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Development of a Risk-Based Decision-Support-Model for Protecting an Urban Medical Center from a Nuclear Explosion

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INTRODUCTION

Nuclear explosion is the worst man-made physical threat on the human society. The nuclear explosion includes several consequences, some of them are immediate and others are long term. The major influences are: long duration blast, extreme thermal release, nuclear radiations, and electro-magnetic pulse (EMP). Their damage range is very wide. When nuclear explosion occurs above or in an urban area it is possible that one or more medical centers will be affected. Medical centers include several layers of structures defined by their resistance capacity to the nuclear explosion influences, beginning with the structure's frame and ending with different systems and with vulnerable medical critical infrastructures such as communications, medical gas supply, etc. A comprehensive literature survey revealed that in spite of the necessity and the importance of medical centers in the daily life and especially in emergency and post nuclear explosion, there is a lack of research on this topic.

The Nuclear Threat Scenario

Nuclear warheads are classified mainly by their equivalency to conventional TNT explosive charge, often called as nuclear weapon yield that ranges between kilotons (kT) to megatons (MT). The enormous bombs that were used in Hiroshima and Nagasaki were less or equal to 21kT. Current Ballistic Missiles have sub-warheads that sums together to the MT scale. The closest point on the ground surface to the above ground explosion is called ground zero (GZ). The burst altitude can vary between decades of kilometers above ground with almost just electromagnetic effect, hundreds of meters above ground for maximizing the blast and the prompt radiation effects, and above ground burst with lower blast effect but with additional radioactive fallout, which has long term hazardous effects. Medical centers will not be a target of nuclear weapon, but being in the centers of big and medium size cities would make them susceptible to late effects of the nuclear explosion. They could be located a few hundred meters (a scenario which is not cost effective to prepare for) to a few kilometers away from GZ, meaning that they are outside the burst main influence depending on the warhead yield. The model which will be presented can be applied to many threats. Nevertheless the scenarios that will be examined will match a blast of 30 kT located above ground ranges between hundreds of meters up to a few kilometers away from GZ.

Implications and consequences of the threat scenario in department of emergency care of the medical center.

There are several possible types of hazards to medical centers that depend on their location, their distance from the blast and their physical characteristics. These hazards can occur exclusively, simultaneously and at different levels at different sections in the facility as described subsequently:

a) No structural or physical hazard but necessity to evacuate the facility because of radioactive fallout or fallout fear in its vicinity and lack of preparedness of sealing and long duration stay;
b) No physical hazard but lack of full availability of the medical, nursing and administrative staff because of their or their relatives' injuries or evacuations;
c) Electromagnetic effect that causes malfunctioning of electrical and electronic devices;
d) Light hit in the exterior envelope such as windows etc.;
e) Fire;
f) Survivability of buildings but hazard to surrounding infrastructures;

g) Survivability of the buildings' skeleton but hazard to brick walls, interior partitions, infrastructures and exterior envelope components.
h) Comprehensive or partial collapse but survivability of shelters and protective spaces.
i) Partial or complete structural collapse but survivability of the shelters and protected areas.
j) Comprehensive collapse that includes protected areas.
k) Injuries to the staff, patients and visitors directly from the blast (irradiation for example) in addition to different degrees of structural damage.
l) Radioactive activation of structural elements.

The blast loading with its main parameters such as incident and reflective pressures and impulses (integration of pressure by time), and duration time can be calculated. A typical medical center department facility made of reinforced concrete, is relatively similar to 900 square meters above ground structure, including two stories described with its pressure-impulse (P-I) damage curves, ranges between no damage (0%) up to severe damage and collapse (100%) depicted by SAFER technical manuals (part of the U.S. Department of Defense manuals). In most cases the non-structural elements, such as masonry walls, will suffer at least one damage level above the structural elements. If the current structural resistance to the nuclear blast, is below the dynamic loading expressed by the calculated P-I, then it needs to be improved by various protective techniques such as strengthening the walls and ceilings, adding protective layers, etc.

Research objective

The research goal is to develop a decision-making model for optimal protection, and the means of its execution for a medical center, which has to continue performing in a nuclear attack event. The model is aimed at finding the optimal working point for investment in protection, based on getting the minimum point of the curve that includes cost scheme:

a. The cost of investment in protective measures;
b. Risk expectancy;

The Risk Management Model

The risk management model is composed of three main functions: (1) the risk function (R); (2) the Cost of Protective Effectiveness (CPE), (3) the Total Cost of Protective Effectiveness (TCPE). The following paragraphs delineate the rational of the Risk function.
The consequence expectancy function expresses the consequence as follows:

$$\mathbf{C = f\ \{M, I, D, P_{(M,I,D)}\}}$$

Where C, the consequences of the event expressed in units of cost, is a function of:
M – direct mortalities
I – direct injuries
D – cost of physical damage
$P_{(M,I,D)}$ – mortalities, injuries and physical damage caused by the medical center's malfunction (partial or complete)

The risk function is expressed as follows:

$$\mathbf{R = f\ \{P_a, 1\text{-}P_E, C\}}$$

Where R, the risk attributed to the threat realization (in US$), is a function of:
P_a - the probability of an attack
1- P_E - the lack of protective effectiveness (vulnerability) of the protection measures that were taken.
C- the general consequence of the attack.

In addition, the Cost of Protective Effectiveness (CPE) and the Total Cost of Protective Effectiveness (TCPE) functions will be developed.

Figure 1 delineates the typical linkages between the CPE and the R, given the threat scenario vs. P_E - The decision variable (independent variable).
The dashed line represents the Cost of Protective Effectiveness, CPE, related to the level of Protective Effectiveness [%], P_E. The dotted line represents the Risk Expectancy vs. the Protective Effectiveness [%], P_E. The solid line expresses the Total Cost of Protective Effectiveness: a superposition of the two above-mentioned functions, TCP, Total Cost of Protective Effectiveness, expresses actually the total cost of the CPE and the Risk Expectancy. The minimum of this curve is the optimal point of investment in protective policy.

The main research assumption is that the Risk curve, R, in the decision diagram is not linear in a nuclear scenario but climbs steeply against reduction in the level of the protective effectiveness level. This is because of the fact that the damage expectancy effects diverge beyond the physical damage and include also indirect mortality caused by loss of healthcare performance in addition to direct injuries and mortalities.

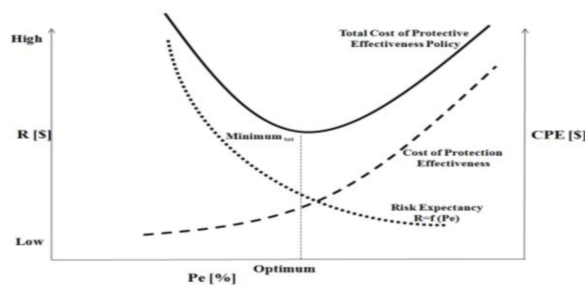

Figure 1: Decision diagram for the optimal investment point for nuclear explosion scenario

The statistical parameters in the proposed model are:

a) The probability distribution of the distance between the blast and the medical center building. This depends on the distances to the city center, to strategic facilities, etc.
b) The probability distribution of the building or its members failure, given specific dynamic loads profile, according to acceptable calculating tools and guidelines.
c) The probability distribution of the number of people of the building, as a function of time, day, night, season, etc.
d) The probability distribution of casualties' rate in the building caused by the direct effects of the explosion and by the building failure.
e) The probability distribution of the number of people that will need medical treatment in the medical center in the area, due to the charge weight, population density, regional distribution of medical centers and the discussed medical center capacity.
f) The probability distribution of mortality for several types of injuries with and without medical treatment.

SUMMARY AND INTERMEDIATE CONCLUSIONS

a) Although the consequences of nuclear explosion are highly severe, they can be estimated and preparedness for the threat can be established to mitigate the consequences.
b) The physical effects and hazards of the nuclear explosion at various locations are compared to the medical center current resistance. Additional protective means will be provided and evaluated if necessary.
c) Although the probability of effective nuclear attack is considered to be low, the consequences and the derived risk expectancy are high and can be analyzed rationality from economic measures.
d) Given a successful nuclear attack event, medical centers have an important role in mitigating disaster consequences.
e) The relevant literature dealing with this issue does not relate to medical center preparedness, probably due to the assumption that medical centers will be beyond the effective range of the blast effect or too close to be considered.