Application of Software Platforms to Enhance Early Warning and Detection System Capabilities for Nuclear Weapons Threat

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Abstract. **The report describes the potential damage from the striking factors of low- and medium-yield nuclear munitions. A scenario of a terrestrial nuclear explosion in a city is modelled. Analytical calculations are proposed for nuclear blast damage for which no simulation platform is implemented. An analysis was made of the damage to residential buildings and the population from the light pulse, radiation pollution through a software platform. Data for the electromagnetic pulse area are extracted. A comparison was made of the sizes of the damage zones for the striking factors of the nuclear weapon in the respective powers of the nuclear explosion.**

Keywords: weapons of mass destruction, nuclear event warning, simulation platforms, early warning.

I. INTRODUCTION

Military science has always been very concerned that effects and protection of radioactive substances. Nuclear events are among the most dangerous events possible. They result in injury and death to exposed persons, destruction of property and long-term risks to both populations exposed to event and those exposed to its consequences, e.g. radioactive waste. Nuclear events cause a combination of damage due to the rapid nuclear effects—radiation, pressure, and heat energy that result from the detonation. [1], [2] According to the environment in which nuclear events occur, we can classify them as radiological events in facilities (from the Interpretive Dictionary of the Bulgarian language - "a building with a specific purpose") and outdoors. The aim of this development is to propose a tool for the rapid evaluation of radiological events in facilities. [3], [4]

Artificial intelligence applications have been implemented more frequently in recent years due to their potential to reduce costs and reliability. Software platforms have a lot of advantage in security and defence training. Nowadays, there is an increasing interest in protection against nuclear, radiological, chemical, and biological events. [3], [4], [5]

Military software applications have the advantage of creating a dangerous virtual environment and verifying training and knowledge before participating in field exercises and actual combat operations. [2], [6].

Predicting the overwhelming effect of a nuclear weapon is a fragment of the warning to military troops and population in nuclear incidents. [7], [8] Nuclear events are among the most dangerous events possible. They result in injuries and deaths to exposed persons, destruction of property and long-term risks to both populations exposed to the event and those exposed to its consequences, e.g. radioactive waste. Nuclear events cause a combination of injuries due to the rapid nuclear effects—radiation, blast overpressure, and thermal energy—as a result of detonation. In addition, there are secondary effects (collapse and collapse of buildings due to secondary, tertiary, and quaternary dynamic pressure) and indirect effects (lightning blindness and burns due to secondary fires) that result from the detonation. The purpose of this development is to provide an answer for the damage zones resulting from detonation of a nuclear weapon through geospatial analysis, to protect the population and infrastructure and planning their evacuation. Nuclear explosions of 20 kt TNT and 50 kt TNT are taken as a limit for the study.

II. MATERIALS AND METHODS

The study is a simplified concept of risk definition and analysis that assesses not probability, but rather spatial exposure and known degrees of hazard magnitude from existing tactical nuclear warheads.

The software platform "Nukemap" used for calculation of damage from nuclear weapons allows users to carry out in spatial planning or protection of the population with a simplified model for making assessments in areas of responsibility. In the present study, we also use the software product HotSpot Version 3.1.2. Terrestrial nuclear explosions of 20 kT and 50 kT TNT are taken as constraints for the study.

To achieve the stunning effect of a nuclear explosion, the detonation can be air or ground. Terrestrial nuclear explosions (NWs) [9], [10] are primarily chosen to exploit heat shock and maximum radiation contamination. Exposure ranges for typical nuclear weapons are chosen continuously with a 50% fission rate estimate and a 30 km/h wind speed [11]. For the effects of radioactive substances, weight ranges of 0,1 Gy and above have been chosen, which lead to severe damage to health.

III. RESULT AND DISCUSSION

Visually, the results are displayed on map bases that depict the strike zones of hypothetical nuclear attacks. The main goal of the research is to predict the dangerous factors of a nuclear attack with software platforms to be used in the early warning system in the Republic of Bulgaria. The choice of nuclear blast power is also arbitrary but is tailored to what nuclear material can be loaded on a tactical munition/missile.

When assessing the nuclear consequences of small and medium-power nuclear weapons (NW), it is of great importance to assess the damage caused by the shock wave. The distribution and severity of these damages depends on durability of device, height of the blast, meteorological factors, protection parameters by shelter, and specifics of the terrain.

To model the evaluation of blast effects and damage assessment, pressure zones should be analyzed according to the pressure peak, and in this study, a maximum of 50 psi and a minimum of 1 psi were considered [12]. The overpressure of the blast that will cause damage to buildings and the population can vary from 0,5 psi to 50 psi. A burst overpressure of 0,5 psi can shatter window glass and some facades. Pressure of 2 to 3 psi can cause damage to some wood and masonry structures. A blast pressure of 3 psi to 8 psi can cause damage to brick and concrete buildings. Based on the calculated distance from the center/epicenter from NW, the buffer zones can be calculated, and the damage can be estimated according to the pressure created in them. [12]
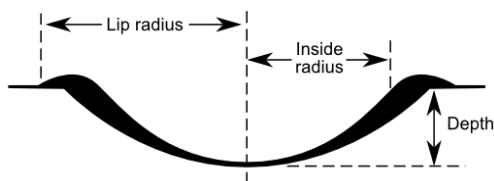

Fig. 1. Crater diagram

TABLE 1 DAMAGE TO PEOPLE FROM THE NW 20 KT SHOCK WAVE

Parameters	20 kT	50 kT
Crater inside radius	52,4 m (0,01 km²)	71,1 m (0,02 km²)
Crater depth:	25,1 m	34 m
Crater lip radius	105 m (0,03 km²)	142 m (0,06 km²)
🔴 Heavy blast damage radius (20 psi)	0,59 km (1.1 km²)	0,8 km (2,02 km²)
⚪ Light blast damage radius (1 psi)	3,19 km (32 km²)	4,33 km (59 km²)

The extent and severity of the damage and destruction in a NW cannot be predicted with great accuracy, as it largely depends on the environment in which the epicentre/centre of the NW is located - an airport, an administrative centre, an industrial area, etc.

If the barrier is not large, the air shock wave begins to flow around it. The air stream then flows around the baffle as in a strong wind. The transient lasts as long as it takes for the discharge wave and vortex motion to completely cover the barrier. This time t_α can be approximately calculated as:

$$t_\alpha = \frac{B}{340}, sek \qquad (1)$$

where: B is the width of the partition.

If t_α is small compared to the time of action of the overpressure, it can be considered that the action of the air shock wave in this case is like a hurricane gust.
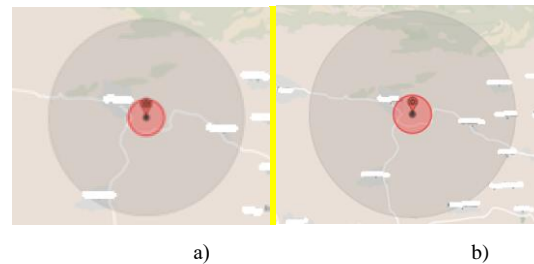

a)   b)

Fig. 2. Zones of impact by the shock wave at the power of the nuclear explosion a) 20 kT and b) 50 kT

In fig. 2 shows the destructive action of the shock wave in two zones, which are concentric circles centred on the site of the nuclear explosion. In real conditions in a populated place or terrain with relief other than flat, perfect concentric circles will not be obtained. Any obstacle in the front of the shock wave will affect their shape. When making predictions for striking action, areas of larger area are always given, i.e. this variant of describing the zones can be accepted as applicable. At 20 psi overpressure, heavily built concrete buildings are severely damaged or demolished: fatalities approach 100 %. Often used as a benchmark for heavy damage in cities. At a around 1 psi overpressure, glass windows can be expected to break. This can cause many injuries in a surrounding population who comes to a window after seeing the flash of a nuclear explosion (which travels faster than the pressure wave). Often used as a benchmark for light damage in cities.

Formula (2) can be used to calculate the overpressure in front of the shock wave in water:

$$\Delta P_{so} = 23000 \frac{\sqrt{W}}{\sqrt{R^3}}, \frac{kg\, TNT}{cm^2} \qquad (2)$$

The time of action of overpressure in water is about 130 times less than in air.

$$L = 0.015\sqrt{R}\sqrt[6]{W}, \quad (3)$$

where L, m is water layer thickness for water shock wave front.

For example, at a NW with 20 kt TNT at 1000 m, L=10 m is obtained. [12]. Table 1 shows the impact of peak overpressure on humans (data from HOTSpot software).

TABLE 2. DAMAGE TO PEOPLE FROM THE NW 20 KT AND 50 KT SHOCK WAVE

Lesions / pressure	Distance from the epicenter of the explosion, km at 20 kt TNT	Distance from the epicenter of the explosion, km at 50 kt TNT
Deadly		
more than 30 psi (30–50)	0,50	0,66
50 % 50 psi (50–75)	0,40	0,53
100 % 75 psi (75–115)	0,33	0,45
Lung Damage		
to 8 psi (8–15)	0,94	1,27
pressure 20 psi (20–30)	0,59	0,80
Eardrum rupture		
to 5 psi	1,21	1,64
50 % 15 psi (15–20)	0,68	0,92
Shattered window glass injury		
Threshold 0.5 psi	5,15	6,99

The thermal effects are an important aspect when considering light emission and play a role in different scenarios where heat can cause different effects. In the context of combat equipment and firearms, thermal action can be of particular importance, causing severe damage and destruction. The thermal radiation can also be dangerous in industrial environments where high temperatures or flames can start fires or cause damage to materials. Understanding the thermal characteristics of different materials is important for the safe operation and design of buildings and sites. Also, the distribution of heat in materials depends on their thermal conductivity. The materials such as wood and concrete have lower thermal conductivity, meaning they can retain heat longer than materials such as armor and aluminum with higher thermal conductivity. This factor can be essential in risk analysis and taking measures to prevent or manage heat damage.

In daytime conditions, a 20 kT explosion can cause temporary flash blindness from scattered light at 23 km. Individuals directly looking at the fireball could experience retinal burns at 25 km. Unprotected individuals could receive more than the dose of thermal radiation required for third-degree burns at a distance of up to 1,9 km.

The thermal energy and the corresponding deposition range (radial distances) can be calculated by formula (4):

$$Q\left(\frac{Cal}{cm^2}\right) = \frac{7.9fw\tau}{D^2}, [12] \quad (4)$$

where:

- W is power of nuclear weapon, kg TNT;
- D is the distance from the epicentre/centre, km.

- f is the thermal distribution coefficient.
- τ – permeability of the medium.

The degree to which a person is struck in the zone of heat radiation at NW can be determined by the HotSpot model. (Table 3)

TABLE 3. DEGREE OF SKIN BURN AND EYE INJURY FROM THERMAL RADIATION (SOURCE – HOTSPOT)

Hazard	Distance from the epicenter of the explosion, km at 20 kt TNT	Distance from the epicenter of the explosion, km at 50 kt TNT
Eye damage		
Day		
- blindness	23	25
- retinal burns	25	28
Night		
- blindness	75	77
- retinal burns	44	48

With the Nukemap software platform, a simulation of an aerial nuclear explosion with a power of 20 kt TNT was made (Fig. 3). The influence of thermal radiation was investigated.
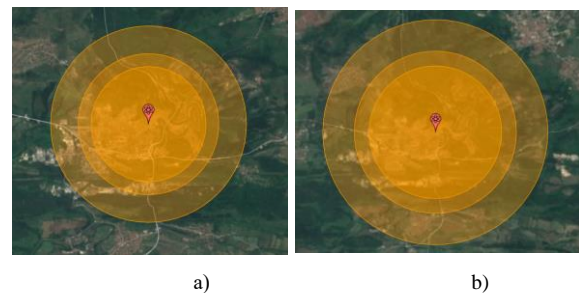
a)   b)

Fig. 3. Zones of impact by the thermal radiation at the power of the nuclear explosion a) 20 kT and b) 50 kT

Third degree burns extend throughout the layers of skin and are often painless because they destroy the pain nerves. They can cause severe scarring or disablement and can require amputation. 50% probability for 3rd degree burns at this yield is 7,57 cal/cm². Second degree burns are deeper burns to several layers of the skin. They are very painful and require several weeks to heal. Extreme second-degree burns can produce scarring or require grafting. 50 % probability for 2nd degree burns at this yield is 4,97 cal/cm². First degree burns are superficial burns to the outer layers of the skin. They are painful but heal in 5-10 days. They are the same thing as a sunburn. 50 % probability for 1st degree burns at this yield is 2,47 cal/cm².

The most significant is gamma–radiation, the presence of which is a danger to humans due to its range and penetrating ability. Residual radiation weakens and scatters in the same way as primary gamma–radiation. The biological effects on humans from residual radiation are the same as for primary radiation. Delayed ionizing radiation is produced by fission products and induced by environmental radionuclides (soil, air, structures, remnants of nuclear devices). These radioactive products will be dispersed to the leeward side. As the cloud moves along the trail, radioactive material that has fallen and settled on the ground creates trails of fallout. Fallout radioactive materials are the dominant source of radiation emission for locations outside the immediate effects of a

nuclear detonation. The dose received depends on the length of time a person remains in the contaminated area.

The study used a Gaussian model of air pollution with radioactive substances through the HotSpot software. In Gaussian models, it is assumed that the spread of the radioactive cloud in vertical and horizontal directions takes place by diffusion along the direction of the mean wind. The reports [13], [14] discusses the health effects and consequences of nuclear weapons, considering the physical, environmental, and medical impacts of nuclear explosions. It may also address the humanitarian aspects of nuclear weapons, advocating for disarmament and emphasizing the need to prevent the use of such destructive weaponry. The maximum concentration at the ground surface is calculated using the following equation:

$$C_x = \frac{Q}{\pi \sigma_y \sigma_z u} e^{-\frac{1}{2}\left[\frac{y}{\sigma_y}\right]^2}, [13] \qquad (5)$$

where:

Q – average emission rate, g/s,

U – average wind speed, m/s;

H – effective cloud height, m;

σ_y– standard deviation of the wind direction in the horizontal, m;

σ_z –standard deviation of the wind direction in the vertical, m;

y – off center distance, m;

e – natural logarithm = 2,71828.

A hypothetical terrestrial nuclear explosion with a yield of 20 kt and 50 kt TNT was simulated using the HotSpot 3.1.2 software product. Fig. 3 shows a model of the trail of radioactive cloud for a nuclear explosion. A wind speed of 8 m/s has been entered for the purpose of analysis. In the model, a dose of 3,000 rem was fixed for the inner plume, and 300 rem for the outer plume. The intermediate loop was set at 1,000 rem. The software has the ability to assess the defeat of people behind a barrier that will reduce the impact of ionizing radiation. The options available in the software are: unshielded, 1 m underground, house, basement, high-rise building - upper floor, high-rise building - lower floor, location behind concrete wall 22.86 cm, behind concrete wall 30.48 cm and in vehicles (car, bus).

When designing the simulation model, the bottom floor of a multi-storey building is set, the time after the explosion is fixed to one hour. In fig. 3 contours of radioactive contamination are shown. The contours are of three plume layers, coloured in red, green and blue with the correspondingly set doses of radiation.

a)
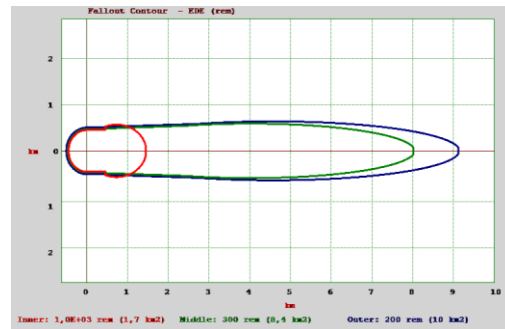
b)

Fig. 4.   Areas of radioactive contamination a) 20 kT and b) 50 kT

Radiation casualties may be caused by prompt nuclear radiation or by radioactive fallout. Unprotected individuals could receive more than the prompt ionizing radiation dose required for 50 % lethality (within weeks), out to 1,5 km for 20 kt nuclear explosion and 1,7 km for 50 kt.

The radioactive products will be dispersed downwind with the fireball/debris cloud. As cloud travels downwind, the radioactive material that has fallen and settled on the ground creates a footprint of deposited material (fallout).

The exposure to fallout is dominant source of radiation exposure for locations beyond prompt effects of nuclear detonation. The dose received depends upon the time an individual remains in the contaminated area. Unprotected individuals remaining in the contamination zone for the first hour following the nuclear explosion could receive more than the fallout dose required for 50 % lethality (within weeks), out to about 12 km for 20 kt NW and 14 km. The idealized maximum width of the fallout footprint (actual width could be larger or smaller) is about 0,56 km for 20 kt yield and 1,64 times more for the 50 kt TNT nuclear explosion. For individuals remaining in the contamination for the first 24 hours, the downwind extent of the 50 % lethality contour increases to approximately 1,37 times at 20 kt TNT vs. 50 kt nuclear blast power. The 50 % lethality contour width increases to about to about at 20 kt TNT is 1.3 km and at 50 kt nuclear blast power is 2,2 km.

The electromagnetic power (EMP) range for the 20 kT detonation is approximately 5 km, for the 50 kT detonation is approximately too. Indeed, not all equipment in the EMP-effect range will fail. The extent of damage depends on several factors, including proximity to the

source, the size of the equipment's receiving antenna, and its susceptibility to EMP effects. In general, semiconductor devices are more vulnerable to EMP than vacuum tube devices, and smaller antennas are less likely to be affected. Indeed, not all equipment in the EMP-effect range will fail. The extent of damage depends on several factors, including proximity to the source, the size of the equipment's receiving antenna, and its susceptibility to EMP effects. In general, semiconductor devices are more vulnerable to EMP than vacuum tube devices, and smaller antennas are less likely to be affected. Electromechanical devices such as electric motors, lamps and heaters are less susceptible to damage from electromagnetic electromagnetic energy due to simpler designs and the absence of sensitive electronic components. Devices such as cell phones and hand-held radios with small antennas may also be less affected, especially if they are not connected to electrical sources during the EMP event. However, this also depends on the specific design and shielding of the device. In general, the effects of an EMP event can vary widely depending on the circumstances, but understanding the principles of susceptibility can help prepare for such an event.

CONCLUSIONS

The security environment is influenced by the risks and challenges of the conflicts in the country and in the countries close to the Republic of Bulgaria. CBRN threats to our country of great importance are related to the conflict in Ukraine. The study of nuclear and chemical hazards is necessary to generate information on the risks to the population and infrastructure not only on the territory of a country, but also on transboundary pollution. Nuclear war is the most threatening scenario in this context. The conflict in Ukraine has renewed attention to the possibility of nuclear war.

The threats and risks of nuclear explosions should not be ignored or glossed over. The software products used can be used in the prediction of the consequences of nuclear explosions at previously scouted targets. The article demonstrates the application of the proposed software platforms in the early warning system for the use of nuclear weapons after clearly defined factors (meteorological and nuclear blast parameters) and targets. In the civil defence line of thinking, the sole purpose is to consider what-if scenarios and focus on possible impacts on populations and societies.

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