# MODELO TNT EQUIVALENTE

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Acúmulo muito grande de energia que é rapidamente liberada.

A liberação rápida de energia é feita através de vários mecanismos, tais como a **formação de uma onda de pressão**, **lançamento de projéteis**, **energia térmica,** etc.

É a grande quantidade de energia liberada em um curto espaço de tempo que causa os danos provenientes de uma explosão. Muitos danos são devidos a onda de choque (deslocamento de ar) que a explosão causa.

# MODELO TNT EQUIVALENTE

**Barotrauma**

Texto sobre vítimas de explosão:

http://link.springer.com/content/pdf/10.1007%2Fs00068-006-6039-8.pdf

http://www.springerlink.com/content/634424270242676m/fulltext.pdf

# MODELO TNT EQUIVALENTE

**Sobrepressão vs Danos as Estruturas**

| Pressure | | Damage |
|---|---|---|
| psig | kPa | |
| 0.02 | 0.14 | Annoying noise (137 dB if of low frequency, 10–15 Hz) |
| 0.03 | 0.21 | Occasional breaking of large glass windows already under strain |
| 0.04 | 0.28 | Loud noise (143 dB), sonic boom, glass failure |
| 0.1 | 0.69 | Breakage of small windows under strain |
| 0.15 | 1.03 | Typical pressure for glass breakage |
| 0.3 | 2.07 | "Safe distance" (probability 0.95 of no serious damage below this value); projectile limit; some damage to house ceilings; 10% window glass broken |
| 0.4 | 2.76 | Limited minor structural damage |
| 0.5–1.0 | 3.4–6.9 | Large and small windows usually shatter; occasional damage to window frames |
| 0.7 | 4.8 | Minor damage to house structures |
| 1.0 | 6.9 | Partial demolition of houses, made uninhabitable |
| 1–2 | 6.9–13.8 | Corrugated asbestos shatters; corrugated steel or aluminum panels, fastenings fail, followed by buckling; wood panels (standard housing), fastenings fail, panels blow in |
| 1.3 | 9.0 | Steel frame of clad building slightly distorted |
| 2 | 13.8 | Partial collapse of walls and roofs of houses |
| 2–3 | 13.8–20.7 | Concrete or cinder block walls, not reinforced, shatter |
| 2.3 | 15.8 | Lower limit of serious structural damage |
| 2.5 | 17.2 | 50% destruction of brickwork of houses |
| 3 | 20.7 | Heavy machines (3000 lb) in industrial buildings suffer little damage; steel frame buildings distort and pull away from foundations |
| 3–4 | 20.7–27.6 | Frameless, self-framing steel panel buildings demolished; rupture of oil storage tanks |
| 4 | 27.6 | Cladding of light industrial buildings ruptures |
| 5 | 34.5 | Wooden utility poles snap; tall hydraulic presses (40,000 lb) in buildings slightly damaged |
| 5–7 | 34.5–48.2 | Nearly complete destruction of houses |
| 7 | 48.2 | Loaded train wagons overturned |
| 7–8 | 48.2–55.1 | Brick panels, 8–12 in thick, not reinforced, fail by shearing or flexure |
| 9 | 62.0 | Loaded train boxcars completely demolished |
| 10 | 68.9 | Probable total destruction of buildings; heavy machine tools (7000 lb) moved and badly damaged, very heavy machine tools (12,000 lb) survive |
| 300 | 2068 | Limit of crater lip |

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**Fonte:**
**Annex 5 Determining the damage to humans from explosions using characteristic curves**
*Industrial Safety Series, Volume 8, 2008, Pages 347-351*

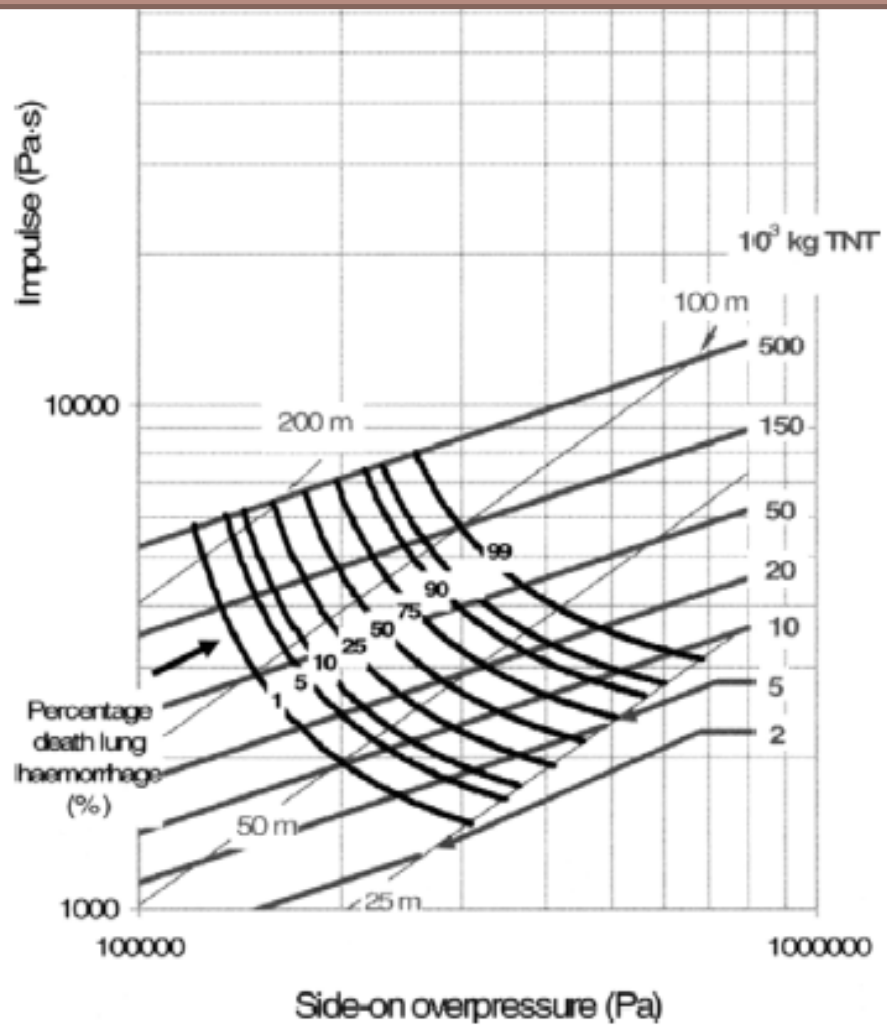


Fig. A-5-1. Percentages of exposed population that would die due to lung hemorrhage (black solid lines) as a function of distance ($d$) (thin grey lines) and TNT equivalent mass (thick grey lines). Taken from [1], by permission.

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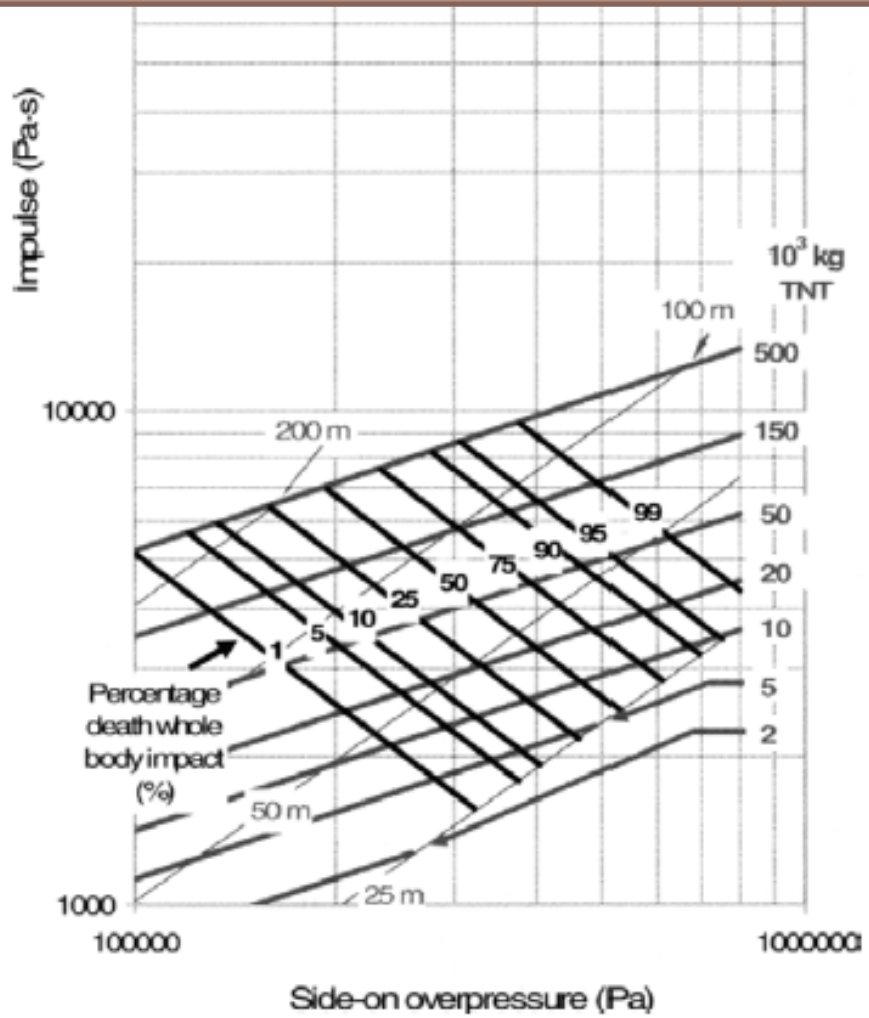
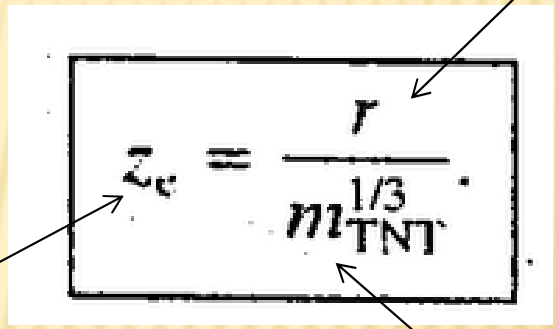



Fig. A-5-2. Percentages of exposed population that would die if their body hits a rigid object (black solid lines) as a function of distance (*d*) (thin grey lines) and TNT equivalent mass (thick grey lines). Taken from [1], by permission.

# MODELO TNT EQUIVALENTE

Estimando distância relativa:

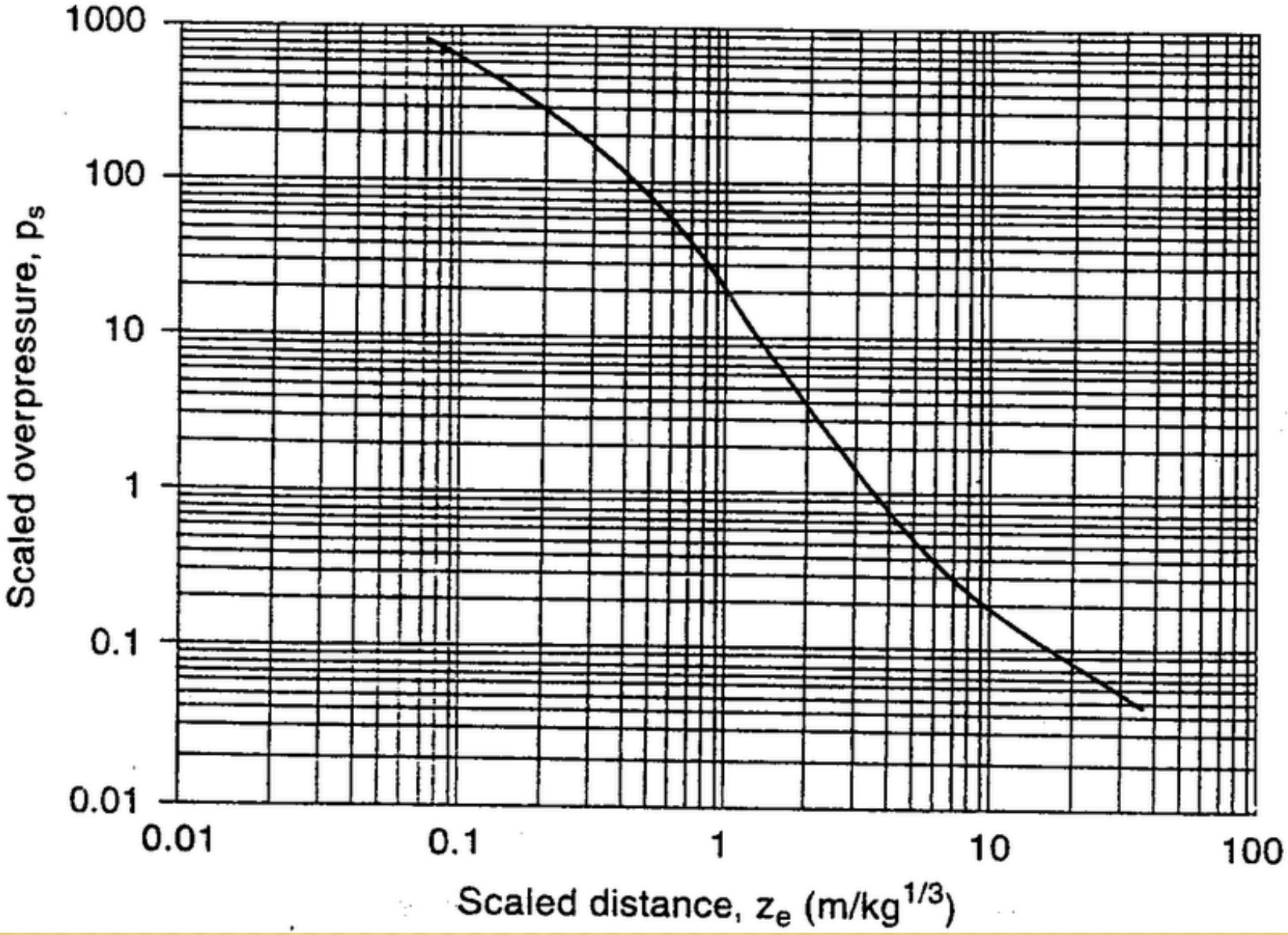
Distância até o explosivo (m)

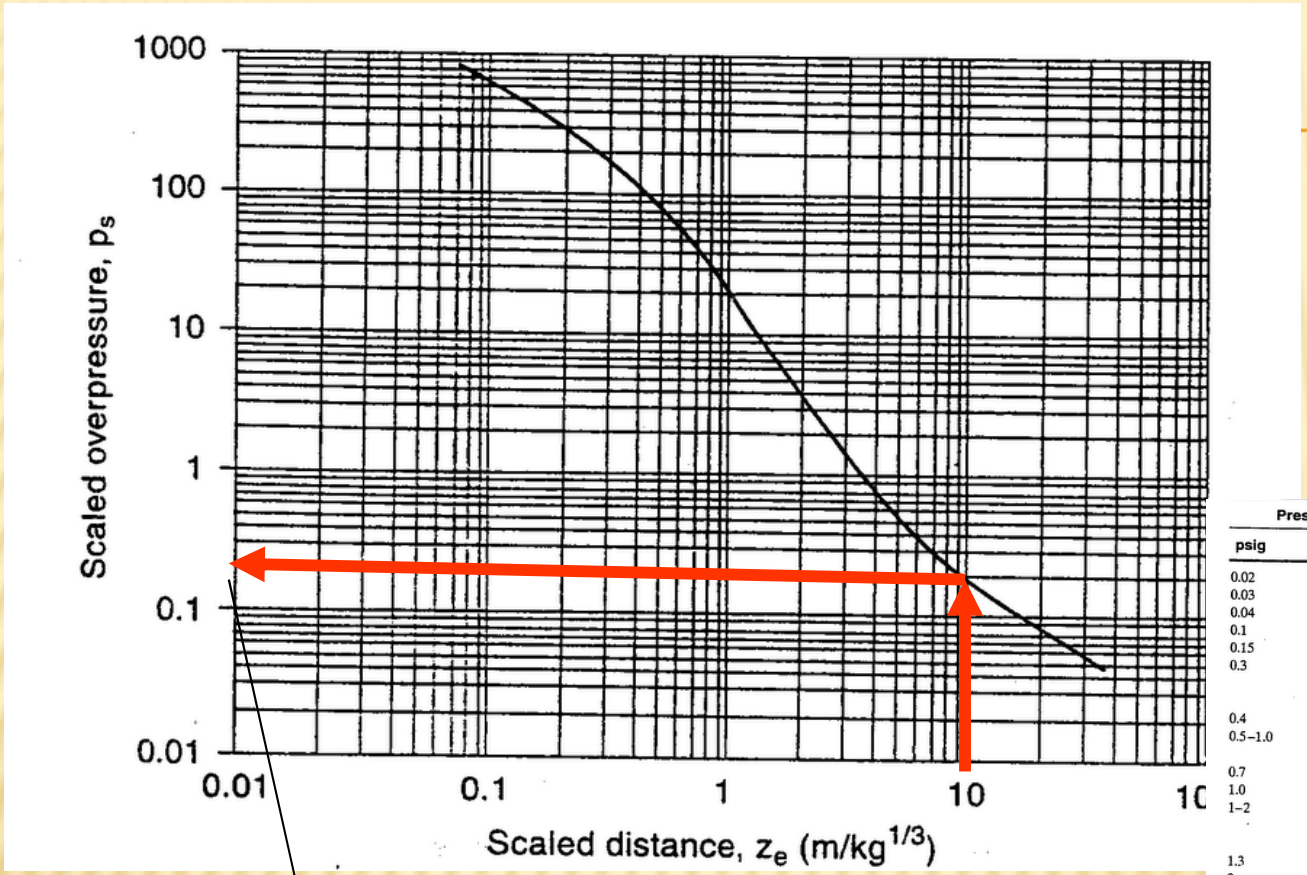



Distância relativa

Massa de TNT (kg)

Convertendo a distância relativa em sobrepressão relativa:



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0.2 * 101,3kPa
20.26 kPa

**Não esqueça dessa conversão!!!**
**(o gráfico é de sobrepressão relativa)**

# MODELO TNT EQUIVALENTE

**Exemplo:**

One kilogram of TNT is exploded. Compute the overpressure at a distance of 30 m from the explosion.

## Solution

The value of the scaling parameter is determined using Equation 6-21:

$$z_e = \frac{r}{m_{TNT}^{1/3}}$$

$$= \frac{30 \text{ m}}{(1.0 \text{ kg})^{1/3}} = 30 \text{ m kg}^{-1/3}.$$

From Figure 6-23 the scaled overpressure is 0.055. Thus, if the ambient pressure is 1 atm. then the resulting side-on overpressure is estimated at (0.055)(101.3 kPa) = 5.6 kPa (0.81 psi). From Table 6-9 this overpressure will cause minor damage to house structures.

# MODELO TNT EQUIVALENTE

**Massa Equivalente de TNT:**

Assumindo que a explosão de um combustível tem comportamento semelhante aquela gerada por TNT, podemos construir uma relação:

$$m_{TNT} = \frac{\eta m \Delta H_c}{E_{TNT}},$$

where

$m_{TNT}$ is the equivalent mass of TNT (mass),
$\eta$ is the empirical explosion efficiency (unitless),
$m$ is the mass of hydrocarbon (mass),
$\Delta H_c$ is the energy of explosion of the flammable gas (energy/mass), and
$E_{TNT}$ is the energy of explosion of TNT.

# MODELO TNT EQUIVALENTE

$\Delta H_c$ is the energy of explosion of the flammable gas (energy/mass).

| Compound | Formula | Energy of explosion[1] (kJ/mol) |
|---|---|---|
| Paraffin hydrocarbons | | |
| Methane | $CH_4$ | −818.7 |
| Ethane | $C_2H_6$ | −1468.7 |
| Propane | $C_3H_8$ | −2110.3 |
| Butane | $C_4H_{10}$ | −2750.2 |
| Isobutane | $C_4H_{10}$ | −2747.9 |
| Pentane | $C_5H_{12}$ | −3389.8 |
| Isopentane | $C_5H_{12}$ | −3383.3 |
| 2,2-Dimethylpropane | $C_5H_{12}$ | −3382.7 |
| Hexane | $C_6H_{14}$ | −4030.3 |
| Heptane | $C_7H_{16}$ | −4671.0 |
| 2,3-Dimethylpentane | $C_7H_{16}$ | −4662.9 |
| Octane | $C_8H_{18}$ | −5301.8 |
| Nonane | $C_9H_{20}$ | −5948.6 |
| Decane | $C_{10}H_{22}$ | −6588.9 |
| Olefins | | |
| Ethylene | $C_2H_4$ | −1332.4 |
| Propylene | $C_3H_6$ | −1959.0 |
| 1-Butene | $C_4H_8$ | −2600.6 |
| 2-Butene | $C_4H_8$ | −2594.1 |
| 1-Pentene | $C_5H_{10}$ | −3239.3 |
| Acetylenes | | |
| Acetylene | $C_2H_2$ | −1236.0 |
| Aromatics | | |
| Benzene | $C_6H_6$ | −3210.3 |
| Toluene | $C_7H_8$ | −3835.1 |
| *o*-Xylene | $C_8H_{10}$ | −4467.0 |
| Cyclic hydrocarbons | | |
| Cyclopropane | $C_3H_6$ | −1998.5 |

**Atenção:**

passe de moles para massa
antes de usar o valor na equação.

# MODELO TNT EQUIVALENTE

$E_{TNT}$ is the energy of explosion of TNT.

1120 cal/g = 4686 kJ/kg = 2016 BTU /lb

$\eta$ is the empirical explosion efficiency (unitless),

Nuvem de Propano: 5%
Nuvem de dietil eter: 10%
Nuvem de acetileno: 15%

# MODELO TNT EQUIVALENTE

- Sabendo a massa de combustível disponível é possível estimar os danos.

- Sabendo os danos causados é possível estimar a massa de combustível que originou a explosão.

# MODELO TNT EQUIVALENTE

**Exemplo:**

One thousand kilograms of methane escapes from a storage vessel, mixes with air, and explodes. Determine (a) the equivalent amount of TNT and (b) the side-on peak overpressure at a distance of 50 m from the blast. Assume an explosion efficiency of 2%.

**Solution**

**a.** Equation 6-24 applies. The energy of explosion for hexane is found in appendix B. Substituting into Equation 6-24, we obtain

$$m_{TNT} = \frac{\eta m \Delta H_c}{E_{TNT}} = \frac{(0.02)(1000\text{ kg})(1\text{ mol}/0.016\text{ kg})(818.7\text{ kJ/mol})}{4686\text{ kJ/kg}} = 218\text{ kg TNT.}$$

**b.** Equation 6-21 is used to determine the scaled distance:

$$z_e = \frac{r}{m_{TNT}^{1/3}} = \frac{50\text{ m}}{(218\text{ kg})^{1/3}} = 8.3\text{ m/kg}^{1/3}.$$

From Figure 6-23 (or Equation 6-23), the scaled overpressure is 0.25. Thus the overpressure is

$$p_o = p_s p_a = (0.25)(101.3\text{ kPa}) = 25\text{ kPa.}$$

This overpressure will demolish steel panel buildings.