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HUMAN CONSEQUENCES OF MULTIPLE NUCLEAR DETONATIONS IN NEW DELHI, INDIA

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Abstract: The human casualties from simulated nuclear detonation scenarios in New Delhi, India are analyzed, with a focus on the distribution of casualties in urban environments and the theoretical application of a nuclear-specific triage system. Model estimates of nuclear war casualties employed ESRI's ArcGIS 9.3, blast and prompt radiation were calculated using the Defense Nuclear Agency's WE program, and fallout radiation was calculated using the Defense Threat Reduction Agency's (DTRA's) Hazard Prediction and Assessment Capability (HPAC) V404SP4, as well as custom GIS and database software applications. ESRI ArcGISTM programs were used to calculate affected populations from the Oak Ridge National Laboratory's LandScanTM 2007 Global Population Dataset for areas affected by thermal, blast and radiation data. Trauma, thermal burn, and radiation casualties were thus estimated on a geographic basis for New Delhi, India for single and multiple (six) 25 kiloton (kt) detonations and a single 1 megaton (1000kt) detonation. Major issues related to the emergency management of a nuclear incident are discussed with specific recommendations for improvement. The consequences for health management of thermal burn and radiation patients is the worst, as burn patients require enormous resources to treat, and there will be little to no familiarity with the treatment of radiation victims.

Keywords: nuclear, detonations, trauma, thermal burn, radiation, fallout, New Delhi, India, Pakistan.

1. Introduction

Since their inception in 1947, the rivalry between India and Pakistan has resulted in four major military conflicts between the two nations in 1947, 1965, 1971, and 1999. The Kargil war of 1999 was particularly significant as it occurred under the shadow of nuclear weapons possessed by both, India and Pakistan. While the outcome of these conflicts proved India's military superiority over Pakistan, they also provided the impetus for a constant stream of terror attacks on Indian soil that were carried out with moral, material and logistical support from Pakistan. The recent spate of terror attacks on Indian military establishments, evidently carried out by Pakistani elements, compelled the Indian government to retaliate with surgical military strikes on terrorist training camps in Pakistan-occupied Kashmir. Although Pakistan denied the occurrence of any surgical strikes on its soil by Indian forces, international opinion weighed heavily in India's favor, particularly in the United States where the Obama administration openly supported the targeted military intervention by India [1]. Along with global isolation, Pakistan also has to contend with India's increasing economic and diplomatic clout in the South Asian sub-continent. In 2016, a

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historic meeting of the South Asian Association for Regional Cooperation (SAARC) scheduled to be held in Islamabad, Pakistan was indefinitely postponed as four (India, Bangladesh, Afghanistan, and Bhutan) of its eight member countries announced a boycott of the conference citing Pakistan's use of cross-border terrorism against India [2].

Pakistan's deteriorating stability is compounded by increasing religious radicalization within its civil society and the military. In January and February of 2017 alone, there were 19 reported bomb blasts within various areas of Pakistan [3]. And in the past decade, numerous terrorist attacks on Pakistani military assets have been reportedly carried out with assistance from extremist elements present within the Pakistan military [4]. This combination of internal instability and external isolation could be reasonably expected to result in a dangerous game of nuclear brinkmanship. If India decides to respond militarily to another terror incident emanating from Pakistan, the Pakistani military may be induced to utilize its nuclear arsenal - either due to fear of defeat because of the Indian military's record of conventional victories, or by military personnel increasingly sympathetic to extremist ideologies.

The following sections present the methodology of analyses, derivation of the results, and a discussion of the impact of nuclear weapons' detonations on New Delhi, India in terms of human casualties with an emphasis on injury distribution by blast pressure, thermal burns, and radiation exposure respectively. Mass casualty management of a nuclear detonation event is discussed along with the application of a nuclear event-specific triage system.

2. Methods

An overview of the effects of a nuclear detonation is provided below, followed by a description of the study area, weapon sizes, variable selection and modeling parameters.

Effects of a Nuclear Detonation

The vast amount of energy from a nuclear detonation is released in the form of a blast wave (50%), thermal energy (35%), or nuclear radiation (15%). The blast wave is propagated outwards from the point of detonation and is measured as the amount of pressure over and above the normal atmospheric pressure (termed 'overpressure') in pounds per square inch (psi). The extent and intensity of the blast wave dissipates as it moves further away from the detonation site. The blast wave also generates very high velocity winds termed dynamic pressure, which can cause serious damage to structures. Taken together, overpressure and dynamic pressure can cause serious injuries due to the physical displacement of individuals into inert objects, collapse of solid structures such as buildings and trees, and glass projectiles from shattered windows. Damage to physical structures at different overpressures can manifest as follows [5]:

- 0.1 to 1 psi – Minor damage, mainly broken windows.
- 1 to 5 psi – Most buildings will sustain considerable damage in the form of blown out interiors and some may even collapse, unless they are constructed using reinforced concrete.
- 5 to 8 psi – Most buildings will be severely damaged or destroyed.
- >8 psi – Even heavily reinforced structures will be significantly damaged.

According to the 2011 population census, approximately 1.8 million of the 16.8 million inhabitants of Delhi are categorized as living in slums [6]. The slum areas consist of very flimsy physical structures constructed from tin sheets, cloth, wood, and in some cases, brick. Therefore, it is logical to assume that almost all slum dwellings will suffer severe blast damage, some even at 0.6 psi overpressure.

Thermal radiation (fluence) is typically measured in calories per square centimeter (cal/cm²). The impact of thermal fluence is a function of the weapon yield, the fraction of that yield released as thermal energy, distance from the blast site, and local atmospheric conditions [7]. Larger weapon yields result in an increased intensity and range of thermal effects [8]. The thermal impacts of a nuclear explosion are significant, particularly for weapons over 100kt, scaling faster than blast, since thermal radiation decays as the inverse square while blast decays as the inverse cube of distance from the detonation point. Thermal energy travels directly from the fireball unless scattered or absorbed. A thermal fluence of 10cals/cm² or above is required to ignite buildings and other structures. Cloud cover is an important consideration in determining the effect of thermal energy. If the fireball from the detonation remains below cloud level, thermal radiation is reflected by the clouds and can amplify fire ignition probabilities [7]. Individual fires have the potential to coalesce and form mass fires. Based on the experiences of mass fires in Germany and Japan during World War II, the minimum requirements to produce mass fires include a burning area of half a square mile with half the structures on fire simultaneously, wind speed less than 8 miles per hour, and at least 8 pounds of combustible substances per square foot of the fire area [8].

Radiation consists of two main types, prompt and fallout. Prompt, or ionizing radiation, is the radiation emitted within one minute of a nuclear detonation. The prompt radiation zone lies within the mass fire zone for the 25kt and 1mt weapons evaluated in this study. In a surface burst, large quantities of soil are sucked into the fireball along with the weapon casing and other materials present in the vicinity of the explosion. The high temperatures within the fireball can either fuse or vaporize these substances which are subsequently contaminated with radioactive fission fragments produced during the nuclear detonation. The contaminated particles gradually descend to the ground, a phenomenon called radioactive fallout. Radioactive fallout is the main source of residual nuclear radiation and manifests itself in the form of gamma rays and beta particles. Some of the heavier fallout particles descend quickly to the earth (within the first 24 hours after a nuclear explosion) and are called local and/or early fallout. Fallout radiation causes a conical shaped plume that is blown downwind from the blast site. Dispersion is greatly affected by turbulence in the atmosphere which in turn mainly depends upon the topography, land use, vertical wind and temperature structure. Fallout radiation, measured in Gray (Gy), has been partitioned into 5 classes (≤0.5 Gy, >0.5-2 Gy, >2-6 Gy, >6-10 Gy, >10 Gy) based upon the modified-SALT triage categories of radiation injury [9].

Study area and Size of weapons

New Delhi is one of the 11 districts that comprise the National Capital Territory (NCT) of Delhi . According to the latest census data in 2011 [6], the population of the NCT of Delhi is approximately 16.8 million, increasing at 2.09% annually [10]. Population density is high with 11,320 individuals per square kilometer [6]. The physical topography of Delhi is relatively flat [10]. The month of May was selected as the time of the nuclear attacks as it is one of the driest months with little cloud cover and is therefore most amenable to dispersion of fallout radiation and thermal energy.

Three separate scenarios were selected for the use of nuclear weapons. First, a single 25kt weapon was detonated in the center of New Delhi. This could either be a highly efficient fission weapon or a less efficient boosted weapon. A height of 25 meters was selected to ensure that

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fallout radiation was high, while thermal effects are still substantially greater than a surface burst. In the second scenario, six 25kt nuclear weapons were detonated at the same height at six separate locations, and in the third scenario, a single 1 megaton (mt) nuclear weapon at a height of 200 meters was detonated. It is recognized that neither India nor Pakistan has thermonuclear weapons at this time, but this will likely become true within the next decade. A fission fraction of 1 was assigned to the 25kt weapons and 0.8 for the 1mt device.

<u>Variable selection and model used</u>

The primary variables used to calculate human casualties in a nuclear detonation are blast, thermal, prompt and fallout radiation. Blast, thermal, and prompt radiation effects extend outwards in all directions from the point of detonation and are depicted as effects circles. Fallout radiation extends as a plume from the point of detonation and its course depends upon local atmospheric conditions such as wind direction. The approximate radii of impact for each effect circle for a 25kt and 1mt yield nuclear weapon respectively are shown in Table 1.

Blast effects for 0.6, 2, and 3 psi primarily consist of their impact on inert structures, whereas the impact of 4.9 and 8.1 psi overpressures were based upon the National Planning Scenarios [11]. 0.6 psi is the approximate threshold for glass breakage and is associated with secondary injuries such as cuts on exposed body surfaces due to wind blown glass and other debris. Therefore, the glass breakage zone will extend out the farthest in a concentric circle from Ground Zero (except for the narrow zone of the radiation plume). Two and three psi blast overpressures can cause tertiary injuries due to physical displacement of the body against inert structures and quaternary injuries owing to collapsed buildings. Individuals in the 4.9 psi effect circle are expected to suffer a 50% injury rate and those in the 8.1 psi effect circle, a 50% fatality rate [11].

Table 1. Radii of effect circles for 25kt and 1mt weapon

Effect	***Radius (in meters)***	
	25kt	***1mt***
0.6 psi	6,185	21,335
1st degree burn	4,223	14,531
2nd degree burn	3,112	11,880
3rd degree burn	2,555	10,332
2 psi	2,527	8,760
50% Mass Fire	2,081	8,099
3 psi	1912	6632
4.9 psi	1,397	4,836
Prompt radiation	1,248	2,564*
8.1 psi	1,037	3,591*

** Note that for 1mt weapon, 8.1psi > prompt radiation (in 25kt weapon, 8.1psi < prompt radiation).*

Thermal effects consist of a 50% probability of 1st, 2nd, 3rd degree burns, and mass fires respectively. Table 2 shows the thermal fluence thresholds for burns based on Figure 12.65 of Glasstone and Dolan [8], and for mass fires based on Binninger's work [7].

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Table 2. Thermal fluence levels for 25kt and 1mt nuclear weapon

Thermal effect	Thermal fluence (cal/cm^2)	
	25kt	1mt
1st degree burns	2.5	3.16
2nd degree burns	5	6.21
3rd degree burns	7.71	9.56
50% probability of mass fires	12.01	19.2

For the prompt radiation effect circle, a dose of 600 rads (6 Gy) with a 50% fatality rate was applied to the 25kt and 1mt weapons. Fallout radiation plumes were categorized according to the modified-SALT triage system for a nuclear detonation [9] and are shown in Table 3.

Table 3. Fallout radiation categories and associated effects

Fallout radiation Dose (Gy)	Effects
>10	Fatal – even with intensive management in a normal resource environment
>6-10	Severe radiation injury – hematopoietic and GI syndromes predominate
>2-6	Moderate radiation injury – after a latency period of days to weeks, hematopoietic syndrome is the primary manifestation, followed by the GI syndrome
>0.5-2	Minimal B radiation injury – produces only mild prodromal symptoms
<0.5	Minimal A radiation injury – no immediate symptoms

Fallout radiation isolines were calculated using DTRA's HPAC v4.04SP4 [12]. The fallout radiation plumes after detonation were analyzed for affected populations after 4 and 24 hours. Population estimates (in interpolated 3 arc-second grid format) were derived from Oak Ridge National Laboratory's LandScan™ 2014 Global Population Dataset [13]. ESRI's ArcGIS™ software [14] was used to create circular buffers around the detonation point representing regions where the population would be exposed to prompt radiation, blast and thermal effects. The population grid for Delhi was converted to polygon data (projected to UTM-WGS84 coordinates) and the population calculated for each intersection polygon of the blast, prompt radiation and thermal effects with the fallout radiation isolines. The polygon's population was interpolated from the 3" Landscan population grid using the area of the intersection polygon divided by the relevant gridcell areas times that gridcell's population. For each scenario the blast, thermal and prompt radiation circular zones of interest, HPAC plume fallout radiation isolines, and the population grid were overlaid. The affected population for each unique combination of blast, thermal and prompt radiation effects and fallout zone was tabulated using Qlik™ software and assigned to the appropriate triage category using the modified-SALT triage system for a nuclear detonation event [9].

3. Results

Simulated explosions of a single 25kt and a single 1mt nuclear weapon were conducted on central New Delhi where some of the most important Indian government institutions (such as the Indian parliament) are located. The six 25kt nuclear detonations were simulated at various locations throughout Delhi in such a manner as to cover the major population clusters in the city, as would be expected to ensue with modern nuclear war planning conducted by all states possessing nuclear weapons. There are some common aspects in each of the three scenarios which should be

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considered while reviewing the results. Since May is one of the hottest months in Delhi, most people will be dressed in light summer clothes and it can be safely assumed that any protection offered by clothing to even minor burns will be minimal. Also, buildings and other concrete structures may offer varying degrees of shielding, particularly from fallout radiation. The level of shielding is denoted by a protection factor (PF). For example, a structure with a PF of 10 indicates that a person inside the building will receive $1/10^{th}$ of the radiation dose compared to a person out in the open. The PF also depends on the location of a person within the building.

PFs have not been considered in the calculation of human casualties due to the significant diversity in the type of structures (slums, single-story houses, skyscrapers) that exist within the affected areas. Therefore, in a real world setting, it is conceivable that some individuals may be exposed to less or no fallout radiation at all, while others in slums or in outdoor settings will have relatively higher exposure to radiation without appreciable shielding.

3.1 Fallout radiation plume

The fallout radiation plume moves and spreads over time according to the prevalent wind direction. The populations affected by the fallout plume at 4 and at 24 hours post-detonation respectively are enumerated in the subsequent sections. However, it must be understood that population groups at 4 and 24 hours are neither mutually exclusive nor are they entirely congruent with each other. For example, a person experiencing fallout radiation of 0.5-2 Gy at 4 hours could very well be subjected to fallout radiation levels of 2-6 Gy at the 24 hour mark. However, the fallout plume also spreads by the 24 hour period and will cover additional people as compared to the 4 hour plume. Therefore, the 24 hour group will contain some individuals that were also included in the 4 hour group.

Based on the assumption that resource availability for medical treatment of victims will be poor, subsets of the affected population are assigned to triage categories of minimal, immediate, or expectant. It is important to note that due to the expected very poor resource availability, the triage category of 'delayed' is not utilized as there is virtually no likelihood of distribution of resources beyond the immediate categories under current expectations of nuclear war preparedness.

3.2 Effects of Single 25kt nuclear weapon

Medical casualties from a 25kt nuclear weapon detonation in New Delhi are presented in Tables 4 and 5.

Of the approximately 3.36 million individuals that lie within the effect circles, 2.9 million (87.4%) will be eligible for triage. 423,175 (12.6%) people confined in the 2 psi + 50% Mass Fire zone up to the detonation point are considered not accessible for triage. 2.12 million (63%) could experience some combination of 0.6 psi blast overpressure, fallout radiation exposure up to 2 Gy, and a 50% probability of 1^{st} degree burns. Injuries associated with these types of trauma include mild prodromal symptoms (nausea, vomiting, and lethargy) due to radiation exposure and, cuts and lacerations due to glass breakage. Therefore, these individuals will be assigned to the triage category 'minimal' (green) with access to medical care only as available after the immediate medical category. It should be kept in mind that these designations are inevitably used due to the very limited medical resources, not due to the actual needs of these patients.

An estimated 576,000 (17%) individuals that lie within the effect circles may be subjected to blast overpressure ranging from 0.6 to 2 psi, fallout radiation exposure up to 6 Gy, and a 50% probability of 2^{nd} or 3^{rd} degree burns. Although this population has been assigned to the 'immediate' (red)

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category, multiple factors will determine their actual triage outcome. The amount of total body surface area (TBSA) covered by the 2^{nd} and 3^{rd} degree burns will dictate whether the victim is triaged as immediate or 'expectant' (black). Additionally, the amount of fallout radiation exposure will also be a significant factor in determining the triage category. Individuals suffering from 2^{nd} or 3^{rd} degree burns covering <20% TBSA and fallout exposure up to 3 Gy may have a fair chance of survival if they receive medical care and will be assigned to the immediate triage category.

Table 4. Human casualties due to combined injuries (1x25kt nuclear weapon)

Fallout radiation (Gy) / Effect(s)	0	0.01 to 0.5	>0.5 to 2	>2 to 6	>6 to 10	>10	TOTAL
0.6 psi only	1,219,277	118,470	49,605	58,228	36,303	81,600	**1,563,483**
0.6 psi + 1st deg burns	652,899	65,626	21,200	21,988	10,334	60,302	**832,349**
0.6 psi + 2nd deg burns	253,400	29,063	8,057	6,148	2,423	22,861	**321,952**
0.6 psi + 3rd deg burns	11,272	1,071	353	237	93	1,177	**14,203**
2 psi + 3rd deg burns	160,919	16,628	5,208	3,444	1,552	16,601	**204,352**
2 psi + 50% MF	51,191	6,844	1,857	1,100	463	4,939	**66,394**
3 psi + 50% MF	114,742	18,570	4,296	2,839	1,102	11,775	**153,324**
4.9 psi + 50% MF	28,420	5,407	1,642	1,205	392	3,748	**40,814**
4.9 psi + Prompt	31,717	8,905	2,384	2,121	741	5,951	**51,819**
8.1 psi + Prompt + 50% MF	18,657	29,396	9,946	9,035	3,821	39,969	**110,824**
TOTAL	**2,542,494**	**299,980**	**104,548**	**106,345**	**57,224**	**248,923**	**3,359,514**

Minimal Immediate Expectant Not accessible for triage

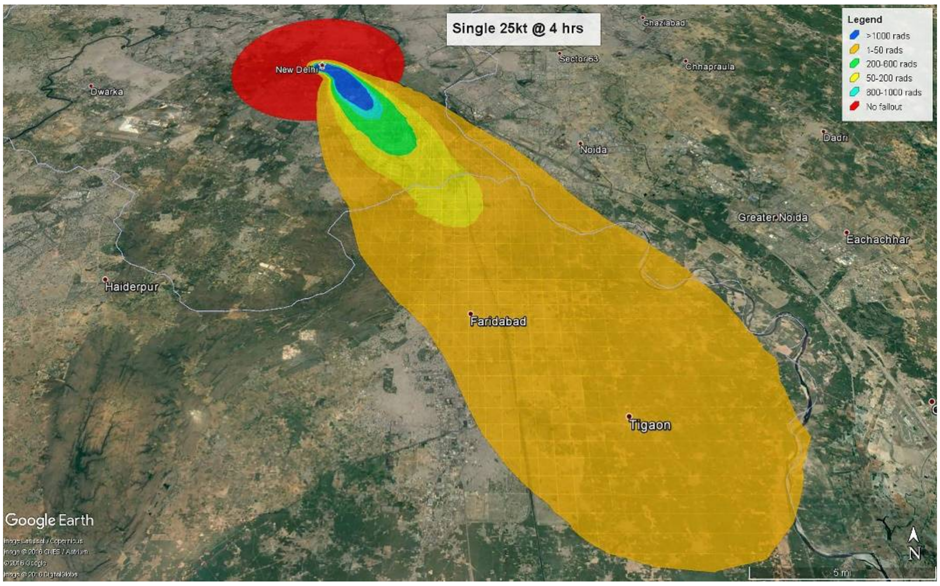
However, people with 2^{nd} or 3^{rd} degree burns covering >20% TBSA and/or fallout radiation exposure greater than 3 Gy will likely be assigned to the expectant category. Furthermore, survivors in the 2 psi overpressure area would have to self-transport themselves to the triage facility as destruction of physical infrastructure would make it almost impossible for emergency workers to reach these individuals. Finally, about 233,000 (7%) of the individuals will suffer from fallout radiation exposure greater than 6 Gy, blast overpressures ranging from 0.6 to 2 psi, and a 50% probability of 1^{st}, 2^{nd}, or 3^{rd} degree burns. Under poor resource conditions, victims with such complicated combined injuries and radiation exposure would be assigned to the expectant triage category.

Table 5. Human casualties from fallout radiation only (1x25kt nuclear weapon)

Fallout radiation dose (Gy)	Triage category allocation for radiation injuries only	Population @ 4 hrs	Population @ 24 hrs
>10	Expectant	4,047	47,557
>6-10	Expectant	59,800	129,924
>2-6	Immediate	484,838	564,803
>0.5-2	Minimal B	520,660	601,079
<0.5	Minimal A	1,757,924	2,475,654
TOTAL		**2,827,269**	**3,819,017**

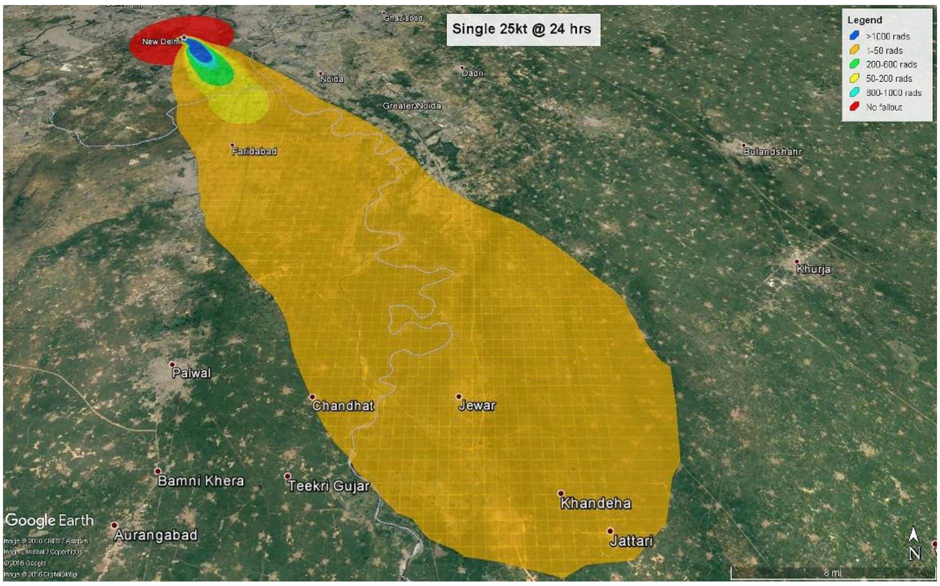
The number of individuals affected *only* by fallout radiation is calculated at 4 and 24 hours after detonation respectively. At 4 hours, the fallout radiation plume will extend almost 28 kilometers (17 miles) into the neighboring state of Haryana with some amount of fallout radiation spilling over into another neighboring state, Uttar Pradesh (Figure 1).

Figure 1. Single 25kt fallout radiation plume at 4 hours



At 24 hours, the plume crosses Haryana and extends almost 21 kilometers (13.5 miles) into Uttar Pradesh (Figure 2).

Figure 2. Single 25kt fallout radiation plume at 24 hours



Therefore, at the 4-hour mark, 2,278,584 (80.6%) people will be triaged as minimal with 1,758,000 exposed to less than 0.5 Gy and 520,000 to 0.5-2 Gy. Everyone triaged to the minimal category will

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be expected to receive little or no treatment. Approximately 484,000 (17.1%) will be triaged as immediate, and 64,000 (2.3%) as expectant based on their radiation exposure levels of 2-6 Gy and greater than 6 Gy respectively. The immediate category will be expected to express a moderate level of radiation injury whereas the expectant group will have received fatal radiation doses. At 24 hours after detonation, the fallout plume affects 3.8 million people with approximately 3 million (80.5%) exposed to radiation levels ranging from 0.01-2 Gy, categorized as minimal. The 565,000 (14.8%) individuals calculated as receiving 2-6 Gy will be categorized as immediate, and 177,000 (4.7%) receiving more than 6 Gy will be assigned to the expectant category.

3.3 Effects of Six 25kt nuclear weapons

Medical casualties from six 25kt nuclear weapon detonations over various locations in Delhi are shown in Tables 6 and 7.

Table 6. Human casualties due to combined injuries (6x25kt nuclear weapons)

Fallout radiation (Gy) / Effect(s)	0	0.01 to 0.5	>0.5 to 2	>2 to 6	>6 to 10	>10	TOTAL
0.6 psi only	515,660	362,583	657,815	1,150,749	608,662	427,857	**3,723,326**
0.6 psi + 1st deg burns	318,209	160,104	344,176	632,551	147,865	263,831	**1,866,736**
0.6 psi + 2nd deg burns	147,959	40,854	136,238	245,202	68,743	129,155	**768,151**
0.6 psi + 3rd deg burns	7,408	2,338	6,430	10,872	3,164	6,775	**36,987**
2 psi + 3rd deg burns	104,884	42,358	96,690	150,381	52,266	113,084	**559,663**
2 psi + 50% MF	27,382	25,493	33,038	50,086	19,422	46,675	**202,096**
3 psi + 50% MF	7,663	152,098	64,176	144,160	30,434	163,022	**561,553**
4.9 psi + 50% MF	0	24,562	25,769	43,284	7,086	46,324	**147,025**
4.9 psi + Prompt	0	3,288	42,141	67,071	13,096	66,371	**191,967**
8.1 psi + Prompt + 50% MF	0	0	2,590	54,862	48,875	298,852	**405,179**
TOTAL	**1,129,165**	**813,678**	**1,409,063**	**2,549,218**	**999,613**	**1,561,946**	**8,462,683**

Minimal Immediate Expectant Not accessible for triage

Table 7. Human casualties from fallout radiation only (6x25kt nuclear weapons)

Fallout radiation dose (Gy)	Triage category allocation for radiation injuries only	Population @ 4 hrs	Population @ 24 hrs
>10	Expectant	31,932	546,561
>6-10	Expectant	784,039	1,612,566
>2-6	Immediate	2,768,985	3,039,286
>0.5-2	Minimal B	3,347,265	3,225,508
<0.5	Minimal A	3,492,934	4,759,268
TOTAL		**10,425,155**	**13,183,189**

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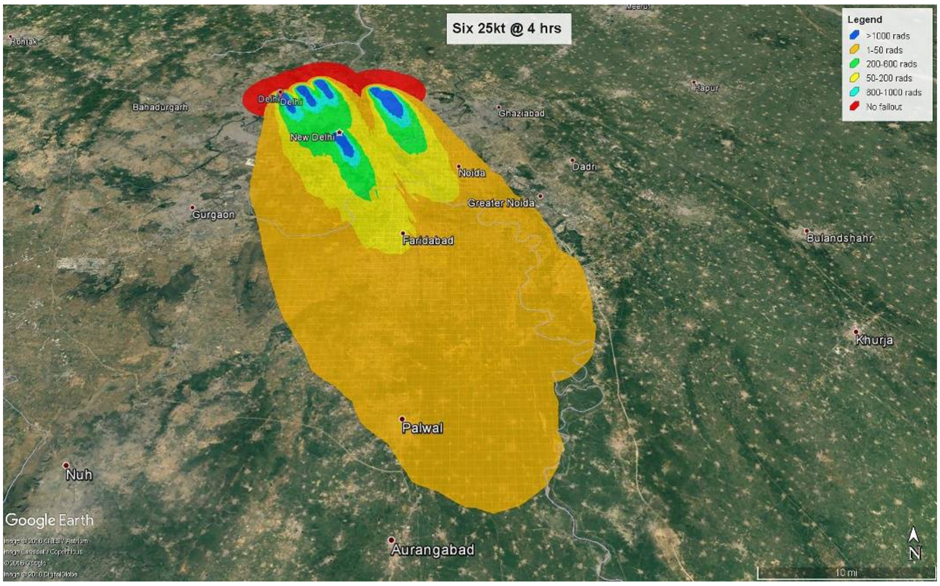
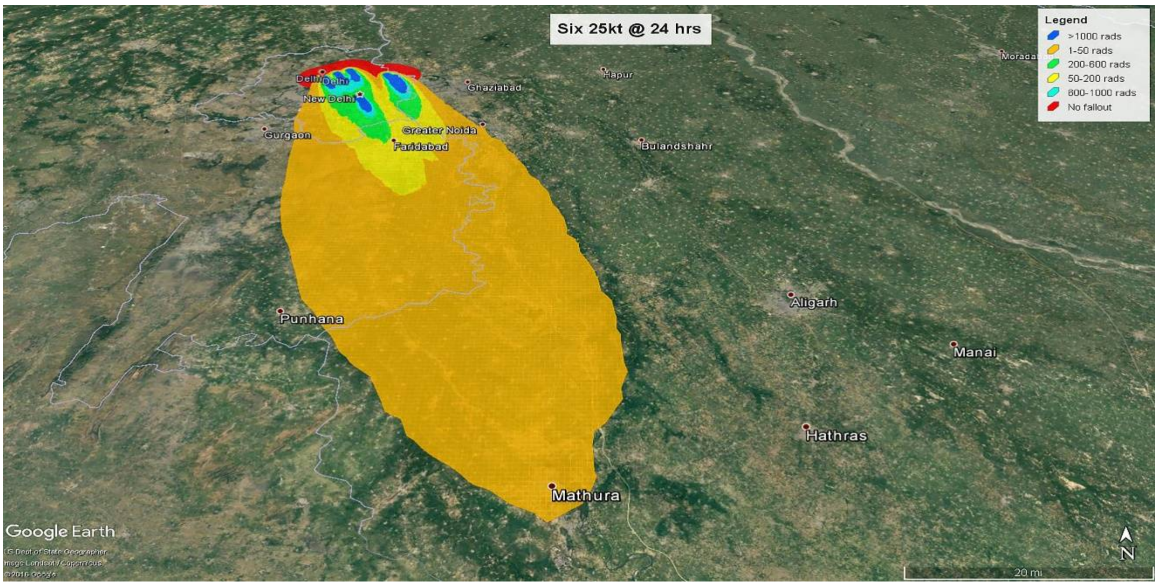
The six detonation points were strategically selected to cover the major population centers in Delhi, as would be expected to occur with most nuclear war planning. Of the 8.46 million individuals that lie within the effect circles, 6.95 million (82%) will be eligible for triage and 1.5 million (18%) people are considered not accessible for triage. Approximately, 2.36 million (27.8%) individuals will be assigned to the minimal category, 2.7 million (32.8%) to immediate, and 1.8 million (21.5%) to the expectant triage category. At 4 hours, the fallout radiation plume will extend almost 50 kilometers (31 miles) into the neighboring state of Haryana with some amount of fallout radiation spilling over into another neighboring state, Uttar Pradesh (Figure 3).

Figure 3. Six 25kt fallout radiation plume at 4 hours



At 24 hours, the plume crosses Haryana and extends almost 54 kilometers (33 miles) into Uttar Pradesh (Figure 4).

Figure 4. Six 25kt fallout radiation plume at 24 hours



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Of the 10.4 million people affected by fallout radiation at 4 hours post-detonation, 6.84 million (65.6%) people will be triaged as minimal, with 3.5 million exposed to less than 0.5 Gy and 3.34 million to 0.5-2 Gy. 2,768,000 (26.5%) will be triaged as immediate, and 816,000 (7.9%) as expectant based on their radiation exposure levels of 2-6 Gy and greater than 6 Gy respectively. At 24 hours, the fallout plume affects approximately 13.2 million people from which approximately 8 million (60.6%) individuals will be exposed to radiation levels ranging from 0.01-2 Gy and categorized as minimal. 2.76 million (23%) individuals receiving 2-6 Gy will be categorized as immediate, and 2.16 million (16.4%) receiving more than 6 Gy will be assigned to the expectant category.

3.4 Effects of Single 1mt nuclear weapon

The amount of human devastation caused by a 1mt nuclear weapon on New Delhi is extraordinary and is shown in Tables 8 and 9.

Table 8. Human casualties due to combined injuries (1mt nuclear weapon)

Fallout radiation (Gy) / Effect(s)	0	0.01 to 0.5	>0.5 to 2	>2 to 6	>6 to 10	>10	TOTAL
0.6 psi only	3,155,533	549,393	131,409	294,732	102,470	3,904	**4,237,441**
0.6 psi + 1st deg burns	2,286,990	418,080	138,514	83,966	102,018	237,913	**3,267,481**
0.6 psi + 2nd deg burns	1,318,048	436,686	147,973	82,526	56,590	286,396	**2,328,219**
0.6 psi + 3rd deg burns	1,061,438	612,034	170,504	61,413	72,198	455,910	**2,433,497**
2 psi + 3rd deg burns	289,637	281,618	66,262	35,773	18,293	219,834	**911,417**
2 psi + 50% MF	181,937	825,575	156,196	127,415	48,757	422,301	**1,762,181**
3 psi + 50% MF	0	708,072	134,413	92,676	40,831	563,713	**1,539,705**
4.9 psi + 50% MF	0	109,800	293,806	114,560	54,854	341,396	**914,416**
8.1 psi + 50% MF	0	0	64,324	198,124	70,136	350,380	**682,964**
8.1 psi + Prompt	0	0	0	0	10,990	635,355	**646,345**
TOTAL	**8,293,583**	**3,941,258**	**1,303,401**	**1,091,185**	**577,137**	**3,517,102**	**18,723,666**

Minimal Immediate Expectant Not accessible for triage

Table 9. Human casualties from fallout radiation only (1mt nuclear weapon)

Fallout radiation dose (rems)	Triage category allocation for radiation injuries only	Population @ 4 hrs	Population @ 24 hrs
>1000	Expectant	0	0
>600-1000	Expectant	0	65,817
>200-600	Immediate	87,780	1,044,833
>50-200	Minimal B	876,304	611,845
<50	Minimal A	1,235,546	8,770,112
TOTAL		**2,199,630**	**10,492,617**

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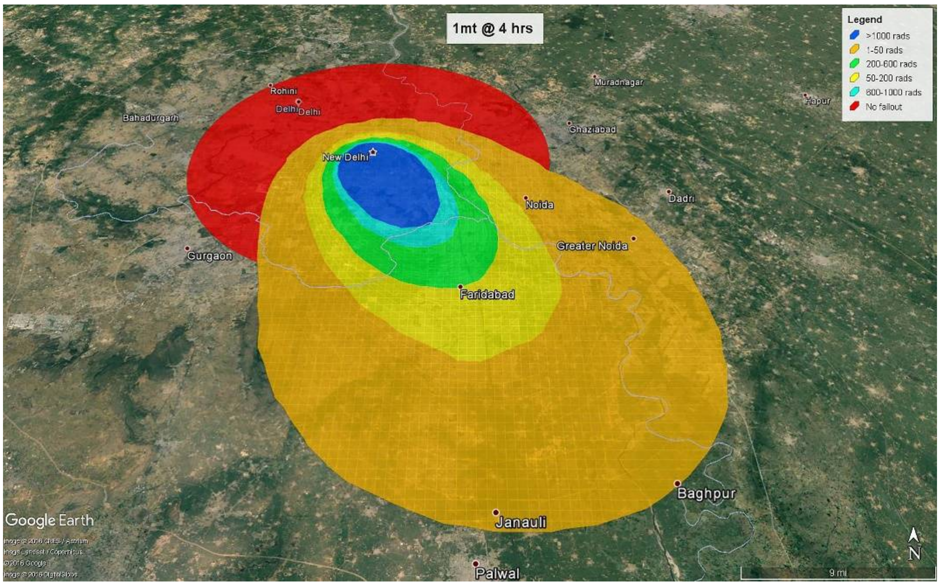
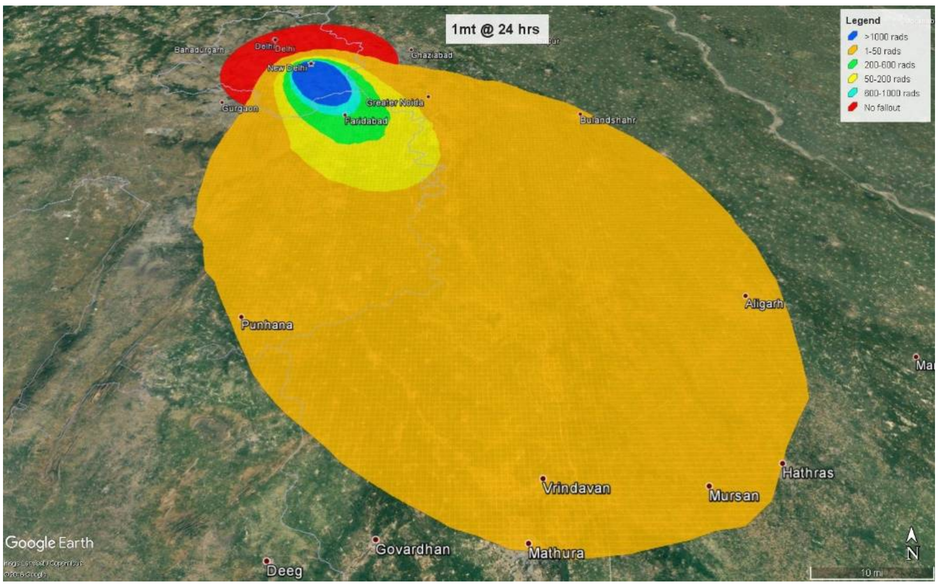
The effect circles for a 1mt nuclear detonation not only cover most of Delhi, but also encompass areas in the neighboring states of Haryana and Uttar Pradesh as shown in Figure 5.

Figure 5. 1mt fallout radiation plume at 4 hours



Of the 18.7 million people that may be expected to have injuries within 4 hours, slightly more than 13 million (70%) are eligible for triage whereas the remaining 5.5 million (30%) would not be accessible for triage. From the triageable population, 6.68 million (36%) are assigned to minimal, 4.94 million (26%) to immediate, and 1.55 million (8%) to expectant. At 4 hours, the fallout radiation plume will extend almost 38 kilometers (24 miles) into the neighboring state of Haryana with some amount of fallout radiation spilling over into another neighboring state, Uttar Pradesh (Figure 5). At 24 hours, the plume crosses Haryana, extends almost 78 kilometers (48 miles) into Uttar Pradesh, and spreads to Haryana's neighboring state of Rajasthan (Figure69).

Figure 6. 1mt fallout radiation plume at 24 hours



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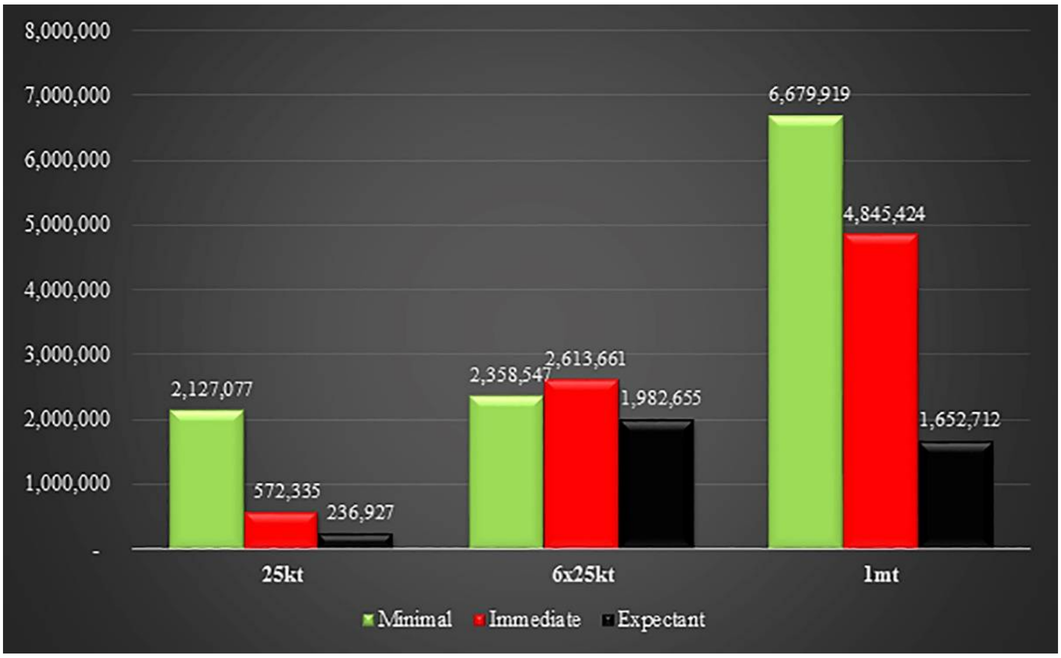
Of the 2.2 million people affected by fallout radiation at 4 hours' post-detonation, 2.12 million (96%) people will be triaged as minimal. 87,780 (4%) will be triaged as immediate based on their radiation exposure levels of 2-6 Gy. Interestingly, in this thermonuclear detonation, the fallout radiation levels greater than 6 Gy lies completely within the effect circles and therefore, there are no individuals affected *only* by fallout radiation greater than 6 Gy. Consequently, there are no expectant individuals at 4 hours, that is, there are no surviving patients who are receiving an eventually lethal dose of radiation without other life-threatening injuries. At 24 hours, the fallout plume affects approximately 10.5 million people from which approximately 9.4 million (89.5%) individuals will be exposed to radiation levels ranging from 0.01-2 Gy, categorized in the minimal triage category. Slightly more than one million (10%) individuals receiving 2-6 Gy will be categorized as immediate, and 66,000 (0.5%) individuals receiving more than 6 Gy will be assigned to the expectant category.

3.6 Comparison of 25kt, 6x25kt, and 1mt casualties

The number of combined injuries based on triage assignments for all three weapon yields are shown in Figure 7. Interestingly, the number of individuals requiring minimal medical care are similar between the single 25kt and the 6x25kt weapons. However, there is an exponential rise in the immediate and expectant triage category numbers between these two weapon sizes. The difference between 6x25kt and the 1mt weapons is even more dramatic for the minimal and immediate triage categories.

Figure 7. Number of combined injuries based on triage assignments for three weapon yields.



Interestingly, the number of individuals requiring minimal medical care are similar between the single 25kt and the 6x25kt weapons. However, there is an exponential rise in the immediate and expectant triage category numbers between these two weapon sizes. The difference between 6x25kt and the 1mt weapons is even more dramatic for the minimal and immediate triage categories. However, the expectant population in the 1mt scenario is less than that in the 6x25kt setting. This is likely due to the intentional inclusion of major population clusters for the 6x25kt simulation compared to the 1mt detonation which is simply geographically located in the center of New Delhi.

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Therefore, the number of expectants may increase significantly if large population groups are specifically targeted by the 1mt weapon by nuclear war planners rather than political targets. The populations requiring immediate medical attention in the 6x25kt and the 1mt situations will be massive, approximately 2.7 million and 4.9 million respectively. It is virtually certain that sufficient human and medical resources would not be available to care for such large numbers of people.

Fallout radiation exposures at 4 hours and 24 hours based on triage assignments are provided (Figures 8 and 9.

Figure 8. Fallout radiation exposure at 4 hours based on triage assignments.

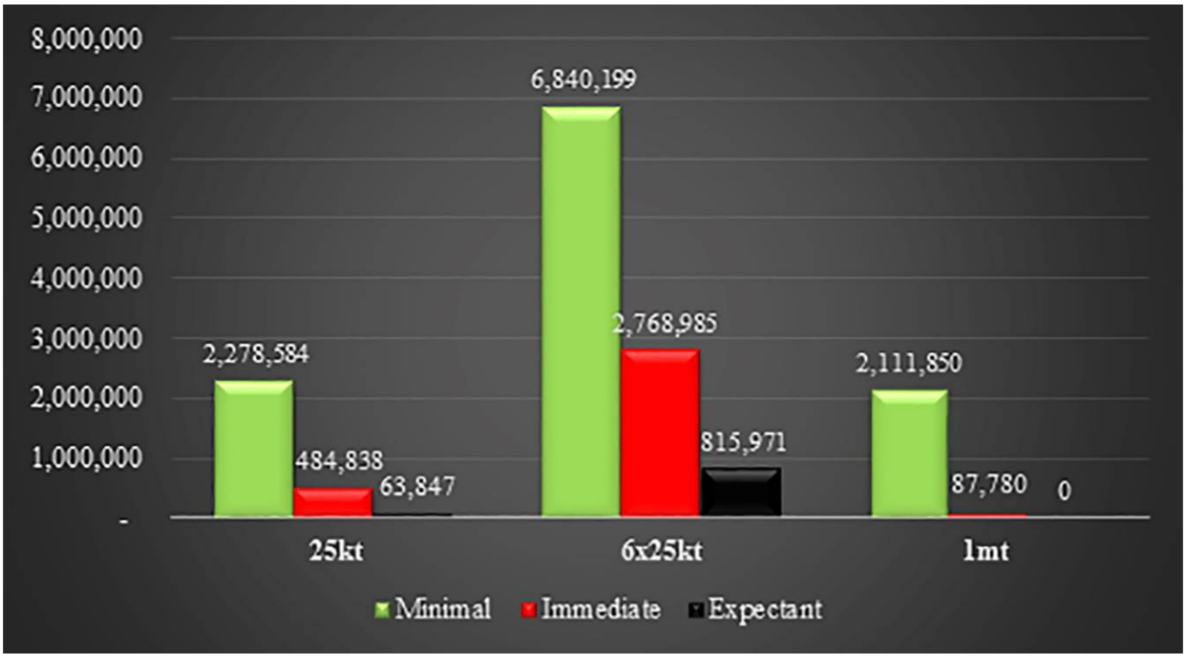
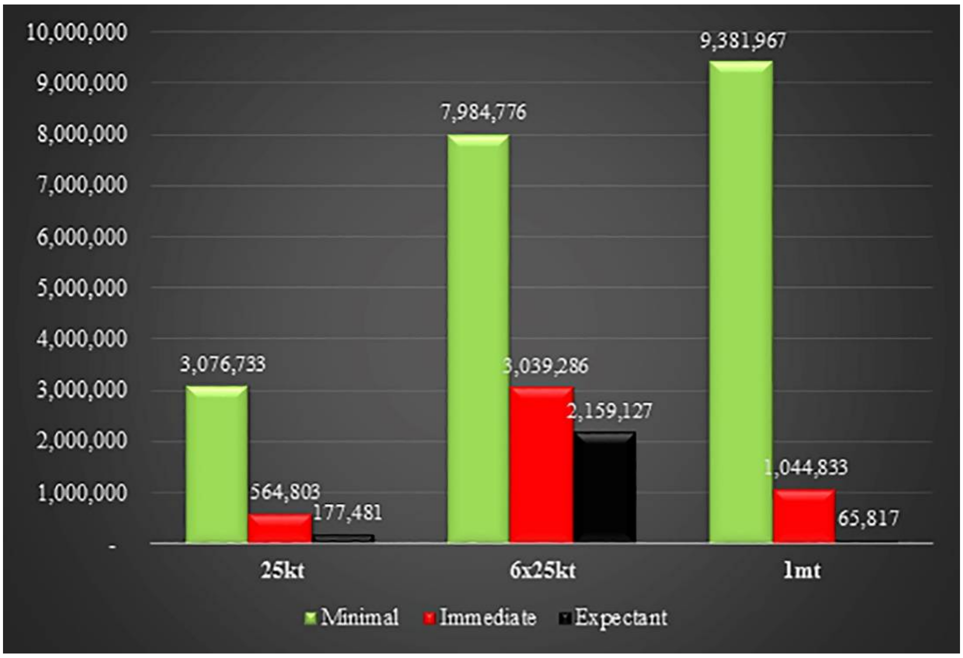


Figure 9. Fallout radiation exposure at 24 hours based on triage assignments.



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Individuals exposed to 2-6 Gy of fallout radiation are categorized as requiring immediate medical attention. At 4 hours, almost half a million individuals will be categorized as immediate in the single 25kt simulation compared to 88,000 people in the 1mt situation. This anomaly is because at 4 hours, most of the 2-6 Gy radiation plume in the 1 mt weapon falls within the blast and thermal zones. At this time point, only a few people are exposed solely to fallout radiation for the 1mt weapon compared to the single 25kt weapon. The above mentioned situation is reversed 24 hours after detonation as the 1mt fallout plume spreads over a greater area than the 25kt plume. The 6x25kt weapons scenario contains the maximum number of people affected by 2-6 Gy of radiation, but in contrast to combined injuries, many of these people could potentially be removed by swift evacuation away from the radiation plume.

Discussion

Each of the three simulation models for a nuclear attack on New Delhi will have a direct impact on the central government infrastructure of India with subsequent political and bureaucratic paralysis. The single 25kt nuclear simulation will involve central, south, and south-west Delhi which are some of the more affluent areas of the city. It is probable that buildings and houses in these areas are constructed using modern methods and materials and may offer some protection from the 0.6 psi blast overpressure, although there may be significant injuries from glass breakage. The six 25kt and 1mt scenarios will also involve some of the most densely populated areas in the city, including slum areas. The main concern from a 0.6 psi blast wave in slums is the potential for decapitating traumatic injuries. Slum construction consists of materials such as sheet metal for roofs which can easily turn into deadly projectiles from a 0.6 psi blast wave. Consequently, although the number of victims in the minimal triage category are almost similar in the single 25kt (2.1 million) and the six 25kt (2.3 million) scenarios, it is possible that individuals categorized as minimal may present with more serious traumatic injuries than expected in the latter simulation. The 1mt weapon will cover more than two-thirds of Delhi, increasing the number of individuals in the minimal triage category (6.6 million) almost three times compared to the 25kt simulations.

There is a massive increase in the number of victims assigned to the immediate triage category, from approximately 0.5 million (single 25kt weapon) to 2.7 million (six 25kt weapons) to 4.9 million (1mt weapon). Structures in the more affluent areas impacted by the single 25kt weapon may offer some protection against 2^{nd} and 3^{rd} degree burns, reducing the number of people requiring immediate medical attention. The reverse may be true in the six 25kt and 1mt situations as the flimsy slum construction will not provide the same level of protection from burn injuries. The highest number of victims in the expectant triage category due to combined injuries are observed in the six 25kt simulation (1.8 million). However, the 1mt simulation contains the highest number of individuals considered inaccessible for triage (5.5 million) which would include a significant number of fatalities.

Of the three separate simulations, the 1mt weapon will result in the maximum number of combined injuries, whereas the six 25kt weapons will affect the highest number of people due to the fallout radiation plume. Despite the greater spread of the fallout plume in the 1mt weapon at 24 hours, only about 1 million individuals could be exposed to 2-6 Gy requiring immediate medical attention compared to approximately 3 million people in the six 25kt scenario.

Emergency management of nuclear detonations in an urban setting is influenced by a number of factors such as availability of medical personnel and resources, evacuation capabilities,

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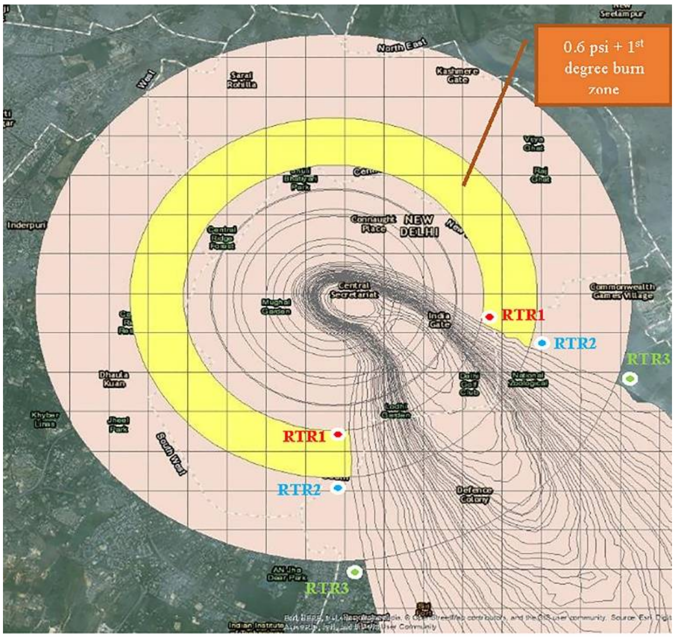
and dissemination of information to the general public regarding the incident. Millions of people categorized even to the minimal triage group will require basic care such as first aid and debridement of wounds. In order to conserve the limited number of medical personnel for those requiring intensive care, ancillary healthcare groups such as dentists and veterinarians could be trained in burn triage and wound debridement [15]. Additionally, the vast number of medical, dental, nursing, pharmacy, and veterinary schools around the country could train students in burn triage and mass casualty approaches to first aid procedures. Deployment of medical personnel and emergency workers to the affected areas will also require a high degree of planning. The **R**adiation **Tr**iage, **Tr**ansport, and **Tr**eatment (RTR) system developed by a US federal interagency working group can be used as a functional model to guide emergency operations after a nuclear detonation event. The primary objective of the RTR model is the efficient organization and deployment of personnel and resources [16]. Typically, RTR1 sites are located as close as possible to the blast epicenter which would mean deployment of personnel within the radiation field. The latest protective action guidelines (PAGs) published by the US Environmental Protection Agency for emergency workers in a radiological environment allows for radiation exposure levels up to 0.25 Gy for life-saving interventions [17]. Therefore, it would be prudent to set up RTR1 sites at the inner periphery of the 0.6 psi and 1st degree burn zone adjacent to (but not in) the fallout plume as shown in Figure 10.

Figure 10. Potential RTR site locations



Survivors requiring immediate medical attention can be treated at RTR1 sites. Specialized teams equipped with radiation monitors, personal protective equipment such as respiratory protection (N95 respirator or higher), and universal precautions such as gloves, light weight covering (to keep off radioactive dust), and booties [18] would decontaminate patients coming out of the radioactive areas and treat patients. It is unlikely that there will be enough personnel to actually go into contaminated areas to gather more patients as the RTR1 sites are expected to have overwhelming numbers of immediate category patients. Brief forays into the fallout plume to rescue survivors might be considered, but only when there is relatively low contamination and the

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time spent there is minimal. RTR2 sites will cater to the victims requiring minimal medical care. These sites could be located on the outer perimeter of the 0.6 psi plus 1st degree burn zone adjacent to (but not in) the fallout plume. RTR3 sites are located away from the prompt and fallout radiation zones. Most victims at RTR3 sites will be ambulatory with minor injuries and insignificant radiation exposure (note that the public is likely to consider any detectable radioactivity as significant, but from a healthcare point of view, low levels of exposure are not expected to result in long term effects). Major activities at these sites will involve symptomatic treatment and evacuation of victims. Therefore, RTR3 sites can be located just outside the blast and fallout zones to assist in evacuation efforts.

Triage and treatment of wounded survivors should be complimented by evacuation efforts, particularly for populations projected to be in the path of the fallout radiation plume. Three major factors will influence evacuation of victims. The projected path of the fallout plume along with its extent of coverage should be identified as soon as possible. Simultaneously, potential evacuation routes should be quickly disseminated to emergency workers. Finally, many people in the fallout plume will self-evacuate and will have to be decontaminated, and then evaluated for the appropriate triage category once they reach an RTR site. Sheltering-in-place is a doctrinal approach used in many urban areas, but the selected shelter needs to provide adequate radiation protection as well as offer adequate water and security. An adequate shelter is defined as one which 'protects against acute radiation effects, and significantly reduces radiation dose to occupants during an extended period' [5]. Concrete, brick, and stone act as good shielding materials and therefore, basements, underground garages, and tunnels are considered adequate shelters capable of reducing fallout exposure dose by a factor of 10 or more [5]. However, having a water supply is likely to be problematic without foresight to that issue, and security for vulnerable populations is highly likely to be a serious problem.

Forward planning is required in order to create stockpiles of medical supplies that can be rapidly mobilized in case of a nuclear event, though this has not actually occurred to a significant extent in most urban areas. Dual-utility therapeutic materials with extended shelf-lives include medical supplies that can be used in mass casualty situations as well as for routine healthcare applications. Cytokines, antibiotics, anti-emetics, and many other products are considered dual-utility [19]. National medical stockpiles should be strategically located away from the most likely target areas (i.e. downtown buildings and military installations), and have adequate security (in particular for narcotics) to afford some degree of survivability in the chaotic initial hours following a nuclear attack.

Healthcare facilities that remain functional will have to be prepared to receive large numbers of wounded people requiring additional treatment. Most of the major government hospitals are located in Delhi proper and it is assumed that almost all of these institutions will become non-operational after a nuclear attack. Therefore, the burden of treating nuclear mass casualty victims will fall on some of the large private healthcare institutions that are peppered all over the outskirts of Delhi within the National Capital Region (NCR). The government could reinforce mass casualty preparedness in these institutions by offering training and education to their staff on nuclear triage and wound management because reassessment of initial triage assignments would be needed to identify patients with the greatest chances of survival. The psychological impact of a nuclear attack on medical personnel is an important consideration.

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Research has also shown that emergency responders are less familiar with situations involving nuclear/radiological exposure compared to other types of emergencies, highlighting the need for nuclear-specific training and education [20].

India's National Disaster Management Authority (NDMA) which is analogous to the US Federal Emergency Management Agency, has published guidelines for the management of nuclear and radiological emergencies including nuclear attacks [21]. Although specific actions and standard operating procedures to be undertaken in the event of a nuclear attack remain classified, the NDMA guidelines do provide some insight into nuclear incident preparedness at the national level. A network of 18 Emergency Response Centers (ERCs), each equipped with protective gear and radiation monitoring equipment, have been set up across India to respond to any type of nuclear emergency.

The ERCs are also tasked with providing timely guidance and advice to first responders. Additionally, basic training on nuclear-related events is being imparted to the National Disaster Relief Force (NDRF) teams and to Quick Reaction Teams (QRTs) of the Indian paramilitary forces. The Bhabha Atomic Research Center (BARC), India's premier nuclear research facility, has developed a host of 'smart' radiation monitoring systems with impact assessment capabilities which can quickly scan and monitor a contaminated area and present the outcomes in the form of a color-coded map. The Indian Defense Research and Development Organization (DRDO) has invested significant resources in developing detection equipment such as high-range radiation monitors for field use, personal dose monitors, and mobile systems such as nuclear field laboratories.

Interestingly, the NDMA guidelines also include a section on 'gap analysis' that elaborates on issues that remain to be adequately addressed in the nuclear/radiological domain. One of the primary issues identified in the gap analysis is the need for education, awareness, and training. The report concedes that currently the national education system does not include any instruction on nuclear/radiological emergencies and that the general public has very limited awareness of such issues. The report goes further claiming that 'Even the intelligentsia have misconceptions about nuclear energy in general'. Disaster management agencies will almost certainly face a lack of sufficient manpower and resources in case of a nuclear detonation. Therefore, creating awareness among the general public is probably the most efficient and cost-effective method in terms of preparedness for nuclear emergencies. However, communicating time-sensitive evacuation and safety information to the general public in the event of a nuclear disaster is critical and can only be accomplished via electronic media. It has been noted that while television has spread only to about 61% of Indian households, market penetration of public and commercial radio broadcasters is almost nationwide. The radio is still the primary means of disseminating electronic information in many rural parts of India and should be duly utilized to circulate official instructions in case of a nuclear emergency.

Another issue that creates additional obstacles to an appropriate response is the paucity of basic infrastructure such as good roads and effective disaster management communication systems. Currently, Indian roadways are ill-equipped to provide egress for a large number of people thereby hindering any potential evacuation efforts. Disaster management communication links between the

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local, state, and federal levels are thought to be neither dedicated nor adequate. However, the NDMA has taken concrete action in recent years to redress the communications issue by creating a dedicated National Disaster Communications Network (NDCN) which will provide fail-safe communications capability during disasters [22]. The need to identify potential locations where people can take shelter during a nuclear emergency is also mentioned in the gap analysis, though as in the United States, it is dubious that action has been taken in major urban areas. Other areas for improvement include creating a pool of radiological safety officers at the national level, strengthening the medical response mechanism, and creating disaster management plans specifically for some of the major Indian cities.

Conclusion

A nuclear strike on Delhi will not only lead to massive loss of life at the local level, but will also have a significant global impact in terms of environmental damage, economic upheaval, and the psychological trauma associated with nuclear war. While the need to bolster India's medical response and emergency management capabilities is apparent, and it is certain India will not have enough resources to treat millions of nuclear attack survivors in the critical immediate days after an attack, there are definitive steps that can be taken to move the nation's capability much further in the direction of saving lives and alleviating suffering. Concerted efforts to spread awareness among the general public, not only on the fundamentals of nuclear energy, but also on how to react to a nuclear incident should be top priority for the Indian government. Our research indicates that millions of people could be potentially saved from fallout radiation exposure by the simple act of evacuating in a timely manner. Effective evacuation however, will require a robust transportation infrastructure and efficient communication strategies to inform the general population. The establishment of emergency preparedness with RTR sites can accomplish a great deal in mobilizing existing and potentially future resources for maximizing emergency response with appropriate mass casualty triage approaches. Therefore, it is in India's best interest to rapidly develop and upgrade its aging infrastructure which would be beneficial during peacetime, but could potentially end up saving millions of lives in the aftermath of a nuclear attack.

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