity in humans and animals. For strategic or operational use, BW agents will be disseminated mainly by aerosols. The impact of such BW attacks will depend chiefly on the following factors:

- the pathogen or toxin used and its concentration in conjunction with the
- method and efficiency of dispersal;
- the size, density and physical protection level of the exposed population;
- the level of immunity in the population at risk;
- the availability and adequate implementation of effective post-exposure prophylactic and/or therapeutic measures;
- potential for secondary spread of infections caused by some contagious BW agents.

Understanding and quantifying the impact of a BW attack and planning the required medical support are very complicated due to lack of solid data on the stability of BW agents in aerosols, on penetration characteristics of released aerosols, on effective inhalative doses in man and on the pathological, clinical and epidemiological features of inhalative human infections or intoxications after an aerogenic challenge with BW agents.
For the assessment and medical management of BW casualties, available non-classified sources were analyzed, such as publications of the United Nations [1] and the World Health Organization (WHO)[2], the NBC/Med STANAG 2068 [3], the ACE Directive 85-8 [4], mathematical procedures for modeling epidemic processes, clinical and epidemiological reports, manuals and monographs on microbiology, infectious diseases and epidemiology, results of animal experiments and expert protocols on the treatment and prophylaxis of naturally occurring diseases caused by the pathogens and toxins referred to below. In addition, national and international laws, regulations and recommendations for the prevention of communicable diseases or for immunizations, technical guidelines for the medical support of German soldiers deployed abroad [5] and for NBC medical defense [6] were also taken into consideration.
In the study for the NBCMedPlanS bio-module the following 13 agents were investigated which were selected from lists of putative biological agents submitted by experts of the WHO [2], the NATO [3] and SIPRI [7]:

Bacteria:	*Bacillus anthracis* (spores), *Yersinia pestis*, *Francisella tularensis*, *Brucella Spp.*;
Rickettsia:	*Rickettsia prowazekii*, *Coxiella burnetii;*
Viruses:	*Orthopoxvirus variolae* (smallpox virus), *Lassa virus, Ebola virus, Venezuelan Equine Encephalitis* (VEE) *virus*;
Toxins:	*Clostridium botulinum toxin, Staphylococcus aureus enterotoxin B*, ricin.

Fundamentals on which to base the simulation of possible BW incidence and epidemic models and the calculation of the probable number of BW casualties, the scale and time frame for medical support had to be developed using only non-classified military, aerobiological, microbiological, toxicological, medical, and epidemiological data.

3. Principles

Principles governing the development of planning concepts for medical support in a threatened or actual BW environment will result from politico-military, strategic, operational, tactical, aerobiological, epidemiological and infection-related clinical parameters of biological warfare. In this context only the main principles can be outlined:

(a) Basically, medical support planning must adhere to the maxim of the German medical care concept for German soldiers abroad according to which soldiers at risk will, in case of illness, an accident or injury, receive medical treatment to the same standard they can expect in Germany [5]. This applies equally to missions under a BW threat or in a BW environment [6].

(b) The planning of medical support must take into account:
- intelligence and military information on BW threats in the concrete mission area, i.e. on the capability and intention to use biological weapons (type, amount and possible combat effectiveness of assumed BW agents, level and type of weaponization and dissemination capacities, expected casualty rates and range of BW-related health disorders);
- politico-military requirements (type and tasks of mission, combat situations, climatic and geographical conditions, strength, location, distribution, tasks and density of troops);
- level of NBC defense readiness among own and allied forces (real-time detection of BW agents, warning and alert procedures, NBC protective equipment, training, decontamination);
- level of biological medical readiness (NBC medical protective equipment for casualties, medical decontamination, chemo-and immunoprophylaxis);

- suitability and effectiveness of medical policies and procedures; availability of medical resources needed to combat an assumed BW threat.

(c) Planning of medical support must be based on the most credible BW conditions resulting in mass casualty situations. It must thus be assumed that an enemy attack will aim at maximum effect on personnel at risk The most probable BW scenario will be massive BW aerosol exposure of unwarned and unprotected personnel causing an explosive onset of mass casualties by an infectious disease or intoxication by inhalation of BW agents. This will result in mass casualty situations characterized by a disparity between short-term casualty overload on the one hand, and local medical and logistic support capabilities on the other. This situation can be further complicated as a result of:

- man-to-man transmissibility of some infectious agents resulting in secondary epidemics;
- delays in swift life-saving diagnostic, therapeutic and preventive measures due to varying periods between exposure to agent and onset of disease;
- uncommon clinical syndromes and unusual course of diseases after inhalation of biological aerosols in conjunction with delayed diagnosis of BW exposure;
- lack of effective and specific prophylaxis and therapy, or delay in buildup of immunity against some BW agents before or immediately after an assumed attack;
- high tenacity of some pathogens (spores) resulting in prolonged contamination of the environment with further spread of disease among people and animals.

(d) The required medical resources (management, personnel, materiel) must be available in the BW theater in good time and for all roles of the medical evacuation chain.

(e) In all situations where the causative BW agent is still unknown or already identified as a transmissible pathogen, the following steps are necessary:

- all exposed individuals must be treated as being potentially infected;
- each symptomatic case is to be deemed a casualty and considered contagious;
- hygiene/anti-epidemic regimens must be established in the BW environment and at all roles of the medical evacuation chain.

4. Medical Policies

4.1. GRADING OF BW CASUALTIES

Materiel and personnel required to evacuate and treat BW casualties will depend on the patient situation which, in turn, will depend on the clinical course of diseases and the daily intake of casualties together with their distribution in categories of severity.
The percentage distribution of BW casualties between different grades of severity were taken from clinical reports of diseases caused by the above listed pathogens or toxins under natural circumstances and partially extrapolated from animal experimental data found in the relevant literature.
Following an attack with BW aerosols, the speed with which symptoms occur and the grade of injury will depend first and foremost on the agent type employed (virulence), the inhaled dose and the effectiveness of NBC protection and biological medical defense measures.
The main criteria and definitions used for categorizing casualties are clinical symptoms and signs typical of serious health disorders which require buddy aid, evacuation by stretcher, ventilation and prevention or treatment of early manifestations of shock. After aerosol attacks with lethal BW agents, casualties may share certain common symptoms which, independent of the type of agent employed, predominate, such as acute life-threatening clinical syndromes. Emergency medical support is essential for diagnosis, life-saving measures, intensive medical care, isolation, and urgent evacuation. The main nosologic groups include [3, 8, 9]:

- infectious toxic syndromes (systemic inflammatory response syndrome; septic shock syndrome) with disseminated intravascular coagulopathy;
- pulmonary or adult respiratory distress syndrome (ARDS);
- haemorrhagic fever syndrome;
- smallpox-like fever syndrome;
- multi-organ distress syndrome (MODS);
- infectious toxic meningoenzephalitis with brain pressure syndrome;
- paralysis syndrome.

BW agents known to induce the above acute syndromes will produce high percentages of severely ill patients. For reasons of practicability in the planning process, the enormous variety of possible clinical manifestations which may be induced by BW agents was reduced to four grades of severity (see below). Splitting casualties into these categories provides the basis for computing the measures to be performed daily by the Medical Service at each role of the medical support.The following grading of patient conditions was

defined primarily in terms of the presence of the above-mentioned syndromes:

- *Grade 1* (mild or "outpatient" cases):
  Symptoms such as febrile rash or a "flu-like syndrome" are not very marked. Patients are able to reach the MedEvac chain without help and requiring no or little treatment.
- *Grade 2* (moderate cases):
  Moderate to low-degree "flu-like" symptoms and signs of manifestation in some organs may appear. Patients need help to reach the MedEvac chain. Their condition may be assumed to improve quickly if a targeted therapy is commenced immediately. The injury is not yet life–threatening, but progression to grade 3 or 4 is always a possibility.
- *Grade 3* (severe cases):
  Severe clinical symptoms indicate an unfavorable prognosis despite treatment. Therapy is very expensive and time-consuming requiring management of patients by interdisciplinary intensive care, in some cases under conditions of isolation. Patients depend on buddy aid and life-saving medical support.
- *Grade 4* (extreme or expectant cases):
  Very severe injury has caused irreversible damage to organs and physiological functions. There is very little chance of survival. Life-saving measures must include treatment of shock, ARDS, MODS or progressive paralysis using interdisciplinary intensive care.

For each BW agent on this baseline, the appropriate typical symptoms and signs for each grade of injury were formulated using expert data. The expected percentage or absolute distribution of casualties per grade, day and role can be computed if the probable number of casualties is known.

4.2. MEDICAL EVACUATION

Timely isolation and treatment of sources of infection, i.e. BW casualties from among the mission forces, is a crucial task of medical care, and this includes anti-epidemic support. If a BW environment associated with a mass casualty situation is to be handled successfully, evacuation procedures must meet high quantitative and qualitative standards. This involves the following tasks:

- remove potential sources of infection from the "healthy" population;
- interrupt chains of infection;
- ensure specialized aid in order to preserve life and to quickly restore BW casualties' health;
- minimize the BW agent concentration affecting exposed personnel and the environment by performing decontamination;

- increase resistance to the BW agent by chemo- and immunoprophylactic measures.

Rapid evacuation and complete segregation of casualties assumed to be contagious shortens the period of disease communicability, reduces the rate of secondary infections and epidemics, accelerates targeted treatment, and brings about the recovery of casualties within a shorter time frame.

The policy for the medical evacuation of biological casualties was adopted on the basis of the technical guideline for the medical support of German soldiers deployed [5], thereby meeting the requirement for the immediate evacuation of BW casualties. According to this guideline, which corresponds to the role classification contained in the ACE Directive 85-8 [4], medical support is provided in three functionally coordinated areas:

Level A medical support provides pre-clinical care (rescue, self and buddy aid) in the field with two types of mobile medical facilities being employed for initial medical care: the rescue station (= NATO role 1) and the rescue center (= NATO role 2). In biological mass casualty situations, they are responsible for:

- rescue and evacuation of casualties from the BW environment;
- triage;
- initial emergency medical measures for maintaining vital functions (shock treatment, emergency surgery);
- decontamination by medical decontamination units;
- hygiene and anti-epidemic measures (e.g. isolation, personal surveillance, segregation, post-exposure chemoprophylaxis and immunizations, disinfection);
- stabilization of casualties for evacuation to level B or intensive internal medicine care and nursing under strict isolation conditions, if direct evacuation of patients is either not possible or not to be expected in view of the prevailing combat and epidemiological situation.

Level B medical support (mobile field hospitals) equals NATO role 3. It comprises immediate clinical care and provides advanced clinical treatment until the patient recovers or can be transferred to a level C medical facility. The field hospitals are manned with inpatient and outpatient medical specialists of all required clinical disciplines including laboratory diagnostics. In the framework of biological medical support, they are responsible for:

- triage of incoming casualties; hospitalization
- clinical and laboratory diagnosis of BW-induced health disorders and epidemics in the mission area;
- life-saving and life-supporting clinical care using isolation precautions
- interdisciplinary intensive care of severely ill patients;
- specific (chemo- and/or immunotherapy) as well as supportive symptomatic treatment;
- establishment of a hygiene and anti-epidemic regime (e.g. isolation, personal surveillance, quarantine, disinfection, pest control) to support treatment of highly

contagious, life-threatening diseases (e.g. pneumonic plague, smallpox, viral haemorrhagic fevers).

Level C medical support (civilian and Federal Armed Forces station hospitals at home) is equivalent to NATO role 4 and compromises definitive specialized treatment and rehabilitation of BW casualties as well as monitoring of patients after return to duty using the whole spectrum of modern diagnostic and therapeutic procedures.

4.3. TRANSPORT

Generally, the type, scope, and speed of evacuation is assumed to be influenced by the BW scenario, the total number and rate of BW casualty intake, the agent-specific epidemiological and clinical features of BW injuries and the available resources for medical support in the BW environment. Planning of MedEvac places will be estimated on the basis of the probable casualty intake. It must observe the following general rules:

- provide for strict isolation of highly contagious and severely ill BW casualties in or at the border of the BW environment depending on the tactical situation;
- initiate urgent evacuation where contamination by highly resistant BW agents (e.g. spores) is suspected;
- in principle use only medical transportation assets (special transport isolators are recommended only where single contagious patients need to be moved);
- if the infectiousness of a disease cannot be excluded, evacuate BW casualties according to nosologic groups (see above), keeping casualties with different diseases or injury separate from each other;
- perform efficient evacuation such that large distances can be covered each time.

The transport of BW casualties from level A to level B medical support should be completed within 6 hours of injury using air, land or sea evacuation assets. Distinctions are to be made between three evacuation priorities (low, medium, urgent), two transport positions (sitting, stretcher) and patients requiring ventilation or not. Priority is given according to general rules based on the patient's condition, clinical prognosis and level of infectiousness. Mild cases will be evacuated in a sitting position and with low priority. Patients falling under grades 2 or 3 will receive high priority to prevent the disease progressing to grade 3 and 4, respectively. Transportation will be by stretcher, with medical aid responsible for monitoring vital functions (cardiopulmonary resuscitation, ventilation). Patients falling under grade 4 will be transported only after stabilization in a manner analogous to grade 3.

4.4. DECONTAMINATION

Timely decontamination is crucial in order to halt the possible uptake of BW agents by the casualty himself or transmission between contacts. The following criteria must be considered when deciding on the necessity of decontamination:

- time elapsing between BW exposure and arrival at the medical decontamination unit;
- assumed extent of contamination;
- duration of contamination of the territory as a function of the survivability of the pathogen.

All BW casualties must pass through level A for complete decontamination by German medical decontamination units. Decontamination of BW casualties should take place within 2 hours of reaching the MedEvac chain, with patients having sustained only a mild injury performing self-decontamination. Casualties falling under grades 2, 3, or 4 must be decontaminated on a stretcher by means of buddy aid. Required decontamination capacities should be calculated on the basis of the probable BW casualty intake rate considering also the arrival of BW contaminated soldiers injured by conventional weapons.

4.5. BED USE

Bed requirements for isolation and treatment of BW casualties depend on the probable total number and rate of patient intake. In terms of type and total numbers, beds will not be required in their entirety at once, but rather this need will manifest itself in a differentiated way during the course of an explosive epidemic in the wake of a BW aerosol attack. For prognostic statements on the beds required in the ensuing days and the type of care (intensive, medium, and minimum care), the daily intake of casualties must be known. The time frame for bed occupation will depend on the duration of treatment which, in turn, will depend on the timeliness and effectiveness of therapy.

For the computation of bed use, the following assumptions regarding the length of stay at the different roles were adopted:

- Not all beds will be needed immediately for the total number of exposed personnel; bed requirements will continuously increase as a function of the infectious disease's incubation period. Accordingly, it is sufficient in the planning phase to have beds available for a third of the force strength that might be exposed to biological agents.
- Casualties classified initially as mild are considered to have inhaled low doses of the agent, but progression to more severe forms cannot be excluded. Such cases will therefore be held under personal surveillance and segregated (preventing a possible spread of infection) at all roles without hospitalization until the causative agent has been identified and the possibility of contagiousness excluded. Self-medication or

outpatient medical care in connection with a specific therapy (antibiotics) and immunoprophylaxis will be instituted, if and when indicated.

- Casualties with medium and severe injuries but without any signs or symptoms of the above-mentioned acute life-threatening syndromes must have reached level C medical support within 2 days (assuming there are no restrictions imposed by isolation requirements) where they will be expected to stay for several weeks. During the first 3 to 7 days, they may require specific and supportive treatment in medium care units followed by nursing wards. Medical care or nursing under strict isolation precautions must be provided at level A and B medical support if a communicable disease is assumed or the causative BW agent has yet to be confirmed.
- Patients with grade 3 or 4 injuries in conjunction, for example, with manifest paralysis, ARDS, septic or haemorrhagic shock syndromes, will require treatment in interdisciplinary intensive care units at level B and C medical support for several days so that they can be stabilized for transport to role 4. There they will be expected to remain for weeks or months in intensive or medium care units and nursing wards.

To plan medical resources, the following time limits for medical care at the different roles were adopted:
At level A medical support, patients will normally stay a maximum of six hours to ensure triage, medical decontamination, emergency medical care and stabilization for evacuation to level B.
At level B, medical care should generally be limited to seven days. Severely ill patients requiring prolonged intensive care or casualties with highly contagious diseases, however, will need strict isolation and targeted chemotherapy until the end of the communicable period which can vary between a minimum of 3-6 days (pneumonic plague) and a maximum of 24 days (some viral haemorrhagic fevers, smallpox). Patients with low or non-communicable diseases may be evacuated to level C earlier on if they have been clinically stabilized.
At level C, the patients should no longer be contagious, which means that the duration of treatment will depend solely on the category of severity that applies after initial medical care at the lower levels of medical support and will vary between 14 and 42 days.

4.6. THERAPY AND POST-EXPOSURE PROPHYLAXIS

A BW attack will produce a special medical emergency leading to a mass casualty situation caused by virulent, sometimes highly contagious biological agents. The scope and nature of treatment will be determined by the number of casualties arriving at the levels of medical support per time unit, the grads of injuries sustained, the assumed diagnosis (alleged or identified BW agent) and the presumed degree of infectiousness.

From a medical database, therapeutic modules were developed for each of the 13 mentioned BW agents. The modules represent packages of different treatment regimes and steps (tasks) which have been adapted to the type and grade of injury in accordance with treatment recommendations defined by Medical Resource Guidance (MRG) Model, NBC/Med STANAG 2068 [3] and the Handbook "Medical Management of Biological Casualties" [9]. Medical materiel based on therapeutic modules and compiled and listed in accordance with WHO and INN standards will include drugs, vaccines, medical instruments and equipment required for level A to C medical support.
For bacterial and rickettsial agents, treatment will consist of combinations of chemotherapy using broad spectrum antibiotics and sulfonamides with supportive and symptomatic treatment (e.g. electrolyte solution substitution, antipyretics, heparinization, ventilation, hemofiltration or corticosteroids). Similar modules exists for viral diseases where clinically approved virostatic drugs or immune-globulins will be used, also in combination with supportive therapeutic measures. In the case of intoxication, symptomatic therapeutic interventions predominate with the exception of the specific treatment of botulism by administering botulinum antitoxins.
The treatment protocols meet national and international standards or recommendations of clinical experts. On the basis of these therapeutic concepts, the full range and volume of medical resources for treatment can be calculated for estimated agent-specific casualty numbers on the basis of the dayly intake rates and the disease specific duration of treatment.

To provide for adequate post-exposure immuno- and/or chemoprophylactic treatment, storage of enough vaccines, immuno-globulins and antimicrobials for a third of all personnel at risk over a period of 10 days is assumed to be optimum. Stockpiling on this scale would make it possible to provide prophylaxis for all personnel at risk for 3 days, thereby relying on resupply only on the 4th day. Drugs for 10% of personnel at risk to cover a period of 10 days are considered to be the minimum stockpiling level for ensuring a prophylactic regimen [2]. This would allow all personnel under threat to receive prophylactic treatment for one day, with resupply already being required on the second day.

4.7. MEDICAL PERSONNEL

All tasks in connection with the management of BW casualties, including decontamination, evacuation or nursing under strict isolation precautions, must be performed by specially trained medical personnel. Physicians, specialists of nearly all clinical disciplines, nurses and other ancillary personnel will be planned. In terms of quantity and quality, the required medical personnel will depend on the probable total number and clinical condition of BW casualties arriving at the levels of medical support, on the treatment regimes envisaged for

the different kinds of BW injuries, and the required duration of treatment. For development of the first version of the NBCMedPlanS bio-module, various recommendations contained in Deployable Medical Systems (DepMedS) were adopted.

5. Procedures for planning biological medical support

5.1. ESTIMATION OF THE PROBABLE NUMBER OF BW CASUALTIES

To be able to provide adequate medical support and implement the necessary hygiene/anti-epidemic measures in BW environments as well as at the different MedEvac levels, it is necessary to know the likely number and rate of BW casualties. Estimates must be made in the planning phase of a mission covering the period beginning with an enemy BW attack and ending with identification of the biological agent(s) employed and for the phase following identification of the biological agent.
The methodology of LOSCHER [10] was adopted to compute these two key parameters and to create mathematical incidence and epidemic models for specific BW agents.
The total number of casualties is to be calculated taking into account:

- Primary casualties through direct exposure to BW aerosols causing airborne infections or intoxications;
- Secondary casualties resulting from indirect effects of infectious aerosols (contamination of environment, transmission through contact, food, secondary aerosols, vectors)

5.1.1. Incidence model

As a rule, BW scenarios will depend on the following factors which constitute key planning inputs:

- type of BW attack (aerosol generation by point or line source dissemination);
- type, virulence (infectiousness, toxicity), effective dose and aerosol stability of the biological agent employed (decay rate k);
- size of BW environment depending on distribution characteristics of BW aerosol cloud (concentration, penetration depth and direction);
- number (strength), deployment density and mission of personnel exposed to BW aerosol;
- meteorological conditions (temperature, relative humidity, wind speed, precipitation, inversion, conversion or convection);
- geographical conditions (mountains, plains, vegetation, buildings);
- level of physical NBC protection and biological medical defense at time of BW attack.

In the planning phase of a mission in which there is no available knowledge concerning

possible BW threats, computation of the incidence model should assume the most credible BW attack scenario, i.e. the "worst case".
An aerosol containing a potential biological agent will be disseminated from a line source, namely an aircraft (10-50 m over the ground along a line across the prevailing wind, with a wind speed of 6 m per second and an optimal particle size of < 5 µm in diameter) and assumed to move ideally as a homogenous cloud under optimal meteorological conditions. Initial loss of the agent's viability or virulence will be negligible. Exposed soldiers distributed evenly throughout the biological attack area will inhale several effective (lethal or incapacitating) doses of an agent during the cloud's 3 hr transit time. Thus a high intensity attack will be assumed, resulting in the most extreme biological conditions. The initial dosage, which may remain suspended in the air for several hours despite biological decay rates of 0.3 - 0.002 % per min, will spread throughout the depth of the combat area, penetrating the upper and lower parts of the respiratory tract of people at risk. Without the necessary alert measures, physical protection, previous buildup of effective agent-specific immunity or administration of chemoprophylaxis, nearly 100 % of exposed and susceptible personnel will be affected and become biological casualties in such a scenario.
According to LOSCHER [10], the probable number of BW casualties can be computed on the basis of formula (1).

$$U = N \times w \times s \times a \times i \qquad (1)$$

The variables are defined as follows:

U = probable total number of BW casualties
N = number of persons exposed to BW aerosol depending on density of troops and size of contaminated BW environment
w = coefficient of combat effectiveness of BW agent
s = coefficient of individual NBC protective equipment and force's NBC protection training status
a = coefficient of effectiveness of chemoprophylaxis
i = coefficient of effectiveness of immunoprophylaxis

In cases where effective early or real-time NBC reconnaissance is not available, or in the planning phase preceding BW agent employment and assuming a BW threat, or after an attack where the size of the BW environment is still not known, the value N equals the total strength of the force at risk which might face complete exposure.
The present incidence model is based on forces ranging from 1,000 to 10,000 soldiers. Depending on the combat situation, operational and tactical missions, deployment in or outside NBC hardened targets, force structure and size, the number of exposed persons will vary. The combat value of the agent w is an average multifactorial estimate (table 1)

varying between about 0.3 and 0.9. It depends on the initial dose and type of agent, its decay rate, the dissemination method (point source, line source, missiles, off-target attacks), and on meteorological (wind speed, precipitation, e.g. rain or snow, relative humidity, temperature) and geographical conditions (topography, vegetation, buildings) in the attack area.

TABLE 1. Values of variables for determining the combat effectiveness coefficient **w** for biological aerosols [12]

Geographic and Metereological conditions	Linear aerosol source on the ground	Linear aerosol source above ground	Multiple aerosol source
Forest/mountains/ built-up terrain	0.6	0.5	0.6
Plain	0.8	0.6	0.8
Rain	0.2	0.2	0.2
Inversion	1.0	1.0	1.0
Isothermal state	0.5	0.5	0.5
Convection	0.01	0.01	0.01
Wind speed: 0.5 m/s to 6 m/s	0.01-1.0	0.01-1.0	0.01-1.0

Coefficient **s** is influenced by the combat situation (BW attack known or unknown, NBC reconnaissance of BW agent and possibility of alert measures) and the readiness, quantity and quality of NBC protective measures for personnel at risk. As table 2 shows, **s** may vary between 0.1 (very good protection) and 1.0 (no protection), depending on the level of efficiency.

Coefficients **a** and **i** are used to assess the effectiveness of pre- and post-exposure chemo- and immunoprophylaxis, respectively. They are indicators of the maximum achievable protection against an aerosol infection with the respective BW agent and correlate directly with the effectiveness of anti-microbial and antiviral chemotherapeutic agents, vaccines, immunoglobulins and immunization techniques.

TABLE 2. Values of coefficient **s** as a function of the force's NBC protection and early biological warning/alert measures [13]

Criteria of efficiency	Coefficient s
very good	0.1
good	0.2
satisfactory	0.3
unsatisfactory	0.6
insufficient (also if there is no warning)	0.9-1.0

These estimates may vary according to the state of the art in the fields of BW development on the one hand and biological medical defense on the other. At present, the coefficient **a** of suitable drugs for pre- or post-exposure chemoprophylaxis ranges from 0.5 to 1.0. Where active or passive immunization is available for a biological agent (licensed or experimental drug), average estimates of effectiveness **i** between 0.25 and 1.0 (i.e. from 75 % to 0% protection against aerosol challenge) can be used for planning (table 3).
When the actual BW agent employed is unknown, the real personnel strength of the force is to be substituted for value **N**. Since at this point, no concrete values for the coefficients **w** (table 1) and **s** (table 2) are as yet available, use of a mean product is recommended for calculating the probable number of primary biological casualties. This takes numerous individual values for the coefficients **w** and **s** into account and has the value 0.282 [11].
Coefficients **a** and **i** are attributed the value 1.0, indicating that no specific prophylaxis has been performed.
Thus, the probable number of primary BW casualties is calculated according to the formula

$$U_B = N_O \times 0.282 \qquad (1.1)$$

Explanation of variables:
U_B = probable number of casualties affected by biological agents
N_O = personnel strength (1,000 in steps of 1,000 to 10,000)
$w \times s$ = 0.282 In this case, nearly 30 % of all personnel at risk will become casualties.
When the time of a BW attack is known, the agent has been identified, e.g. *Yersinia (Y.) pestis*, and if the best use could be made of NBC protection (**s** = 0.1), and of immuno- and chemoprophylaxis (estimate for **a** = 0.5 and **i** = 0.5), a maximum of 200 casualties will be expected as a result of exposure of 10,000 persons and an aerosol combat value **w** = 0.8.

TABLE 3. Estimates of the coefficients **a** and **i** for the degree of effectiveness of chemo-and immunoprophylaxis, respectively for selected BW-related diseases [11]

Disease	Coefficient	
	a	i
Pulmonary anthrax	0.5	0.5
Pneumonic plague	0.5	0.5
Tularemia	0.5	0.35
Brucellosis	0.75	0.5
Q fever	0.5	0.35
Smallpox	0.75	0.35
Lassa fever	0.75	1.0
Venezuelan equine encephalitis	1.0	0.35
Ebola fever	1.0	1.0
Botulism	1.0	0.5

But, in the case of a surprise attack without any protection or prophylaxis whatsoever, i.e. when coefficients **s**, **a** and **i** = 1.0 and **w** = 0.8 a maximum of 8,000 casualties are to be expected among 10,000 exposed personnel.
Even if the pathogen, e.g. *Y. pestis*, contained in the BW aerosol is identified early and antibiotics (assumed effectiveness coefficient **a** = 0.5) are administered just in time, but immunoprophylaxis was not possible (**i** = 1.0), as many as 4,000 cases of pneumonic plaque are to be expected among a total of 10,000 BW exposed persons

5.1.2. Epidemic model
In addition to computing the probable number of BW casualties, it is necessary to assess the dynamics of epidemics that may develop in the force exposed to aerosols of highly infectious and virulent BW agents, such as anthrax spores or plague pathogens.
For simulating the course of the epidemic, the following presuppositions are made:

- All personnel will be infected by the BW aerosol a single time and simultaneously which will result in an explosive epidemic.
- Since incubation periods will be distributed binomially in such a case and the majority of casualties will fall within the deviation range of the mean incubation period, the epidemic curve will also be governed by the laws of Gaussian distribution.
- The epidemic curve will typically climb without remission, thus forming an acceleration curve (see figure 1). Provided infections occur on a single day, the epidemic curve will be identical to the binomial distribution curve of the incubation

periods. As this interval between infection and manifestation of the disease is a biological magnitude (depending on the inhaled dosage, virulence of the agent and individual susceptibility of the exposed person), explosive epidemics can be calculated using the mean value of the incubation periods for the disease in question and the ± 3 σ deviation range.

Average values of the minimum and mean incubation periods were taken from the relevant literature on natural epidemics caused by the above listed pathogens and the difference between these estimates together with the appropriate standard deviations were calculated. Using this data it is possible to calculate the time that elapses between the infection of a population and the beginning of an epidemic. If the time of exposure (i.e. infection) to a BW agent is known, it is possible to work out the beginning and probable duration of the primary wave of the epidemic as well as the time available for providing medical support.
This data was used to calculate the arithmetical mean for minimum and mean incubation periods. The difference between the two corresponds to half the duration of the epidemic (table 4, column 4). The intake of cases of infectious disease per unit of time is calculated for the interval of one day. The 1st day of an epidemic starts when the disease occurs for the first time (intervalls see table 5) and ends 24 hours later.
The standard deviation was calculated by means of formula 2:

$$\text{From } \mu = 3\,\sigma \text{ follows:} \quad \delta = \frac{\mu}{3} \tag{2}$$

σ = standard deviation
μ = difference between mean and minimum incubation period

The following formula is used to calculate the arithmetical mean for the mean incubation periods:

$$\bar{x} = \frac{\Sigma xi}{u} \tag{3}$$

The arithmetical mean for the minimum incubation periods is computed as follows:

$$\bar{y} = \frac{\Sigma yi}{u} \tag{4}$$

These values are used to calculate the difference μ between the mean and minimum incubation periods on the basis of the following formula:

$$\mu = \bar{x} - \bar{y} \tag{5}$$

These values are shown in table 4.
The normal distribution according to Gauss can then be calculated using the transformed formula

$$U_i = \frac{x_i - \mu}{\sigma} \tag{6}$$

Explanation of variables:

U_i = transformed time value
X_i = time in days (days of epidemic)
μ = difference between average and minimum incubation time (table 4)
σ = standard deviation (table 4)

Thus, the normal function with the parameters μ, and σ can be transformed into a standardized normal function with the parameters $\mu = 0$, and $\sigma = 1$ according to the limits set. The respective areas $\Phi(U_i)$ in the case of normal distribution are taken from stastitical tables. According to Weber [14], cumulative percentage curves can be drawn and the actual daily proportional intake of personnel affected by selected BW agents read off.
For transforming the Gaussian distribution, the formula (6) is used. Accordingly, the values for **Ui** are calculated using the time **Xi** specified in days (of the epidemic) minus μ, which is the difference between the mean and minimum incubation period, divided by the standard deviation σ.
By means of the value **Ui**, the Gaussian function compromising the parameters μ and σ can be transformed into a standardized Gaussian function with the parameters $\mu = 0$, $\sigma = 1.0$ according to the defined limit. The respective areas Φ**(Ui)** are read from tables below the Gaussian distribution curve.

Disease	Mean value of minimum incubation period days	Mean value of average incubation period days	Difference between average and minimum incubation period μ	Standard deviation for 1 sigma σ

TABLE 5. Probable time interval from the infection of a population until the first case of disease occurs and duration of epidemic in the case of primary infected persons [11]

Disease	Interval from time of infection until first case of disease occurs days	Duration of epidemic in days
Pulmonary anthrax	on the day of infection	4.6
Pneumonic plague	on the day of infection	4.0
Tularemia	0.7	5.6
Brucellosis	4.0	16.6
Q fever	6.7	14.0
Smallpox	6.7	11.6
Lassa fever	5.4	12.0
Venezuelan equine encephalitis	1.8	3.8
Ebola fever	3.7	13.2
Typhus fever	5.4	12.6

Computation of the probable daily intake uses the following formula:

$$T_i = \frac{U_B * x_i}{100} \tag{8}$$

The symbols are to be replaced by the following values:

T_i = daily intake of cases of infectious disease out of the total number of primary BW casualties in absolute figures (**i** = day of epidemic)

U_B = total number of primary BW casualties in accordance with the results of the computation according to formula (1)

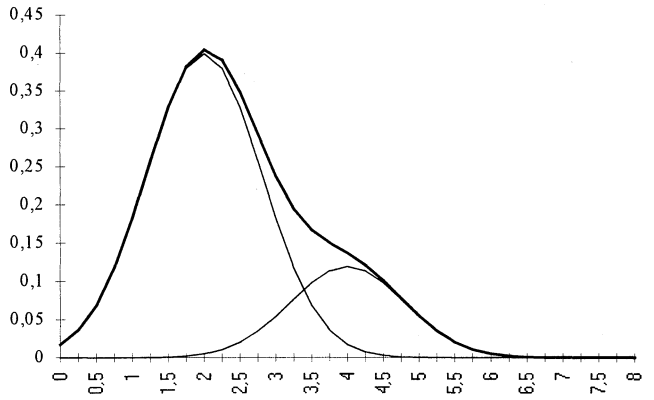
x_i = intake value for day **i** according to formula (6) in percent.

5.2. COURSES OF EPIDEMICS

5.2.1. Primary epidemic

Table 5 shows the values for the period from the infection of a population to the start of the epidemic based on the values of the minimum incubation periods (Table 4, column 2). The probable duration of the epidemic in the case of primary infected persons was calculated using the values of the median incubation periods of the respective diseases.

In the figure 1 the typical dynamics of primary explosive and secondary epidemics after an assumed aerosol attack using *Y. pestis* as a BW agent are presented.



"Figure 1." Computation of the course of pneumonic plague epidemics caused by an attack with BW aerosols containing *Y. pestis*. (abscissa: time in days; coordinate: BW casualties x 1000)

5.2.2. Secondary epidemics

If BW agents are used which trigger a disease that can be transmitted between humans, cases of secondary disease are to be expected from 1st and 2nd degree contacts. Table 6 lists estimated values for diseases which are transmissible in this way. In the case of certain infections which are highly contagious, such as pneumonic plague, secondary tardive epidemics are to be expected in the wake of the primary wave (figure 1).The probable number of secondary cases will then be influenced by the effectiveness of hygiene/anti-epidemic measures.

In the case of pulmonary anthrax, tularemia, brucellosis, Q fever, Venezuelan equine encephalitis and typhus fever, secondary diseases are unlikely to occur.

TABLE 6. Percentage of cases of secondary disease as a function of hygiene and anti-epidemic measures in the case of diseases which are transmissible between humans [11]

Disease	Contact period between ill and healthy persons	Cases of secondary disease %
Pneumonic plague	unlimited	43
	less than 3 days	< 6
Smallpox	unlimited	30
Lassa fever, Ebola fever	unlimited	20

In summary, using the above described computed incidence and epidemic models the daily intake of casualties can be calculated in absolute numbers or as a percentage of the total figure. Valid estimates of the daily intake of e.g Q fever patients can be read from figure 2. The x-axis shows the corresponding days of the epidemic. The first day of the epidemic is always defined as a period of 24 hours beginning with the occurrence of the first case. From this date, the percentage of casualty intake per day of the epidemic can be calculated on the basis of the probable number of primary casualties in the course of the epidemic. The results provided by the computation of the epidemic model make it possible to

- determine the intake of BW casualties as a percentage of the total number for each day of the epidemic;
- predict the point in time when the first BW casualties will arrive at the roles of the MedEvac chain if the time of a BW attack is established in time;
- determine approximately the point of time of an enemy covert BW attack on the basis of BW casualty intake.

6. Conclusions

The purpose of this study was to optimize medical care for German armed forces under threatened or actual BW conditions and, using existing or developing new principles, policies and procedures, to assess the required medical support.
The resulting mathematical models for computing the incidence of BW casualties and simulating epidemics after an aerosol attack will help the planner to estimate personnel and materiel requirements for medical care at 3 different levels of medical support.
Initial infection-related, epidemiological and clinical data, results of the computation of the number of BW casualties caused by 13 possible BW agents, and corresponding treatment protocols were used for the development of the software prototype "NBCMedPlanS

Biological module". This comprises a computer-assisted expert data processing system which gives the user (e.g. planner of medical support) the following options:

- assessing the number and structure of BW casualties, either on the basis of certain BW model scenarios or using real BW initial situations derived from BW threat analyses as a starting point;
- simulating primary (explosive) and secondary epidemics caused by exposure to aerosols of 10 different pathogens and 3 toxins;
- estimating probable numbers and intake of casualties in absolute figures or as a percentage of casualties per day and role distributed in 4 grades of severity;
- calculating the required personnel and material resources (e.g. bed usage, decontamination and transport capacities, prophylactic and therapeutic agents, personnel) per day and role, differentiating between several types of medical care (ICU, MedCU, MinCU).

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