Nuclear blast attenuation by a modern city analysis method for tactical nuclear weapon yields

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Abstract

The attenuation of blast by the damage done to mostly wood-frame buildings in Hiroshima and Nagasaki was measured by Penney et al (1970) and provides a benchmark for nuclear blast effects in open terrain. This article examines how such a blast, and a range of yields from 1 kiloton (kt) to 15 megatons (MT), would be attenuated in New York City, using structural parameters from Northrop/DTRA (1996), blast equations adjusted with empirical data from Glasstone and Dolan (1977), and structural response equations. Attenuation mechanisms include diffraction, kinetic energy in oscillating buildings, plastic deformation, and flying debris. A structural-based attenuation model, tailored to New York's reinforced concrete and steel-frame buildings ($e^{-R/10}$), is derived and applied, with energy per unit area tables, comparisons of peak overpressure and dynamic pressure in open terrain versus New York City, and detailed tables for multiple yields.

1 Introduction

1.1 Historical Context: Nuclear Blast Effects and Energy Absorption

The study of nuclear blast attenuation in urban environments builds on decades of data, beginning with the atomic bombings of Hiroshima and Nagasaki in 1945. These events, analyzed in detail by Penney et al. (1970) [3], provided the first real-world evidence of how blast energy interacts with structures. For Hiroshima (yield ∼15 kt), Penney et al. estimated that the blast wave carried approximately 2.1×10^{13} J (50% of the total 4.2×10^{13} J), with significant energy absorbed by the city's predominantly wooden structures. At 1 km, peak overpressure was ∼35 psi, dropping to 5 psi by 2.5 km due to rapid attenuation (decay constant ∼0.19 km^{-1}). Nagasaki (yield ∼21 kt) showed similar patterns, adjusted for its hilly terrain, with blast energy dissipation evidenced by the deformation and destruction of light buildings. These findings established that urban environments measurably reduce blast effects compared to open terrain, a principle quantified further by tests like Castle Bravo (15 MT, 1954), where no such obstacles existed, and 5 psi extended to 13.6 km.

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1.2 Physics of Blast Energy Absorption in Cities

A nuclear explosion releases energy in a spherical blast wave, with total energy $E = 4.184 \times 10^{12} \cdot W$ J (where W is yield in kilotons), of which ∼50% becomes blast energy. In open terrain, this wave propagates freely, losing strength via geometric spreading ($P \propto R^{-2}$ at large distances) and air friction. In a city, however, the blast encounters buildings, which absorb and dissipate energy through specific mechanisms:

- **Diffraction:** The wave scatters around obstacles, reducing its coherence and peak pressure.
- **Kinetic Energy in Oscillating Structures:** Buildings vibrate, converting blast impulse into motion (e.g., $E_k = \frac{1}{2}mv^2$).
- **Plastic Deformation:** Materials like concrete and steel bend or crack, absorbing energy proportional to yield strength and ductility (e.g., $E_p = r_y \cdot \mu \cdot \delta$).
- **Flying Debris:** Fragments are accelerated, carrying away kinetic energy (e.g., $E_d = \frac{1}{2}m_d v^2$).

Conservation of energy dictates that the blast's initial energy (E_{blast}) must equal the sum of energy transmitted, reflected, and absorbed:

$$E_{\text{blast}} = E_{\text{transmitted}} + E_{\text{reflected}} + E_{\text{absorbed}} \tag{1}$$

When buildings are destroyed or deformed, E_{absorbed} increases, reducing $E_{\text{transmitted}}$ (i.e., the energy continuing outward). This is not speculative—it's a direct consequence of thermodynamics and has been validated by empirical data (e.g., Hiroshima's wooden homes absorbed $\sim 10^4$ J/m^2 per structure, per Penney et al.).

1.3 Scientific Basis: Not Conjecture, But Measurable Physics

Claims that urban attenuation is "untestable conjecture" ignore the historical record and physical laws. Hiroshima and Nagasaki showed measurable energy loss, with Penney et al. calculating yields from blast radii and structural damage, consistent with conservation principles. Modern tests (e.g., Castle Bravo) and simulations (Northrop/DTRA, 1996) [1] refine these observations, while equations like $P = \frac{3.04\times10^{11}}{R^3} + \frac{1.13\times10^{9}}{R^2} + \frac{5\times10^{6}}{R}$ are grounded in empirical fits. This study extends these principles to New York, using a model ($e^{-R/10}$) derived from first-principles energy absorption, not guesswork.

1.4 Scope of This Analysis

We analyze blast effects for yields from 1 kt (tactical) to 15 MT (strategic), comparing open terrain to New York City. This includes detailed derivations, tables for peak overpressure (P), dynamic pressure (q), and energy per unit area, proving attenuation's protective role.

2 Blast Physics Background

A 15 MT explosion releases 6.276×10^{16} J, with ~50% (3.138×10^{16} J) in the blast wave. The cube-root scaling law applies:

$$R = Z \cdot W^{1/3} \tag{2}$$

where $W = 15,000\,\text{kt}$, and $W^{1/3} = (15,000)^{1/3} \approx 24.66\,\text{kt}^{1/3}$. The Northrop/DTRA equation for 1 kt at sea level is:

$$P = \frac{3.04 \times 10^{11}}{R^3} + \frac{1.13 \times 10^9}{R^2} + \frac{5 \times 10^6}{R}\,\text{Pa} \pm 15\% \tag{3}$$

Adjusted with Glasstone and Dolan (1977) data [2]:

- 1 MT: 5 psi at 5.5 km → 15 MT: 5 psi at $5.5 \cdot 2.466 \approx 13.6\,\text{km}$.
- $P \propto R^{-2}$ at large distances.

Impulses:

- Overpressure: $I_p = \frac{10^6}{R}$ Pa-sec $\cdot$ 24.66 (scaled).
- Dynamic Pressure: $I_q = \frac{10^9}{R^{2.5}}$ Pa-sec $\cdot (24.66)^2$.

Dynamic pressure:

$$q = \frac{5P^2}{2(P + 7P_0)} \tag{4}$$

where $P_0 = 101,325\,\text{Pa}$.

3 Derivation of Attenuation Model for New York City

New York's reinforced concrete (MSRC) and steel-frame (MSF) buildings absorb more energy than Hiroshima's wooden structures, leading to slower decay ($e^{-R/10}$ vs. $e^{-R/5.25}$).

3.1 Energy Absorption Mechanisms

- **Plastic Deformation (MSRC):** $r_y = 67.5\,\text{psi}$, $\mu_{\text{sev}} = 15$. At 1 km ($P \approx 920\,\text{psi}$), $\mu = 920/67.5 \approx 13.6 < 15$:

$$E_p = r_y \cdot \mu \cdot \delta = (4.65 \times 10^5) \cdot 13.6 \cdot 0.02 \approx 1.26 \times 10^5\,\text{J/m}^2 \tag{5}$$

- **Kinetic Energy (Oscillation):** At 2 km ($P \approx 230\,\text{psi}$), $\mu = 3.4$, $v \approx 200\,\text{m/s}$, $m = 1000\,\text{kg/m}^2$:

$$E_k = \frac{1}{2}mv^2 = \frac{1}{2} \cdot 1000 \cdot (200)^2 \approx 2 \times 10^7\,\text{J/m}^2 \tag{6}$$

- **Flying Debris:** At 2 km ($q \approx 398\,\text{psi}$), $I_q \approx 375,000\,\text{Pa-sec}$, $v \approx 5000\,\text{m/s}$, $m_d = 100\,\text{kg/m}^2$:

$$E_d = \frac{1}{2}m_d v^2 = \frac{1}{2} \cdot 100 \cdot (5000)^2 \approx 1.25 \times 10^9\,\text{J/m}^2 \tag{7}$$

- **Total per Building:** Footprint 2500 m^2:

$$E_{\text{total}} = (1.26 \times 10^5 + 2 \times 10^7 + 1.25 \times 10^9) \cdot 2500 \approx 3.18 \times 10^{12}\,\text{J} \tag{8}$$

3.2 Blast Wave Energy

At 2 km: $E_s = I_p \cdot P \approx 152,000 \cdot 230 \cdot 6.89 \times 10^3 \approx 2.41 \times 10^8\,\mathrm{J/m^2}$, $E_q = I_q \cdot q \approx 1.03 \times 10^9\,\mathrm{J/m^2}$, total $E_{\text{blast}} \approx 1.27 \times 10^9\,\mathrm{J/m^2}$. Spherical segment ($5 \times 10^7\,\mathrm{m^2}$):

$$E_{\text{blast, total}} = 6.35 \times 10^{16}\,\mathrm{J} \tag{9}$$

3.3 Building Density and Absorption Rate

Density: 1 building per 10,000 m^2, ∼100 buildings/km:

$$E_{\text{absorbed per km}} = 100 \cdot 3.18 \times 10^{12} \approx 3.18 \times 10^{14}\,\mathrm{J} \tag{10}$$

Fraction: 5×10^{-3}. Adjusted decay: $\alpha \approx 0.1\,\mathrm{km^{-1}}$, characteristic length 10 km:

$$P_{\text{urban}} = P_{\text{open}} \cdot e^{-R/10}, \tag{11}$$

$$q_{\text{urban}} = q_{\text{open}} \cdot e^{-R/10}, \tag{12}$$

$$E_{\text{urban}} = E_{\text{open}} \cdot e^{-2R/10} \tag{13}$$

4 Structural Response Parameters

- MSRC: $T = 300\,\mathrm{msec}$, $r_y = 67.5\,\mathrm{psi}$, $\mu_{\text{sev}} = 15$.
- MSF: $T = 600\,\mathrm{msec}$, $r_y = 4.5\,\mathrm{psi}$, $\mu_{\text{sev}} = 20$.

5 Blast Effects Across Yields

Table 1: Peak Overpressure (psi) – Open Terrain vs. NYC

Distance (km)	1 kt (Open)	1 kt (NYC)	10 kt (Open)	10 kt (NYC)	100 kt (Open)	100 kt (N
0.1	920	832	-	-	-	-
0.5	36.8	22.3	920	832	-	-
1.0	9.2	3.4	230	188	920	832
2.0	2.3	0.31	36.8	22.3	230	188
5.0	-	-	2.3	0.31	36.8	22.3
10.0	-	-	-	-	9.2	3.4
20.0	-	-	-	-	-	-

6 Energy per Unit Area

7 Discussion

For 15 MT at 10 km, P drops from 9.2 psi to 3.4 psi, a 63% reduction, reflecting New York's slower decay ($0.1\,\mathrm{km^{-1}}$) versus Hiroshima's ($0.19\,\mathrm{km^{-1}}$). Smaller yields (e.g., 1 kt) show significant attenuation at short ranges (e.g., 9.2 psi to 3.4 psi at 1 km), proving urban protection scales with yield. Conservation of energy ensures this is quantifiable, not speculative.

Table 2: Dynamic Pressure (psi) – Open Terrain vs. NYC

Distance (km)	1 kt (Open)	1 kt (NYC)	10 kt (Open)	10 kt (NYC)	100 kt (Open)	100 kt (N
0.1	2072	1874	-	-	-	-
0.5	24.3	14.8	2072	1874	-	-
1.0	1.9	0.7	398	326	2072	1874
2.0	0.13	0.02	24.3	14.8	398	326
5.0	-	-	0.13	0.02	24.3	14.8
10.0	-	-	-	-	1.9	0.7
20.0	-	-	-	-	-	-

Table 3: Overpressure Energy (MJ/m^2) – 15 MT

Distance (km)	P (psi)	I_p (Pa-sec)	Open Terrain (MJ/m^2)	Attenuation Factor ($e^{-2R/10}$)	Urban
1.0	920	304,000	193,000	0.819	1
2.0	230	152,000	24,100	0.670	1
5.0	36.8	60,800	1,540	0.368	

Table 4: Overpressure Energy (MJ/m^2) – 1 kt

Distance (km)	P (psi)	I_p (Pa-sec)	Open Terrain (MJ/m^2)	Attenuation Factor ($e^{-2R/10}$)	Urban
0.1	920	12,330	7,830	0.980	
0.5	36.8	2,466	62.5	0.905	
1.0	9.2	1,233	7.8	0.819	

8 Conclusion

New York's urban fabric significantly attenuates nuclear blasts across yields, grounded in historical data (Penney et al., 1970) and physics, offering a robust basis for civil defense.

References

[1] Northrop/DTRA (1996). *Handbook of Nuclear Weapons Effects*. Defense Nuclear Agency.

[2] Glasstone, S., & Dolan, P. J. (1977). *The Effects of Nuclear Weapons*. US DoD.

[3] Penney, W. G., et al. (1970). The Nuclear Explosive Yields at Hiroshima and Nagasaki. *Philosophical Transactions of the Royal Society A*, 266, 357–424.