UCRL-TM-202990

The NARAC Emergency Response Guide to Initial Airborne Hazard Estimates

Michael B. Dillon, Ronald L. Baskett, Kevin T. Foster, and Connee S. Foster

March 18, 2004

U.S. Department of Energy

Lawrence Livermore National Laboratory

University of California
Lawrence Livermore National Laboratory
Technical Information Department
Livermore, CA 94551

The authors would like to gratefully acknowledge the assistance of Mr. Steve Homann from Lawrence Livermore National Laboratory, Mr. William Storck and Mr. Michael McCoy from the Chemical and Engineering News, Dr. Ronald Rehm from NIST, Professor Patrick Pagni from U.C. Berkeley, Dr. Steve Pemberton from Los Alamos National Laboratory, Drs. Robert Jones and Mark Miller from NOAA, and the members of the 52nd Weapons of Mass Destruction Civil Support Team for their assistance in gathering and interpreting the information contained within this publication. The authors would also like to thank the City of Seattle Fire Department and Hazmat Team, the NOAA Hazmat team, and our colleagues at LLNL for their feedback and assistance on the initial drafts. We would particularly like to thank Dr. John Nasstrom for his helpful review, Mr. Michael Bradley assistance in classifying the content, and Dr. David Price and Ms. Lori Carroll for their helpful comments and source material.

DISCLAIMER

AUSPICES STATEMENT

This work was performed under the auspices of the U. S. Department of Energy by the University of California, Lawrence Livermore National Laboratory under Contract No. W-7405-Eng-48.

IMPORTANT NOTE

The NARAC Guide to Estimating Airborne Hazards is intended to provide emergency response professionals the tools necessary to convert observable quantities into qualitative data for use in assessing atmospheric hazards. As such, this method generates information that is inherently qualitative and should be used only when resource constraints preclude more accurate techniques.

This guide reproduces the tables and graphs found in the Observationally Based and Commonly Used section of the The iClient Companion (UCRL-TM-202991) with such changes necessary to ensure unlimited distribution of this document.

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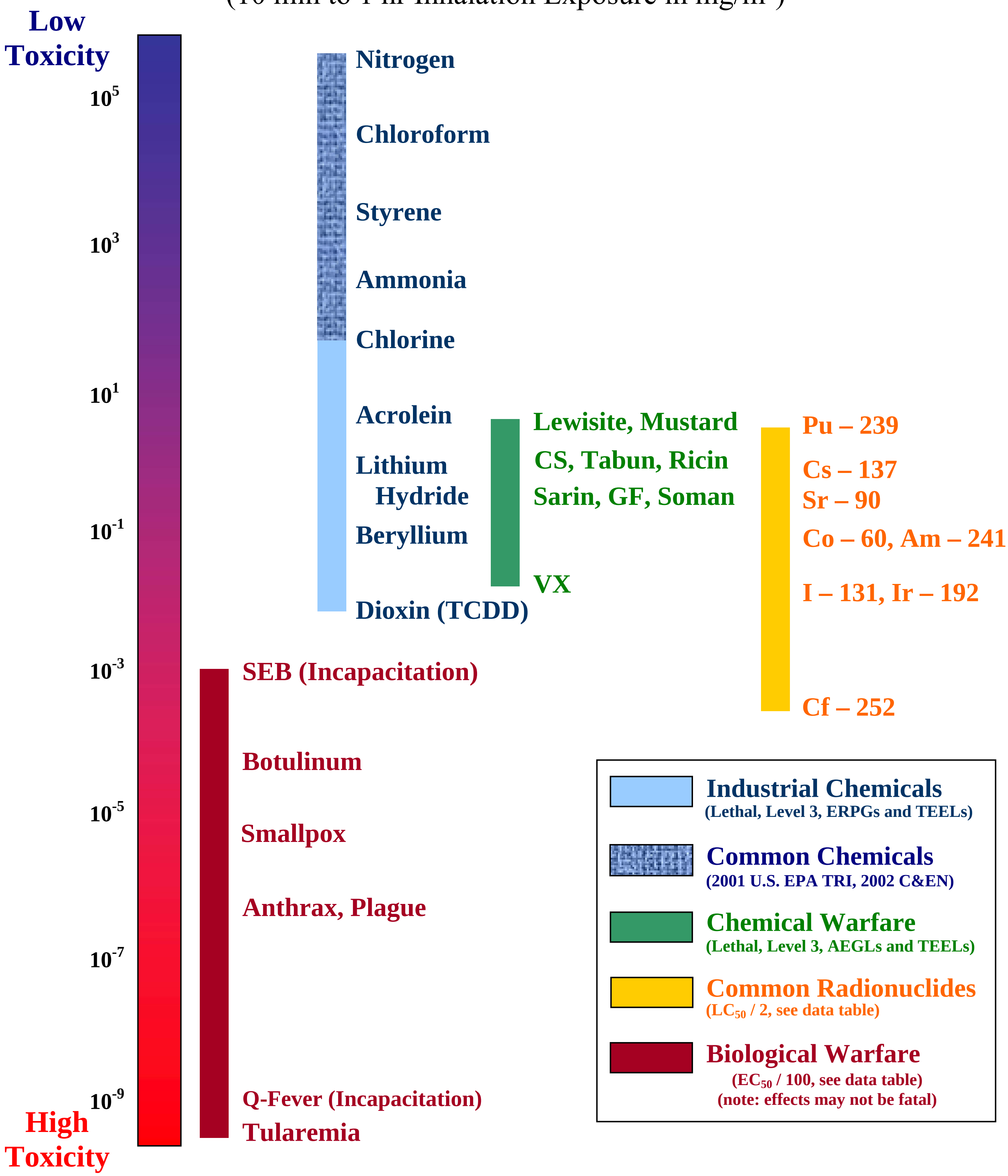
Acute Inhalation Toxicity

(10 min to 1 hr Inhalation Exposure in mg/m^3)



Acute Chemical and Biological Toxicity Data

(Inhalation Exposure, note: 1.5E+3 = $1.5x10^3$ = 1500)

Industrial Chemicals

Chemical Name	Level 3 (lethal)		Level 2 (major health effects)		Level 1 (minor health effects)		Reference
	mg/m^3	ppm	mg/m^3	ppm	mg/m^3	ppm	
Nitrogen	6.0E+5	5.2E+5	4.0E+5	3.5E+5	2.5E+5	2.2E+5	(a)
Chloroform	2.5E+4	5.1E+3	2.5E+2	5.1E+1	1.0E+1	2.0E+0	(b)
Styrene	4.3E+3	1.0E+3	1.1E+3	2.6E+2	2.1E+2	5.0E+1	(b)
Ammonia	5.3E+2	7.6E+2	1.1E+2	1.6E+2	1.8E+1	2.6E+1	(b)
Chlorine	6.0E+1	2.0E+1	7.5E+1	2.6E1	3.0E+0	1.0E+0	(b)
Acrolein	6.0E+0	2.6E+0	1.0E+0	4.4E-1	2.0E-1	8.7E-2	(b)
Lithium Hydride	5.0E-1	1.6E+0	1.0E-1	3.1E-1	2.5E-2	7.8E-2	(b)
Beryllium	1.0E-1	2.7E-1	2.5E-2	6.8E-2	5.0E-3	1.4E-2	(b)
Dioxin (TCDD)	7.5E-3	5.7E-4	7.5E-3	5.7E-4	1.5E-3	1.1E-4	(a)

Chemical Warfare

Chemical Name	Level 3 (lethal)		Level 2 (major health effects)		Level 1 (minor health effects)		Reference
	mg/m^3	ppm	mg/m^3	ppm	mg/m^3	ppm	
Lewisite	4.7E+0	5.5E-1	4.7E+0	5.5E-1	1.3E+0	1.5E-1	(a)
Mustard Gas	3.9E+0	6.0E-1	6.0E-1	9.2E-2	4.0E-1	6.2E-2	(c)
CS	2.0E+0	2.6E-1	4.0E-1	5.2E-2	4.0E-1	5.2E-2	(a)
Ricin	1.5E+0	5.6E-4	5.0E-1	1.9E-4	7.5E-2	2.8E-5	(a)
Tabun	7.6E-1	1.1E-1	8.7E-2	1.3E-2	6.9E-3	1.0E-3	(c)
Sarin	3.8E-1	6.6E-2	8.7E-2	1.5E-2	6.9E-3	1.2E-3	(c)
Soman	3.8E-1	5.1E-2	4.4E-2	5.9E-3	3.5E-3	4.7E-4	(c)
GF	3.8E-1	5.2E-2	4.4E-2	6.0E-3	3.5E-3	4.8E-4	(c)
VX	2.9E-2	2.7E-3	7.2E-3	6.6E-4	5.7E-4	5.2E-5	(c)

Biological Warfare

Biological Name	50% of exposed population infected (EC_{50} in mg/m^3)	Lethality[1] (%)	Incubation (Days)	Contagious	Reference
SEB	0.01 to 0.1	0	0.04 to 0.25		(d)
Botulinum	5E-3	100	0.5 to 1		(d)
Smallpox	5E-4	15 to 40	7 to 21	✓	(d)
Anthrax	5E-5	100	1 to 6		(d)
Plague	5E-5	100	2 to 3	✓	(d)
Q-Fever	1E-7	0 to 1	10 to 21		(d)
Tularemia	5E-7	5-60	2-10		(d)

[1] without medical attention

The Biological Warfare data has been normalized for a 10-min exposure. To be consistent with the ERPG and TEEL definitions, the values plotted in the Acute Inhalation Toxicity Graph are divided by 100.

(a) Temporary Emergency Exposure Limits (TEELs) for a 15-min exposure from USDOE SCAPA, Rev19, April 2003 (http://www.bnl.gov/scapa/).
(b) Emergency Response Planning Guidelines (ERPGs) for a 1-hour exposure as given in reference (a) above.
(c) Acute Exposure Guideline Levels (AEGLs) for a 10-min exposure from *Acute Exposure Guideline Levels for Selected Airborne Chemicals: Vols I, II, and III*, National Academy Press, 2001, 2002, and 2003, respectively.
(d) Chow, B.G., G.S. Jones, I. Lachow, J. Stillion, D. Wilkening, H. Yee, *Documented Briefing: Air Force Operations in a Chemical and Biological Environment (Project Air Force)*, RAND Corporation, ISBN 0-8330-2578-3, 1998, p. 29.

Commonly Released Chemicals

Chemical Name	Million Kg released into the Atmosphere in 2001	ERPG and TEEL Level 3 (lethal) mg/m^3	ppm	Pure Liquid Density (at °C) in g/cm^3	Aqueous Solution at 20-25 °C in g/cm^3
Hydrochloric Acid	270	224 [(b)]	150	1.19 (-85 °C) [(c)]	1.17 (35% wt) [(c)]
Methanol	80	6540 [(b)]	4990	0.787 (20 °C) [(c)]	0.916 (50% wt) [(d)]
Ammonia	55	525 [(b)]	750	0.682 (-33 °C) [(c)]	0.88 (35% wt) [(c)]
Sulfuric Acid	67	30 [(b)]	4.1	1.85 (25 °C) [(c)]	1.395 (50%) [(d)]
Toluene	33	3750 [(b)]	995	0.863 (25 °C) [(c)]	-
Hydrogen Fluoride	31	41 [(b)]	50	0.97 (20 °C) [(c)]	1.25 (80% wt) [(c)]
n-Hexane	21	4,000 [(a)]	1100	0.663 (20 °C) [(d)]	-
Xylenes	21	4000 [(a)]	920	0.87 (20 °C) [(c)]	-
Styrene	22	4260 [(b)]	1000	0.901 (25 °C) [(d)]	-

The list and amount of the compounds released (both fugitive and accidental) was taken from the *2001 Toxics Release Inventory (TRI) Public Data Release, Executive Summary* written by the U.S. EPA (www.epa.gov/tri/index.htm). The above table accounts for 80%, by mass, of the 2001 reported toxic chemical releases to the atmosphere.

Commonly Produced Chemicals

Chemical Name	Million Kg produced in 2002	ERPG and TEEL Level 3 (lethal) mg/m^3	Ppm	Pure Liquid Density (at °C) in g/cm^3	Aqueous Solution at 20-25 °C in g/cm^3	Pure Solid at 20-25 °C in g/cm^3
Nitrogen Gas	33,100,000	60,000 [(a)]	52,000	0.808 (-221 °C) [(c)]	-	-
Oxygen Gas	23,900,000	-	-	1.141 (-183 °C) [(c)]	-	-
Hydrogen Gas	1,250,000	3,500 [(a)]	44,000	0.071 (-278 °C) [(c)]	-	-
Sulfuric Acid	36,600	30 [(b)]	4.1	1.85 (25 °C) [(c)]	1.395 (50%) [(d)]	
Phosphate rock	29,200	-	-	-	-	-
Ammonia	24,500	525 [(b)]	750	0.682 (-33 °C) [(c)]	0.88 (35% wt) [(c)]	-
Ethylene	23,600	15,000 [(a)]	13,000	0.57 [(d)]	-	-
Phosphoric Acid	20,900	500 [(a)]	125	-	1.69 (85% wt) [(c)]	1.834 [(d)]
Polyethylene	16,000	500 [(a)]	-	-	-	0.96 (HDPE) [(c)]
Propylene	14,400	40,000 [(a)]	23,000	0.506 (25 °C) [(c)]	-	-
Urea	11,800	500 [(a)]	200	-	-	1.335 [(c)]
Chlorine	11,400	60 [(b)]	21	1.6 (-34 °C) [(c)]	-	-
Diammonium Phosphate	10,800	250 [(a)]	46	-	-	1.62 [(d)]

The list and amount of compounds produced is taken from Chemical & Engineering News, July 7, 2003, p. 51-61 (www.cen-online.org) for the reported organic, inorganic, plastic, synthetic rubber, and fertilizer chemicals produced in the United States in 2002.

(a) Temporary Emergency Exposure Limits (TEELs) for a 15-min exposure from USDOE SCAPA, Rev19, April 2003 (http://www.bnl.gov/scapa/).
(b) Emergency Response Planning Guidelines (ERPGs) for a 1-hour exposure as given in reference (a) above.
(c) *Ullman's Encyclopedia of Industrial Chemistry 7th Edition*, Wiley-VCH Vertag, 2003. (www.interscience.wiley.com) [Accessed 11-25-03].
(d) *Perry's Chemical Engineer's Handbook 7th Edition*, Ed. R.H. Perry and D.W. Green, McGraw-Hill, 1997 (www.knovel.com) [Accessed 11-25-03].

Common Radionuclide Toxicity Data

(note: 1.5E+3 = 1.5×10^3 = 1500)

	Radionuclide Name	Lethal Air Concentration for 50 % of the exposed population [2] (LC_{50} in mg/m^3)	Half Life [3] (Years)	Radiation Emitted [3] α	β	n	γ & x-ray	Specific Activity [4] (Ci/g)	Ground Shine Dose Rate [5] (Rem/hr/Ci)
Possible RDD Radionuclide [1]	Pu – 239 (Plutonium)	8.6E+0 (S)	2.4E+4	✓			✓	6.1E-2	negligible
	Cs – 137 (Cesium)	1.8E+0 (M)	3.0E+1		✓			8.7E+1	3.8E-1
	Sr – 90 (Strontium)	7.3E-1 (M)	2.9E+1		✓		✓	1.4E+2	4.0E-3
	Ra – 226 (Radium)	5.9E-1 (S)	1.6E+3	✓	✓		✓	9.9E-1	8.3E-1
	Co – 60 (Cobalt)	1.7E-1 (M)	5.3E+0		✓		✓	1.1E+3	1.4E+0
	Am – 241 (Americium)	1.5E-1 (M)	4.3E+2	✓	✓		✓	3.4E+0	4.5E-3
	I – 131 (Iodine)	3.3E-2 (F)	2.2E-2		✓		✓	1.2E+5	2.8E-1
	Pu – 238 [a] (Plutonium)	2.7E-2 (S)	8.8E+1	✓			✓	1.7E+1	negligible
	Ir – 192 (Iridium)	1.6E-2 (M)	2.1E-1		✓		✓	9.2E+3	5.9E-1
	Cf – 252 [a] (Californium)	7.2E-4 (S)	2.7E+0	✓	✓	✓	✓	5.4E+2	4.6E+0 [b]
Other	U – 238 [a] (Uranium) (Depleted Uranium)	1.0E+1 [c]	4.5E+9	✓	✓	✓	✓	3.3E-7	negligible
	U – 235 (Uranium) (Highly Enriched Uranium)	1.0E+1 [c]	7.0E+9	✓	✓		✓	2.2E-6	negligible
	HTO (Tritium)	2.8E+0 (V)	1.2E+1		✓			9.6E+3	negligible

(a) Spontaneous fission also produces other fragments.
(b) 4.3 Rem/hr is from spontaneous fission neutrons, the remaining 0.3 Rem/hr from gamma radiation.
(c) Chemical toxicity only (TEEL-3). Lethal radioactive levels for U-238 and U-235 are reached at 2.2e+6 and 3.1E+5 mg/m$_3$, respectively.

This radioisotope toxicity data is based on the probability that 50% of individuals will die within 60 days after breathing the radionuclide for 1 hour. To be consistent with the ERPG, AEGL, and TEEL definitions, we divide the LC_{50} by 2 to convert to a LC_5 before plotting on the Acute Inhalation Toxicity Graph.[6]

(1) The nuclides presented here were chosen from those commonly used or produced in industrial and/or medical settings. These nuclides were complied by the *Report to the Ranking Minority Member, Subcommittee on Financial Management, the Budget, and International Security, Committee on Governmental Affairs, U.S. Senate, NUCLEAR SECURITY, Federal and State Action Needed to Improve Security of Sealed Radioactive Sources*, United States General Accounting Office, Document GAO-03-804, August 2003 (www.gao.gov) and *Van Tuyle, G.J. and E. Mullen*, Life-Cycle of Large Radiological Sources – Assessing RDD Concerns & Options, American Nuclear Society Winter Meeting (New Orleans, LA), November 2003.

(2) LD_{50} values are from Steve Homann (personal communication). This data is based on Acute Dose Conversion Factors developed by Keith Eckerman at the Oak Ridge National Laboratory and is described in detail in the Hotspot Health Physics Code (v2.05) Onboard User Documentation (www.llnl.gov/nai/technologies/hotspot). In summary, the reference individual is assumed to a) have a respiration rate of 1.2 m^3/hr, b) will die if her/his red marrow, lungs, or small intestine is exposed to 200, 1000, or 500 Rem respectively, and c) whose tissue has a Relative Biological Effectiveness of 7 for high Linear Energy Transfer radiation (e.g. alpha particles). The (S), (M), (F), and (V) listed in this column refers to the rate of radioisotope transfer from the lung to the blood stream (slow, moderate, fast, and vapor, respectively) and later uptake by the targeted organ. This rate is determined by the chemical form of the radionuclide. The radiation dose due to ground shine and air immersion is ignored.

(3) *Radionuclide Transformations: Energy and Intensity of Emissions*, ICRP Publication 38, Annals of the ICRP, Pergamon Press, Elmsford, NY, 1983. Radiation Emitted column includes all radiation from short-lived daughters ($\tau_{1/2,\,daughter} \leq \tau_{1/2,\,parent}$) but does not include the subsequently generated radiation due to the interaction of β particles or γ and x-rays with matter.

(4) Calculated from the half-life and molecular weight and assumes no impurities.

(5) The external dose rate from 1 Ci of radiation at a distance of 1 meter (infinite plane). This column assumes the pure radionuclide is initially deposited, but includes the dose from its short-lived daughters. Data for Cs-137, Co-60, I-131, and Ir-192 is taken from the *Handbook of Health Physics and Radiological Health*, 3rd Ed. Williams & Wilkins, 1998 (ISBN 0-0683-18334-6). Data for Sr-90 was calculated from the *Federal Guidance Report 11 (FGR-11)* ground shine data (S. Homann). Data for Ra-226 is taken from the *Radiological Health Handbook*, Revised Edition, Jan 1970, U.S. Dept of Health Education and Welfare. Data for Am-241 is based on actual measurements of a 0.3Ci Am241 Amersham Corporation source (Be source window – Victoreen 450 Ionization Survey instrument @ 7 mg/cm^2 mylar window) (S. Homann). Data for Cf-252 is taken from *Radiation Sources for Industrial Gauging and Analytical Instrumentation*. Amersham Corporation, March 1985.

(6) The factor of two is derived from the ratio of LD_5 and LD_{50} acute lethality based on a whole body dose of 140 and 300 rad, respectively. This data is from the *Manual of Protective Action Guides and Protective Actions for Nuclear Incidents* (EPA 400-R-92-001, May 1992), p. B-8.

Heat of Combustion

	Chemical Name	Heat of Combustion [c]			
		Btu/lbs	kJ/g	kJ/mol	Ratio to Diesel Fuel (by weight)
Commonly Released Chemicals [a]	Methanol	9,740	22.7	726	0.50
	Ammonia	9,650	22.5	383	0.50
	Toluene	18,200	42.4	3910	0.94
	n-Hexane	20,700	48.3	4163	1.07
	Xylenes	18,400	42.9	4550	0.95
	Styrene	18,100	42.2	4395	0.93
Commonly Produced Chemicals [b]	Hydrogen Gas	60,900	142	286	3.13
	Ammonia	9,650	22.5	383	0.50
	Ethylene	21,600	50.3	1410	1.11
	Propylene	21,000	48.9	2058	1.08
	Urea	4,500	10.5	632	0.23
Common Fuels	Diesel Fuel Oil [d]	19,400	45.2	-	1.00
	Kerosene [d]	19,800	46.2	-	1.02
	Motor Gasoline [d]	20,100	46.9	-	1.04
	Medium Fuel Oil [d]	18,900	44.1	-	0.98
	Aviation Fuel [d]	20,420	47.6	-	1.05
	Wood (dry) [d]	8,600	20.0	-	0.44
	Natural Gas (Methane)	23,800	55.5	891	1.23
	LPG (Propane)	21,600	50.3	2220	1.11
	Butane	21,200	49.5	2878	1.10
	Acetylene	21,400	49.9	1300	1.10

The **Heat of Combustion** estimates the heat released when a compound is completely burned. Specifically, this is defined as the enthalpy released at 298K and 1 atmosphere such that all carbon is oxidized to CO_2 (gas), hydrogen to H_2O (gas), phosphorous to H_3PO_4 (solid), silicon to SiO_2 (crystobalite), sulfur to SO_2 (gas), and all other elements to their thermodynamic reference state.

Miscellaneous Heat Sources

Heat Source	Heat Released	Radius		Heat in Diesel burned per hour	
	MW	ft	m	lbs	gal
Burning House [e]	45 (first hour)	30	9	8,900	1,200
Small Power Plant Stack [f]	5	7	2	1,000	135
Large Power Plant Stack [f]	100	13	4	20,000	2,700

(a) *2001 Toxics Release Inventory (TRI) Public Data Release, Executive Summary,* U.S. EPA (www.epa.gov/tri/index.htm). Hydrogen Chloride, Sulfuric Acid, and Hydrogen Fluoride do not significantly burn. These compounds may react with other chemicals to release large amounts of heat.

(b) Chemical & Engineering News, July 7, 2003, p. 51-61 (www.cen-online.org). Nitrogen, oxygen, sulfuric acid, phosphoric acid, and chlorine do not significantly burn. Oxygen and chlorine may induce other compounds to burn (oxidize). Sulfuric and phosphoric acids may react with other compounds to release large amounts of heat.

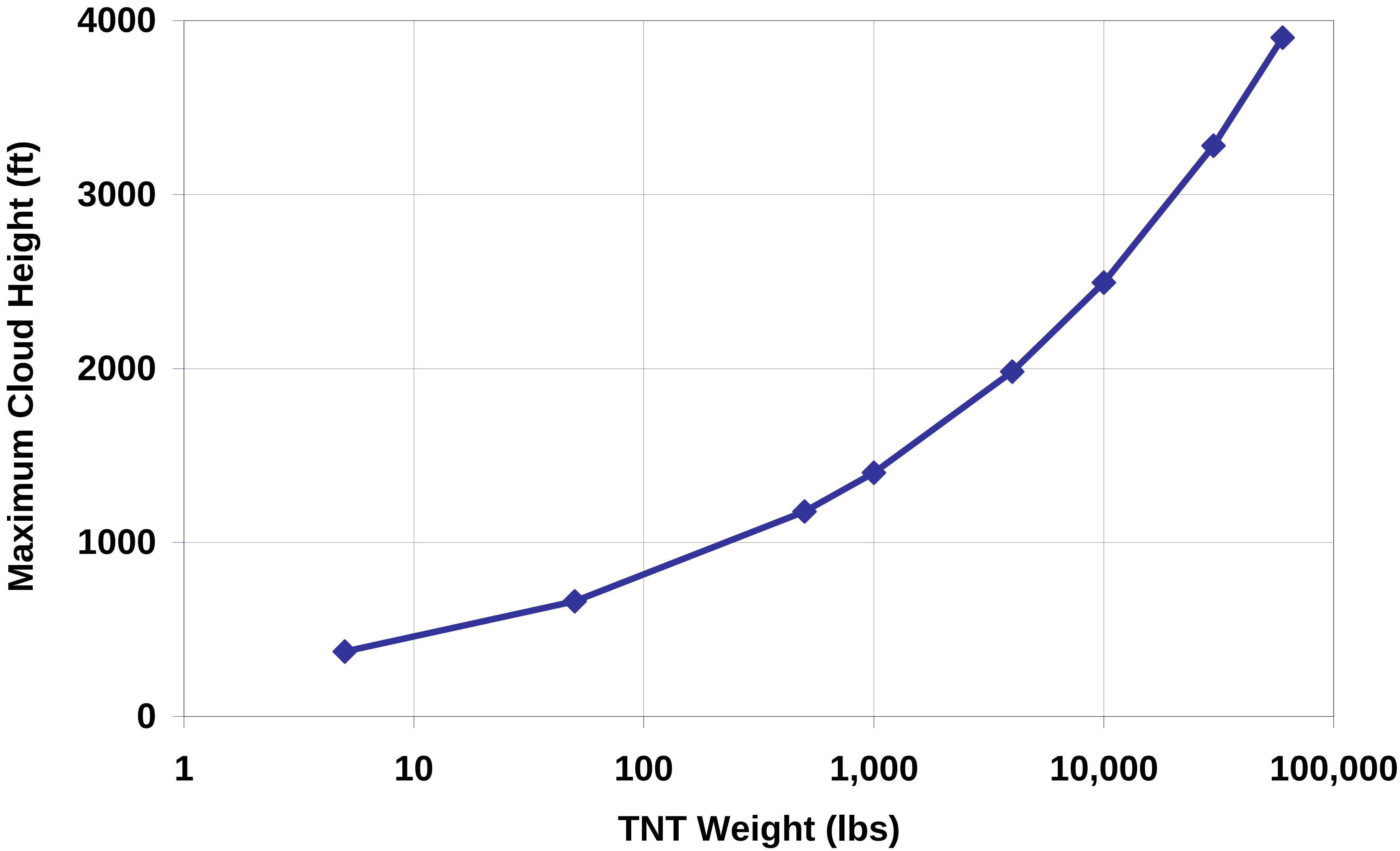
(c) Heat of Combustion Online Table, 84^{th} *CRC Handbook of Chemistry and Physis, 2003-2004,* (www.hbcpnetbase.com) [Accessed 12-22-03].

(d) Forsythe, W.E., *Smithsonian Physical Tables 9^{th} Revised Ed*, New York, 2003, (www.knovel.com) Tables 174 and 175. [Accessed 12-23-03]. Real world heats of combustion may be slightly lower since some of this data may be referenced to H_2O (liquid) instead of H_2O (gas).

(e) Trelles, J. and P.J. Pagni, *Fire-induced Winds in the 20 October 1991 Oakland Hills Fire*, Fire Safety Science – Proceedings of the Fifth International Symposium, p. 911-922. Assumes 50% of a 2,000 ft^2 wood-frame building burns in 1 hour.

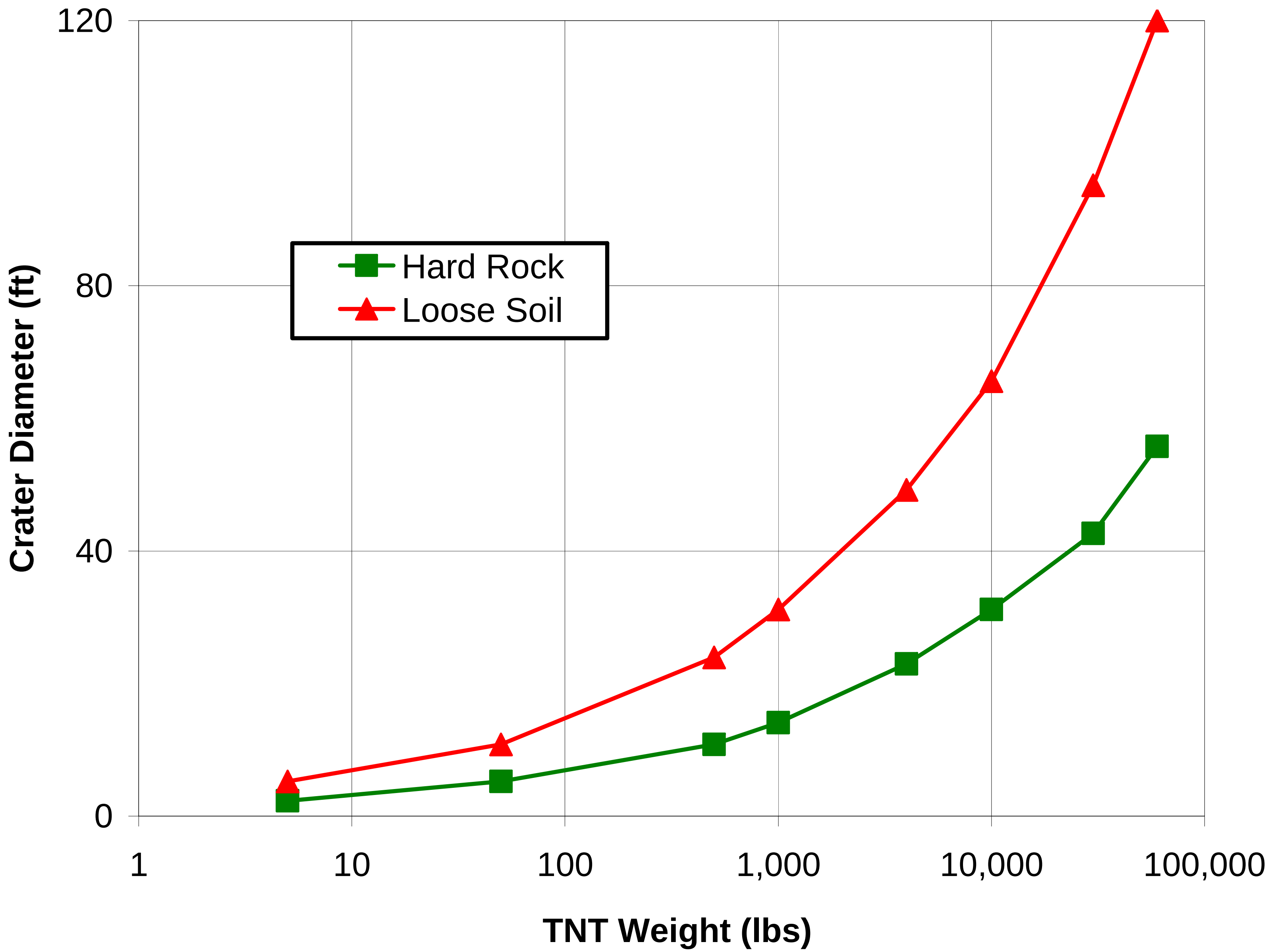
(f) Briggs, C.A., *Plume Rise*, U.S. Atomic Energy Commission, Division of Technical Information, 1969, p. 44.

Surface Explosions



Surface TNT Explosions

(Fertilizer/Fuel (ANFO) craters are half as big as TNT craters)



Surface Explosion Data

Explosive Capacity (TNT Equivalent mass)	SNL-BLAST Onset of lethality (25 psi)[1]	SNL-BLAST Lung damage and complete incapacitation (10 psi)[1]	SNL-BLAST Eardrum rupture and incapacitation (5 psi)[1]	SNL-BLAST IABTI Safe Distance[2]	TNT Crater Diameter[3]		Stabilized Cloud Top Height[5]
					Hard Rock	Loose Soil	
5 lbs 2.3 kg	11 to 17 ft 4 to 6 m	17 to 26 ft 6 to 8 m	25 to 39 ft 8 to 12 m	900 ft 275 m	2.4 ft 0.7 m	5.3 ft 1.6 m	374 ft 114 m
50 lbs 23 kg	24 to 37 ft 8 to 12 m	37 to 56 ft 12 to 17 m	53 to 84 ft 17 to 26 m	1,078 ft 329 m	5.3 ft 1.6 m	11 ft 3.3 m	663 ft 202 m
500 lbs 227 kg	51 to 79 ft 16 to 24 m	79 to 120 ft 24 to 37 m	114 to 180 ft 35 to 55 m	2,321 ft 708 m	11 ft 3.3 m	24 ft 7.3 m	1,178 ft 359 m
1,000 lbs 454 kg	64 to 99 ft 20 to 31 m	99 to 151 ft 30 to 46 m	143 to 227 ft 44 to 70 m	2,925 ft 892 m	14 ft 4.3 m	31 ft 9.5 m	1,401 ft 427 m
4,000 lbs 1,814 kg	101 to 157 ft 31 to 48 m	157 to 239 ft 48 to 73 m	227 to 360 ft 70 to 110 m	4,642 ft 1,415 m	23 ft 7.0 m	49 ft 15 m	1,982 ft 604 m
10,000 lbs 4,536 kg	137 to 213 ft 42 to 65 m	212 to 324 ft 65 to 99 m	308 to 488 ft 94 to 149 m	6,300 ft 1,921 m	31 ft 9.5 m	66 ft 20 m	2,493 ft 760 m
30,000 lbs 13,608 kg	198 to 307 ft 61 to 94 m	306 to 467 ft 94 to 143 m	444 to 704 ft 136 to 215 m	9,087 ft 2,770 m	44 ft 13 m	96 ft 29 m	3,281 ft 1,000 m
60,000 lbs 27,216 kg	249 to 387 ft 76 to 118 m	385 to 588 ft 118 to 180 m	559 to 886 ft 171 to 271 m	11,448 ft 3,490 m	56 ft 17 m	120 ft 37 m	3,902 ft 1,189 m

Sources:

Columns 2 - 5: Generated by Sandia National Laboratory's BLAST model.
The BLAST model is based on data contained within *Structures to Resist the Effects of Accidental Explosions,* Department of Army Technical Manual TM 5-1300, 1969.

Columns 6 - 7: From Cooper, P.W., *Explosives Engineering*, Wiley-VCH, New York, 1996, Chapter 29.

Column 8: From Church, H.W., Cloud Rise from High-Explosive Detonations, Sandia National Laboratory, TID-4500, June 1969.

Each stick of dynamite is approximately 1/2 pounds. Equivalent pounds (#) of TNT:

1# **Amatol 80/20** = 0.59# TNT
1# **ANFO** = 0.27# TNT
1# **Baronal** = 1.05# TNT
1# **Nitroglycerin** = 1.49# TNT
1# **Explosive D** = 0.74# TNT
1# **HMX** = 1.26# TNT
1# **Lead Azide** = 0.34# TNT
1# **Picric Acid** = 0.93# TNT
1# **PBX9404** = 1.20# TNT
1# **PETN** = 1.29# TNT
1# **Pentolite 50/50** = 1.13# TNT
1# **RDX** = 1.19# TNT
1# **Tetryl** = 1.00# TNT
1# **Comp B** = 1.15# TNT
1# **Silver Azide** = 0.42# TNT
1# **C-4** = 1.08# TNT
1# **Octol 70/30** = 1.00# TNT

1. Preferred evacuation distance for people in buildings (if possible) and mandatory for people outdoors.
2. Range given is for side-on overpressure (near-range value) to reflected overpressure (far-range value). Developed from U.S. Army Technical Manual 5-1300, Structures to Resist the Effects of Accidental Explosions, Figure 4-12, June 1969.
3. IABTI = International Association of Bomb Technicians and Investigators. Calculated as the maximum of 900 or $300 * w^{1/3}$ feet, where w = pounds of c4 equiv.
4. For a TNT ground explosion, $D = 1.9(2E_{CR}E)^{1/3}$ where $E_{CR} = 0.2$ (hard rock) to 2.0 (loose soil). Crater size estimates are best for large (500+ lbs TNT) explosion due to uncertainty in the explosion height. (ANFO crater diameter) = 0.6(TNT crater diameter), (C4 crater diameter) = 1.2(TNT crater diameter).
5. Based on cloud top (meters) = $76w^{1/4}$, where w = pounds of TNT equivalent; for unmitigated, open-air explosion at ground level.

Beaufort Wind Scale

Beaufort Number	Description	Wind Speed mi/hr	Wind Speed km/hr	Wind Speed m/s	Observations
0	Calm	< 1	< 2	< 0.6	Vertical smoke plumes
1	Light Air	2	4	1.1	Horizontal smoke plumes
2	Slight Breeze	5.5	9	2.5	Wind vanes move, Leaves rustle, and Wind felt on face
3	Gentle Breeze	10	16	4.3	Leaves move and Flags stir
4	Moderate Breeze	16	25	6.8	Flags flap and Wind raises dust
5	Fresh Breeze	22	35	9.6	Small trees sway and Flags ripple
6	Strong Breeze	28	45	13	Umbrellas are difficult to use and Large branches move
7	High Wind	35	56	16	Whole trees move and Flags straighten
8	Gale	43	68	19	Walking is difficult and Wind breaks twigs off trees
9	Strong Gale	51	81	23	Signs and antennas broken
10	Whole Gale	59	95	26	Trees uprooted
11	Storm	69	110	31	Widespread damage
12	Hurricane	≥ 75	≥ 120	≥ 33	Extensive damage

Adapted from Appendix C in Ahrens, C.D., *Meteorology Today: An Introduction to Weather, Climate, and the Environment, 5th Ed.*, West Publishing Company, St. Paul, MN, 1994.

Size of Common Objects

Common Containers

Container	Volume[a]	Weight[a]	Ref.
Soda Can, Small spray bottle	0.092 gal (0.35 L)	0.77 lbs (0.35 kg)	
Gallon Milk Container	1 gal (3.79 L)	8.4 lbs (3.79 kg)	
Gas Cylinder	18 gal (68 L)	150 lbs (68 kg)	(1)
Semi-Trailer Tanker	4,800 gal (18,000 L)	40,000 lbs (18,000 kg)	(1)
Railroad Tank	12,000 gal (46,000 L)	200,000 lbs (91,000 kg)	(1)
Barge	190,000 gal (730,000 L)	1,600,000 lbs (730,000 kg)	(1)
Fixed Location Storage Tank[b]	> 6,100 gal (> 23,000 L)	> 51,000 lbs (> 23,000 kg)	(1)

[a] Assumes the stored material has the same density of water at 4 ºC (1 g/cm^3). This assumption is accurate (within a factor of 2) for many chemicals, but is not accurate for most metals and high molecular weight compounds.
[b] Highly variable

Surface Area

Object	Surface Area			Ref.
	m^2	ft^2	acres	
8½” x 11” paper	0.060	0.65	0.000015	
Medium Desk	1.4	15	0.00035	
Small Room	8.9	96	0.0022	
Tennis Court	195	2,100	0.048	(2)
Football Field (w/ end zones)	5,300	57,000	1.3	(3)

Height

Object	Height		Ref.
	ft	m	
1-Story Building	20	6	
4-Story Building or Mature Tree	80	24	
Radio Tower	490	150	
Empire State Building	1,400	430	
Large TV Tower	2,000	610	
Low Clouds	< 6,600	< 2000	(4)

(1) Report for Work Assignment 51, U.S. EPA Contract No. 68-DO-0125, *Guidance to a Systematic Approach for Applying Hazardous Air Pollutant Mathematical Models*, Radian Corporation, 1993. (Container sizes are specified by mass.)
(2) “Play of the game, tennis” *Encyclopedia Britannica Online* http://search.eb.com/eb.article?eu=114964&tocid=29710&query=tennis%20court&ct= [Accessed October 17, 2003]
(3) “Play of the game, football, American” *Encyclopedia Britannica Online* http://search.eb.com/eb/article?query=football&ct=&eu=11495&tocid=29636#29636.toc [Accessed October 17, 2003]
(4) Ahrens, C.D., *Meteorology Today: An Introduction to Weather, Climate, and the Environment, 5th Ed.*, West Publishing Company, St. Paul, MN, 1994, p. 143.