Estimating the Impacts Associated with the Detonation of an Improvised Nuclear Device

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ABSTRACT

The explosion of an improvised nuclear device (IND), in any American city, would cause devastating physical and social impacts. These impacts would exceed the response capabilities of any city, state or region. The potential loss and suffering caused by an IND detonation can be dramatically reduced through informed planning and preparedness. By incorporating estimates of the impacts associated with the detonation of an IND into the planning process, jurisdictions can estimate the scale and scope of their response requirements. A prototype, computer-based tool was developed to quantify the human impacts associated with an IND detonation. Using various types of information such as the approximation of the prompt radiation footprint, blast footprint, and thermal footprint of the detonation, along with an estimation of the level of protection provided by building structures the system calculates the number and type of injuries that can be expected in a monocentric urban area.

Keywords

Improvised Nuclear Device, Disaster Modeling, Man-made Disasters, Preparedness

INTRODUCTION

Preparing to respond to the immediate aftermath of the detonation of an improvised nuclear device (IND) in a populated area requires two separate analyses or estimations. First, the human impact of the blast must be calculated or estimated. Given a nuclear detonation of a given size at a given location: How many people will die? How many people will be contaminated? How many will be injured by blast and thermal effects? Where will the surviving victims be located? As shown in Figure 1, in addition to the location of the detonation, this calculation requires the estimation of the prompt and fallout radiation footprint, blast footprint, and thermal footprint of the detonation, and the population exposed to these effects. Since different types of building structures provide different levels of protection, the distribution of structure types and the fraction of people located in each type are also required. The output of Figure 1, the estimate of the impacted population, is the first step in determining the response capabilities and capacities that will be required to meet the critical needs of these victims.

The goal of this research is to develop a computer-based tool to determine baseline estimates for US cities based on their size (population and area), population distribution, and geographical region. The modeling tool will enable the rapid initial estimation of impacts, and is intended to guide planning, by providing a baseline for injuries, fatalities, and impacted population for various city sizes.

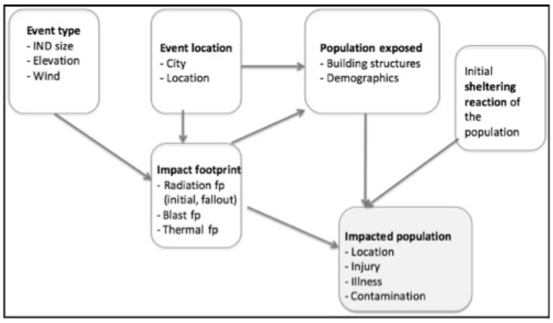


Figure 1. Factors in Determining the Impacted Population

BACKGROUND

The literature provides evidence of a number of models used for estimating the human impacts associated with a disaster. However, there are relatively few models, beyond the prototype stage, that have addressed response to manmade disasters such as conventional warfare, radiological and chemical accidents, acts of terrorism, and large-scale industrial accidents. Research by Filippoupolitis and Gelenbe (2009) addressed the evacuation of a multi-story building under different hazard conditions. Campbell and Schroder (2009) developed RimSim, a simulation system for a medical logistics person to train as a first responder in an earthquake. McGrath and McGrath (2005) built a "game" named Unreal Triage in which a player categorizes victims in the game into one of four categories, based on data transmitted from sensors placed on those victims. Several additional models have evaluated public health responses to nuclear incidents. These models tend to focus on specific scenarios of interest while neglecting the geographic features of the area where the disaster occurs. This research focuses on modeling a rare and infrequent, extreme event. It combines scientific modeling of the event, with the geographic features of the place of interest, to produce estimates of human impacts.

One of the most widely used modeling tools for planning for natural disasters is HAZUS-MH (FEMA, 2008). HAZUS-MH is a computer-based tool that models losses from earthquakes, winds, and floods and is used extensively by the emergency management community. HAZUS-MH combines both a scientific model of the event with place specific demographic information, to produce an estimation of the impacted population. Features of HAZUS-MH, such as its characterization of the built environment have been incorporated into the current research effort. Another computer modeling tool, SimSeries, is developed in conjunction with the U.S. Army Corps of Engineers, which also builds on the methodology contained in HAZUS-MH, computes damage generated by both natural and man made disasters (Soyler, Bull, Zhu, Sharawi and Bush, 2012). Currently, however, SimSeries does not model events related to INDs. Current IND modeling efforts of the U.S. Government have focused on tier 1 cities, with populations over one million people[1]. These studies, which have been conducted by Lawrence Livermore National Laboratory (LLNL), are very detailed, and take a great deal of time, effort and resources to conduct. This research attempts to build upon the methodology developed by LLNL and create a tool that provides baseline estimates of IND impacts to emergency managers in smaller cities, who do not have the benefit of full scale modeling efforts.

METHODOLOGY

The majority of planning assumptions and factors that are included in this document have been taken in part or in their entirety from a variety of documents (Buddemeier, 2008, 2009; Homeland Security Interagency Policy Coordination, 2010; U.S. Department of Homeland Security, 2009). Additional assumptions are noted. The data used as the baseline for all estimates shown in this document has been derived from a 10KT analysis of Washington, DC, that was conducted by Lawrence Livermore National Laboratory (LLNL) in 2006. This goal of this research is to provide an estimation of the impacts of an IND detonation for urban areas, with the site of the detonation occurring where population density is highest, the city center. For calculation purposes, urban areas are considered to be monocentric, that is having only one center, and to be unconstrained from growth on all sides. In order to determine the impacted population, the following inputs are required: city size, total population, population density at the city center, the population gradient, and the distribution of building types based on construction materials.

[1] Private Conversation with Lawrence Livermore National Laboratory.

Determining the Population

Using census data (U.S. Census Bureau, 2000[2]), an analysis of over 650 urban areas was performed. The analysis showed that the vast majority of city sizes (470) fell into 38 population/size categories, as shown in Table 1.

City Area (sq. km)	Population (1000's)							Total
	50	100	200	350	500	750	1000	
25	40	17						57
50	64	60	12	2				138
100	29	70	15	3				117
175	12	34	24	4	5		1	80
250		12	8	6	4	2		32
350		3	11	4	2	4		24
500			3	1	3	2	1	10
750				1	2	3		6
1000				2	2	1	1	6
Total	145	196	73	23	18	12	3	470

Table 1. City Size/Population Categories

The impacts of the detonation on the population depend not only on the total number of people within a city but also on their density and distribution. Population density is greatest at the city center (for modeling purposes, this is assumed to be the point of detonation). Using the census data, it was determined that the central density (people/sq. km.), can be estimated using the following five categories 2000, 3000, 5800, 11,500 and 23,000. It is important to note that this density represents the peak population based on time of day and/or season of the year. For example, the population in a downtown area may peak during afternoon rush hour in the spring when tourism is at its greatest. Population density decreases as the distance from the city center increases. The relationship of density and distance can be described using population density gradients (Clark, 1951; Alperovich, 1980; Mills and Tan, 1980). Density gradients were calculated as a function of total population, total city area, and peak population density. In order to determine the distribution of people throughout the city, an estimate of the population density at various distances from the point of detonation is required. Population density, D(X), at distance from the city center, X, is given by

$$D(X) = b \bullet e^{-ax} \quad (1)$$

where b is the central density and a is the density gradient (Clark, 1951). The next step was to determine the population in various impact rings around the city center. The number of people, N(R), within a radius, r, from the city center, is given by

$$N(R) = \frac{2a\pi}{b^2}\{1 - e^{-br}(1 + br)\} \quad (2)$$

where b is the central density and a is the density gradient (Clark, 1951). Using the negative exponential function described in equation (1), population will eventually decrease to 0 people per square kilometer. Therefore, a minimum number for population density was used, based upon suburban areas corresponding to the various city sizes and geographical region of the country (Demographia, 2000).

Estimating Casualties Associated with Prompt Radiation

An individual's ability to survive the radiation associated with a nuclear detonation is based on two main factors: the distance from the detonation and the type of structure in which a person is located. Buildings, even those with windows, provide a level of shielding from radiation exposure. Therefore, people who are located outside are much more susceptible to harmful levels of exposure than people located inside multi-story steel frame buildings.

In order to calculate injuries and fatalities due to prompt radiation, people were distributed into various building structures. This methodology utilizes the structure type distributions that are used in HAZUS-MH (FEMA, 2008). An analysis of HAZUS data showed that percentage of the population in different structure types is a function of both geographical region and population density. Table 3 provides the percentages that were derived from HAZUS-MH and used in these calculations for urban areas with population density greater than 3500 people per square kilometer. The percentages for the core and periphery of steel building structures are based on Davis (1965).

[2] Census 2000 data was used since Census 2010 data was unavailable in HAZUS-MH at the time of this effort.

Density	Region	Wood	Steel Total (Core, Periphery)	Concrete	Masonry	Other
Population Density > 3000 (people/sq km)	Midwest	0.27	0.19 (0.05, 0.14)	0.12	0.26	0.17
	Northeast	0.23	0.3 (0.09, 0.21)	0.07	0.23	0.16
	Southwest	0.28	0.18 (0.05, 0.13)	0.13	0.24	0.18
	Southeast	0.21	0.28 (0.08, 0.2)	0.08	0.27	0.16
	West	0.32	0.1 (0.03, 0.07)	0.18	0.15	0.25

Table 3. Population by Structure Type

Using various algorithms developed by LLNL it is possible to determine the amount of prompt radiation based on distance from the point of detonation. An example of this is shown in Table 4. The term “Core”, is used to describe the internal areas of a steel building; those areas that are not located along a building’s periphery.

Distance from Center	Description	Prompt Radiation Dosage					
		Lethal	Very Severe	Severe	Moderate	Mild	None
0.92	No survivors	Wood Outside Core					
0.981	Only survivors are those in the core of multi-story steel frame buildings and they experience a very severe level of radiation	Wood Outside All Other	Core				

Lethal - greater than 8.3 Gy
Very Severe – 5.3 to 8.3 Gy
Severe – 3.0 to 5.3 Gy
Moderate – 1.25 to 3.0 Gy
Mild – 0.5 to 0.7 Gy
None - <.5 Gy

Table 4. Subset of Prompt Radiation Impacts by Distance and Structure Type

COMPUTER-BASED ESTIMATION TOOL

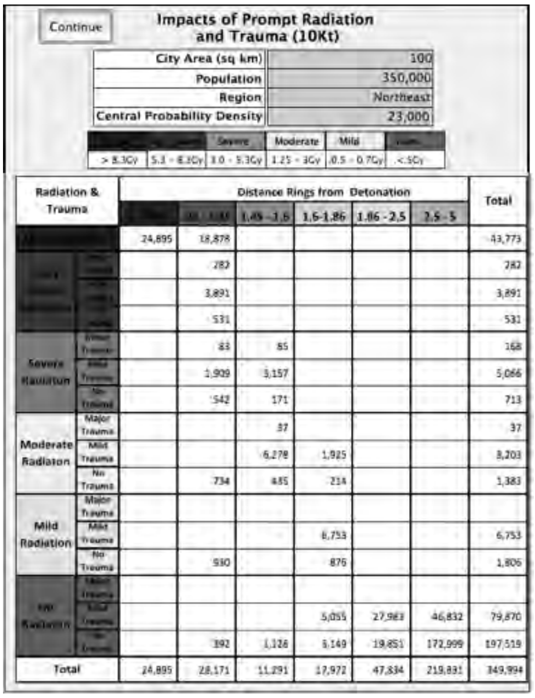
Using the methodology described above, a prototype, computer based tool was developed to provide an estimation of the prompt impacts of an IND detonation for urban areas, with the site of the detonation occurring where population density is highest, the city center. The first step in the analysis requires the user to specify the size of the city in terms of physical area and total population. The user can choose from 38 different size categories (see Table 1). Then, the user must specify the geographical region of the city: Northeast, Southeast, Midwest, Southwest or West. The geographical region is used to determine the distribution of people into various building structure types (wood, steel-frame, etc.) and default population densities for suburban and rural areas. Data for building distributions was obtained from HAZUS-MH. The impacts of the detonation on the population depend not only on the total number of people within a city but on their density and distribution. Population density is greatest at the city center and then decreases as a function of distance from the city center. The user selects the central density for their city. Default values are provided for suburban and rural population densities. These values are based on both geographical region and city size. The user is able to modify these values to more closely reflect their city of interest. Figure 2 presents the primary results of the analysis, the impacts of prompt radiation and trauma.

FUTURE WORK

There are a number of areas that need to be addressed in order for the modeling tool to provide more accurate estimates. Currently, cities are modeled as monocentric and unconstrained from growth on all sides. Many of the cities within the US are not monocentric. Sometimes, they are constrained in growth by natural barriers such as bodies of water or mountains. In addition, there is often a close neighboring city (such as Philadelphia, PA and Wilmington, DE) and the land in between the cities is predominantly urban. Additional modeling efforts will attempt to address these limitations. Future efforts will also attempt to determine human impacts based on fallout radiation. While the current modeling tool does provide a very rough estimate of the potential danger due to fallout (not discussed in this paper), it requires a great deal more development work.

CONCLUSION

This modeling provides a baseline for injuries, fatalities, and impacted population for over 900 different user-defined urban areas, based on total population, area (sq. km), geographical region and central density. These numbers are intended to provide an order of magnitude for estimates of impacts, and, it should be noted, that there still exists a fairly large degree of uncertainty due to the population distributions and building structures mentioned earlier. The data provided by the analysis of specific city sizes can be very useful when planning for the first 72 hours following the detonation.. It is intended that emergency management personnel could use the outputs from the modeling tool as inputs when determining critical response information, such as: How many people need to be evacuated? How many people need medical treatment? What are the requirements for search and rescue? In other words, the estimation tool provides an order of magnitude for impact estimates that allows the planner to derive the scale of the disaster for their individual city and an estimate of response requirements.



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Impacts of Prompt Radiation and Trauma (10Kt)

City Area (sq km)	100
Population	350,000
Region	Northeast
Central Probability Density	23,000

[illegible]	[illegible]	Severe	Moderate	Mild	[illegible]
> 8.3Cy	5.3 - 8.3Cy	3.0 - 5.3Cy	1.25 - 3Cy	.0.5 - 0.7Cy	.<.5Cy

Radiation & Trauma		Distance Rings from Detonation						Total
		[illegible]	[illegible]	1.45 - 1.6	1.6-1.86	1.86 - 2.5	2.5 - 5	
[illegible]		24,895	18,878					43,773
[illegible]	[illegible]		282					282
	[illegible]		3,891					3,891
	[illegible]		531					531
Severe Radiation	[illegible]		83	85				168
	[illegible]		1,909	3,157				5,066
	[illegible]		542	171				713
Moderate Radiaton	Major Trauma			37				37
	Mild Trauma			6,278	1,925			8,203
	No Trauma		734	435	214			1,383
Mild Radiation	Major Trauma							
	Mild Trauma				6,753			6,753
	No Trauma		930		876			1,806
[illegible]	[illegible]							
	[illegible]				5,055	27,983	46,832	79,870
	[illegible]		392	1,128	6,149	19,851	172,999	197,519
Total		24,895	28,171	11,291	17,972	47,834	219,831	349,994

Figure 2. Output: Prompt Radiation and Trauma

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