UNIVERSITI SAINS MALAYSIA

Second Semester Examination
2011/2012 Academic Session

June 2012

EKC 463 – Advanced Process Safety Engineering
[Kejuruteraan Keselamatan Proses Lanjutan]

Duration : 3 hours
[Masa : 3 jam]

Please ensure that this examination paper contains SIX printed pages and FOUR printed pages of Appendix before you begin the examination.

[Sila pastikan bahawa kertas peperiksaan ini mengandungi ENAM muka surat yang bercetak dan EMPAT muka surat Lampiran sebelum anda memulakan peperiksaan ini.]

Instruction: Answer **ALL** questions.

*[**Arahan:** Jawab **SEMUA** soalan.]*

In the event of any discrepancies, the English version shall be used.

[Sekiranya terdapat sebarang percanggahan pada soalan peperiksaan, versi Bahasa Inggeris hendaklah digunapakai].

Answer ALL questions.
Jawab SEMUA soalan.

1. [a] Why the permit-to-work is important in term of plant safety?
Mengapa permit kerja adalah penting dari segi keselamatan loji?
[3 marks/markah]

[b] Why the cost of accidents are more expensive than cost of prevention?
Mengapa kos kemalangan adalah lebih mahal daripada kos pencegahan?
[4 marks/markah]

[c] Briefly discuss how employee/employer could participate in safety program.
Bincangkan secara ringkas bagaimana pekerja/majikan boleh mengambil bahagian dalam program keselamatan.
[6 marks/markah]

[d] A mixing vessel of 1 m^3 capacity was fitted with a hinged with counter-weighted lid as shown in Figure Q.1.[d].[i]. In order to empty the vessel, the lid has to be opened [Figure Q.1.[d].[ii]] and the vessel need to be rotated anti-clockwise so that the contents could shove out [Figure Q.1.[d].[iii]].

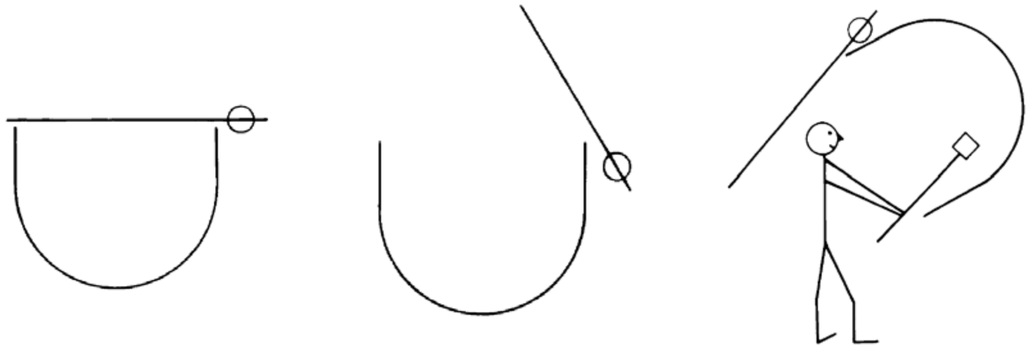
Sebuah bekas percampuran berkapasiti 1 m^3 telah dipasangkan dengan penutup berengsel balas seperti yang ditunjukkan dalam Rajah S.1.[d].[i]. Demi untuk mengosongkan bekas, penutupnya perlu dibuka [Rajah S.1.[d].[ii]] dan bekas tersebut perlu diputarkan pada arah lawan-jam supaya kandungannya boleh dikeluarkan [Rajah S.1.[d].[iii]].

One day the lid fell off and hit the man who was emptying the vessel. Fortunately his injuries were not serious. It was a fatigue failure where the welds between the lid and its hinges had cracked due to the strains set up by repeated opening and closing of the lid. There was nothing wrong with the original design but the lid had been modified one year ago before the incident occurred. In addition, some repairs carried out had not been to a high enough standard.

Pada suatu hari, penutupnya terjatuh dan terkena pada seorang lelaki yang sedang mengosongkan bekas tersebut. Beliau bernasib baik kerana kecederaannya tidak serius. Ia adalah kegagalan lesu yang disebabkan oleh retakan di antara kimpalan penutup dan engsel akibat daripada terikan yang berpunca daripada pembukaan dan penutupan berulang pada penutup tersebut. Rekabentuk asal tiada masalah tetapi penuntupnya telah diubahsuai setahun yang lalu sebelum kejadian ini berlaku. Tambahan pula, beberapa pembaikan telahpun dilakukan tetapi masih belum lagi mencapai tahap piawai.

Prepare a flow chart describing that incident and your recommendations for prevention/mitigation.

Sediakan satu carta aliran bagi menggambarkan kejadian tersebut dan cadangan anda untuk pencegahan/pengurangan.



[i] [ii] [iii]

Figure Q.1.[d].[i] The mixing vessel in use [ii] the lid is opened and [iii] the vessel is rotated so that the contents can be removed
Rajah S.1.[d].[i] Bekas percampuran dalam penggunaan [ii] penutupnya dibuka dan [iii] bekas itu diputarkan supaya kandungannya boleh dikeluarkan

[12 marks/markah]

2. [a] What is system safety concept? How it is different from fly-fix-fly approach?
Apakah konsep sistem keselamatan? Bagaimana ia berbeza daripada pendekatan terbang-tetap-terbang.

[3 marks/markah]

[b] What is the difference between the plant-specific data and generic data?
Apakah perbezaan antara data spesifik-loji dan data generik?

[3 marks/markah]

[c] [i] What do you understand about the failure severity?
Apakah yang anda faham tentang keparahan kegagalan?

[5 marks/markah]

[ii] Briefly discuss the “bathtub curve” used in analysis of an equipment failure rate.
Bincangkan secara rigkas “lengkung tab mandi” yang digunakan dalam analisis kadar kegagalan peralatan.

[5 marks/markah]

[iii] If the failure data for a motor transmission shows the beta (β) parameter is 1.0 and the characteristic life alpha (α) is 7500 hours. Estimate:

Jika data kegagalan untuk penghantaran motor menunjukkan parameter beta (β) ialah 1.0 dan alfa (α) hayat ciri ialah 7500 jam. Anggarkan:

(I) The reliability of the motor for an initial 7500 hours operating interval.
Kebolehpercayaan motor untuk permulaan 7500 jam sela operasi.

[3 marks/markah]

(II) The failure rate at 500 hours and 7500 hours, respectively.
Kadar kegagalan masing-masing pada 500 jam dan 7500 jam.

[6 marks/markah]

3. [a] Briefly describes two types of fire hazards that are commonly occur in chemical and process industries.

Jelaskan secara ringkas dua jenis bahaya kebakaran yang sering berlaku dalam industri kimia dan proses.

[3 marks/markah]

[b] With the aid of sketches, describe the difference between Solid Plume and Point Source radiation models.

Dengan bantuan lakaran, terangkan perbezaan antara model-model Sinaran Plum Padu dan Punca Titik.

[3 marks/markah]

[c] A pool fire incident has occurred in SCE Petrochemical Sdn Bhd due to the released of hydrocarbon H1. The hydrocarbon liquid escaped from a leak at a volumetric rate of 0.4 m^3s^{-1}. A circular dike with a 30 m diameter contained the leak. The result of the consequence analysis indicated that the radiation intensity of the pool fire was 15.0 kW/m^2 being experienced by a worker who stood 100 m away from the source. Estimate the heat of combustion of the liquid hydrocarbon by using the Point Source Model.

Suatu kebakaran berkolam terjadi di SCE Petrochemical Sdn. Bhd. disebabkan pembebasan hidrokarbon H1. Cecair hidrokarbon tersebut terbebas daripada satu kebocoran pada kadar isipadu 0.4 m^3s^{-1}. Satu takungan berbentuk bulat dengan garis pusat 30 m menakung kebocoran tersebut. Hasil daripada analisa impak menunjukkan keamatan sinaran daripada kebakaran berkolam itu adalah 15 kW/m^2, dirasakan oleh seorang pekerja yang berdiri sejauh 100 m daripada punca tersebut. Anggarkan haba pembakaran cecair hidrokarbon tersebut dengan menggunakan Model Punca Titik.

<u>Data:</u>

Heat of vaporization of the liquid	400	kJ/kg
Boiling point of the liquid	370	K
Ambient temperature	298	K
Liquid density	750	kg/m^3
Heat capacity of liquid (constant)	3.0	kJ/kg-K

<u>Data:</u>

Haba pengewapan cecair	*400*	*kJ/kg*
Takat didih cecair	*370*	*K*
Suhu persekitaran	*298*	*K*
Ketumpatan cecair	*750*	*kg/m^3*
Muatan haba cecair (pemalar)	*3.0*	*kJ/kg-K*

[19 marks/markah]

4. [a] Briefly outline the steps taken in conducting the Quantitative Risk Assessment.
Jelaskan secara ringkas langkah-langkah yang perlu diambil dalam menjalankan Penilaian Risiko Kuantitatif.

[5 marks/markah]

[b] Figure Q.4.[b].1. illustrates the Fault Tree diagram for the reactor system shown in Figure Q.4.[b].2. The jacketed reactor is cooled by redundant, 100 % capacity cooling pumps P1 and P2. During normal operation, both pumps are run at 50 % capacity. If all cooling is lost, the reactor will overheat and potentially explode.

Rajah S.4.[b].1. menunjukkan Pokok Kegagalan bagi sistem reaktor yang ditunjukkan dalam Rajah S.4.[b].2. Reaktor berjaket tersebut disejukkan dengan menggunakan pam P1 dan P2 yang berkapasiti 100% lelebih. Sewaktu operasi biasa kedua-dua pam beroperasi dengan kapasiti 50%. Sekiranya kesemua penyejuk hilang, reaktor tersebut akan panas lampau dan berpotensi untuk meletup.

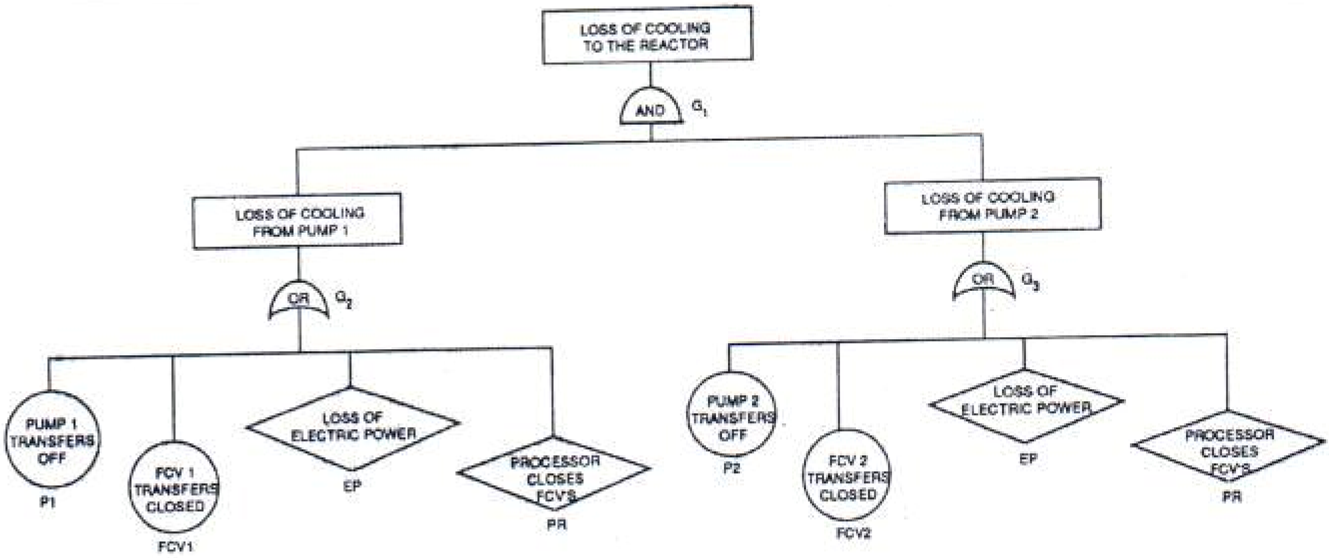


Figure Q.4.[b].1.
Rajah S.4.[b].1.

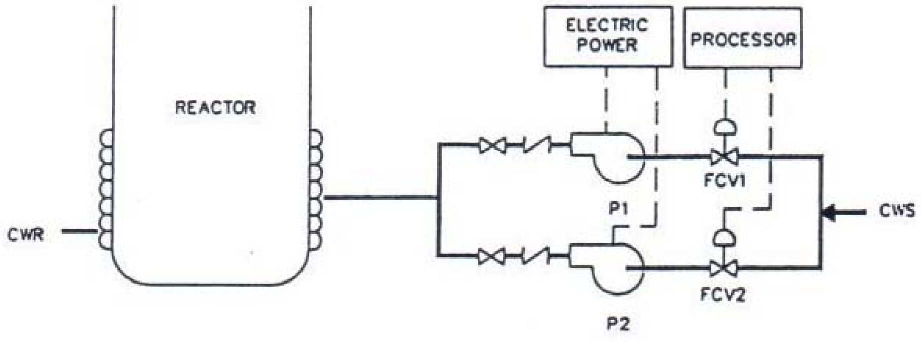


Figure Q.4.[b].2.
Rajah S.4.[b].2.

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Basic event	Description	Failure rate λ (hr^{-1})	Restoration time τ (hr)
FCV1	FCV-1 transfers closed	2.0×10^{-5}	4
P1	Pump 1 transfers off	4.0×10^{-4}	8
FCV2	FCV-2 transfers closed	2.0×10^{-5}	4
P2	Pump 2 transfers off	4.0×10^{-4}	8
EP	Loss of electric power	5.7×10^{-5}	2
PR	Processor closed FCVs	1.0×10^{-5}	4

Table Q.4.[b].[ii].
Jadual S.4.[b].[ii].

[i] Determine the combination of possible minimal cut set numbers for the Fault Tree diagram.

Tentukan kombinasi nombor set potongan minima yang mungkin bagi rajah Pokok Kegagalan tersebut.

[ii] Calculate the probability of the top event based on both minimal cut set and gate to gate methods using data in Table Q.4.[b].[ii].

Kirakan kebarangkalian bagi peristiwa teratas berdasarkan kedua-dua teknik set potongan minima dan get ke get dengan menggunakan data dalam Jadual S.4.[b].[ii].

[20 marks/markah]

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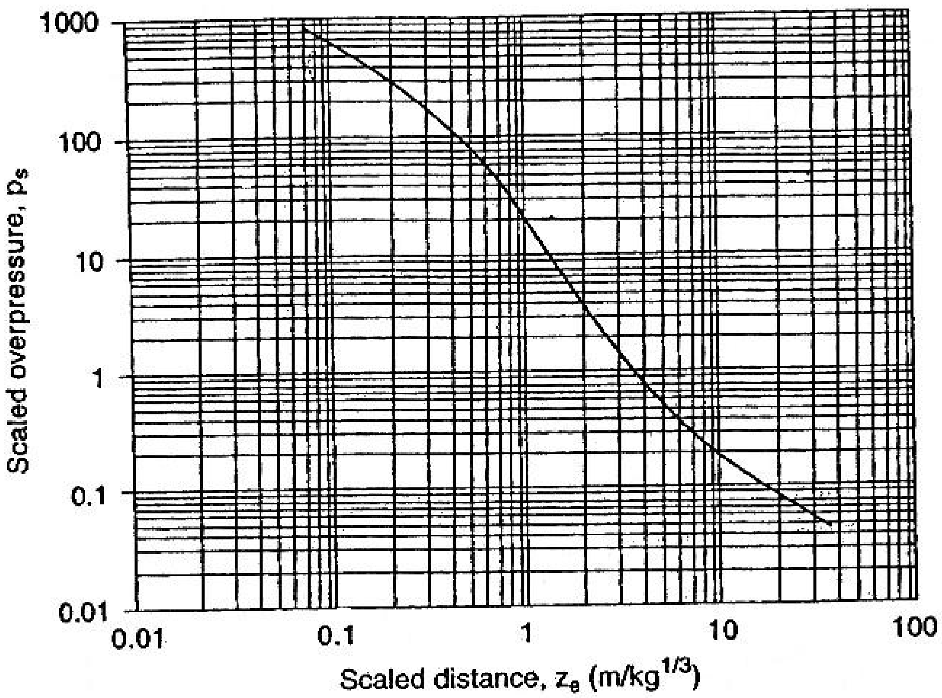
Appendix

$$C(x,y,z) = \frac{q}{2\pi\sigma_y\sigma_z v}\exp\left[-\frac{1}{2}\left(\frac{y}{\sigma_y}\right)^2\right]\exp\left[-\frac{1}{2}\left(\frac{H}{\sigma_z}\right)^2\right]$$

$$C(t) = \frac{qL}{vH}\left(1 - e^{(-vt/L)}\right)$$

$$\Delta H = \frac{2v_s r_s}{v}\left[1.5 + 2.68\times10^{-2} P\left(\frac{T_s - T_a}{T_s}\right)2r_s\right]$$



Correlation between scaled distance and explosion peak side-on overpressure foı a TNT explosion occurring on a flat surface. Source: G. F. Kinney and K. J. Graham, *Explosive Shocks in Air* (Berlin: Springer-Verlag, 1985).

$$\frac{p_o}{p_a} = \frac{1616\left[1 + \left(\frac{z_e}{4.5}\right)^2\right]}{\sqrt{1 + \left(\frac{z_e}{0.048}\right)^2}\sqrt{1 + \left(\frac{z_e}{0.32}\right)^2}\sqrt{1 + \left(\frac{z_e}{1.35}\right)^2}}$$

Volume Equivalents

in^3	ft^3	US gal	L	m^3
1	5.787×10^{-4}	4.329×10^{-3}	1.639×10^{-2}	1.639×10^{-5}
1728	1	7.481	28.32	2.832×10^{-2}
231	0.1337	1	3.785	3.785×10^{-3}
61.03	3.531×10^{-2}	0.2642	1	1.000×10^{-3}
6.102×10^4	35.31	264.2	1000	1

Ideal Gas Constant R_g

1.9872 cal/g-mol K
1.9872 Btu/lb-mol°R
10.731 psia ft^3/lb-mol°R
8.3143 kPa m^3/kg-mol K = 8.314 J/g-mol K
82.057 cm^3 atm/g-mol K = 8.2057×10^{-5} m^3 atm/mol K
0.082057 L atm/g-mol K = 0.082057 m^3 atm/kg-mol K
21.9 (in Hg) ft^3/lb-mol°R
0.7302 ft^3 atm/lb-mol°R
1545.3 ft lb_f/lb-mol°R

Gravitational Constant, g_c

32.174 ft-lb_m/lb_f-s^2
1 (kg m/s^2)/N
1 (g cm/s^2)/dyne

Miscellaneous

1 Poise = 100 centipoise = 0.1 kg/m s = 0.1 Pa s = 0.1 N s/m^2
1 N = 1 kg m/s^2
1 J = 1 N m = 1 kg m^2/s^2
1 centipoise = 1×10^{-3} kg/m s = 2.4191 lb/ft-hr = 6.7197×10^{-4} lb/ft s

TABLE Selected Rules of Boolean Algebra

Rule	Mathematical form
Commutative Rule	$A \cdot B = B \cdot A$ $A + B = B + A$
Associative Rule	$A \cdot (B \cdot C) = (A \cdot B) \cdot C$ $A + (B + C) = (A + B) + C$
Distributive Rule	$A \cdot (B + C) = A \cdot B + A \cdot C$ $A + (B \cdot C) = (A + B) \cdot (A + C)$
Idempotent Rule	$A \cdot A = A$ $A + A = A$
Rule of Absorption	$A \cdot (A + B) = A$ $A + A \cdot B = A$

Source Model

$$\frac{P_2 - P_1}{\rho} + \frac{g}{g_c}(z_2 - z_1) + \frac{1}{2g_c}(v_2^2 - v_1^2) + \sum e_f + \frac{W_s}{\dot{m}} = 0$$

$$e_f = K_f\left(\frac{v^2}{2g_c}\right)$$

$$K_f = \frac{K_1}{N_{RE}} + K_\infty\left(1 + \frac{1}{ID_{inches}}\right)$$

$$\dot{m} = AC_D\sqrt{2\rho g_c(P_1 - P_2)}$$

$$\dot{m} = \rho vA = \rho AC_D\sqrt{2\left(\frac{g_c P_g}{\rho} + gh_L\right)}$$

$$Q_m = C_o AP_o\sqrt{\left(\frac{2g_c M}{R_g T_o}\frac{\gamma}{\gamma - 1}\right)\left[\left(\frac{P}{P_o}\right)^{2/\gamma} - \left(\frac{P}{P_o}\right)^{(\gamma+1)/\gamma}\right]}$$

$$\frac{P_{choked}}{P_o} = \left(\frac{2}{\gamma - 1}\right)^{\gamma/(\gamma-1)}$$

$$(Q_m)_{choked} = C_o AP_o\sqrt{\left(\frac{g_c M}{R_g T_o}\right)\left[\left(\frac{2}{\gamma + 1}\right)^{(\gamma+1)/(\gamma-1)}\right]}$$

Dispersion Models

$$\langle C\rangle_{max} = \frac{\dot{m}}{\pi\sigma_y\sigma_z u}$$

$$\langle C\rangle_{ppm} = \frac{\dot{m}}{\pi\sigma_y\sigma_z u}\left[\frac{RT}{MP}\times 10^6\right]$$

$$\sigma_y = \exp\left[4.23 + 0.9222\ln\left(\frac{x}{1000}\right) - 0.0087\left[\ln\left(\frac{x}{1000}\right)\right]^2\right]$$

$$\sigma_x = \exp\left[3.414 + 0.7371\ln\left(\frac{x}{1000}\right) - 0.0316\left[\ln\left(\frac{x}{1000}\right)\right]^2\right]$$

Equations related to Fire Modeling

Pool Fires:

$$\dot{y}_{max} = 1.27\times 10^{-6}\frac{\Delta H_c}{\Delta H^*}$$

$$\Delta H^* = \Delta H_v + \int_{T_a}^{T_{BP}} C_p dT$$

$$m_B = 1\times 10^{-3}\frac{\Delta H_c}{\Delta H^*}$$

$$D_{max} = 2\sqrt{\frac{\dot{V}_L}{\pi\dot{y}}}$$

$$\frac{H}{D} = 42\left(\frac{m_B}{\rho_a\sqrt{gD}}\right)^{0.61}$$

$$E_{av} = E_m e^{-SD} + E_s\left(1 - e^{-SD}\right)$$

$$F_P = \frac{1}{4\pi x^2}$$

$$\tau_a = 2.02(P_W X_S)^{-0.09}$$

$$E_r = \tau_a Q_r F_P = \tau_a \eta m_B \Delta H_c A F_P$$

Jet Fires:

$$\frac{L}{d_j} = \frac{5.3}{C_T}\sqrt{\frac{T_f/T_j\left[C_T + (1 - C_T)\frac{M_a}{M_f}\right]}{\alpha_T}}$$

$$E_r = \tau_a Q_r F_p = \tau_a \eta\dot{m}\Delta H_c F_P$$

Equations related to Explosion Modeling

TNT Model

$$W = \frac{\eta M E_c}{E_{TNT}}$$

$$Z_e = \frac{R}{M_{TNT}}$$

$$P_S = \frac{P_o}{P_a}$$

TNO Model

$$\bar{R} = \frac{R}{(E/P_o)^{1/3}}$$

$$P_s = \Delta\bar{P}_s . P_o$$

$$t_+ = \bar{t}_+\left[\frac{(E/P_o)^{1/3}}{c_o}\right]$$

Damage Estimates for Common Structures Based on Overpressure (these values are approximations)[1]

Pressure		
psig	**kPa**	**Damage**
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

[1] V. J. Clancey, "Diagnostic Features of Explosion Damage," paper presented at the *Sixth International Meeting of Forensic Sciences* (Edinburgh, 1972).