Protective Action Distance Estimation in the Emergency Response Guidebook

David F. Brown

608-442-1249

dbrown@anl.gov

Argonne National Laboratory

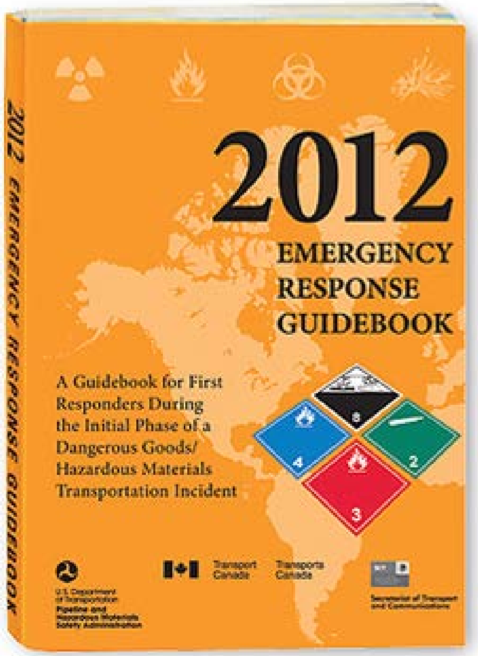
OHMS 2016 R&D Forum
March 23, 2016

Outline

- Background on Protective Action Distances
- Analysis procedure
- Reactivity considerations

ERG Background

- Developed by USDOT to assist first responders
- More than 1300 substances are cross-referenced by name and by UN number
- Initial Isolation and Protective Action Distances for 250+ TIH substances



  - Pure substances (e.g., chlorine, ammonia, sulfur dioxide)
  - Generic substances (e.g., poisonous gas, n.o.s)
  - Mixtures and solutions
  - Water-reactive materials (e.g., chlorosilanes, aluminum phosphide, etc.)

A Few Key TIH Entries (2012 ERG)

- **Distances provided for small and large spills**
  - **Small spills:** up to 200 liters, standard cylinder, or many small packages
  - **Large spills:** everything else (cargo tanks, tank cars, etc.)
- **Day and night distances provided**

			SMALL SPILLS (From a small package or small leak from a large package)						LARGE SPILLS (From a large package or from many small packages)					
			First ISOLATE in all Directions		Then PROTECT persons Downwind during-				First ISOLATE in all Directions		Then PROTECT persons Downwind during-			
					DAY		NIGHT				DAY		NIGHT	
ID No.	Guide	NAME OF MATERIAL	Meters	(Feet)	Kilometers	(Miles)	Kilometers	(Miles)	Meters	(Feet)	Kilometers	(Miles)	Kilometers	(Miles)
1005 *	125	Ammonia, anhydrous	30 m	(100 ft)	0.1 km	(0.1 mi)	0.2 km	(0.1 mi)	150 m	(500 ft)	0.8 km	(0.5 mi)	2.0 km	(1.3 mi)
1005 *	125	Anhydrous ammonia												
1008	125	Boron trifluoride	30 m	(100 ft)	0.1 km	(0.1 mi)	0.5 km	(0.4 mi)	300 m	(1000 ft)	1.7 km	(1.1 mi)	4.8 km	(3.0 mi)
1008	125	Boron trifluoride, compressed												
1016	119	Carbon monoxide	30 m	(100 ft)	0.1 km	(0.1 mi)	0.2 km	(0.1 mi)	200 m	(600 ft)	1.2 km	(0.8 mi)	4.8 km	(3.0 mi)
1016	119	Carbon monoxide, compressed												
1017 *	124	Chlorine	60 m	(200 ft)	0.4 km	(0.2 mi)	1.5 km	(1.0 mi)	500 m	(1500 ft)	3.0 km	(1.9 mi)	7.9 km	(4.9 mi)

- **For 6 high volume materials large spill distances are broken out by container type and transportation model (highway and rail) – examples to follow**

Table 3 Distances for Chlorine

2016 Distances (2012 in parentheses)

Transport container	First ISOLATE in all Directions (ft)	Then PROTECT persons Downwind during					
		Day [mi]			Night [mi]		
		Low wind [< 6 mph]	Moderate wind [6-12 mph]	High wind [> 12 mph]	Low wind [< 6 mph]	Moderate wind [6-12 mph]	High wind [> 12 mph]
Rail tank car	3000 (3000)	6.2 (7+)	4.0 (5.6)	3.2 (3.4)	7+ (7+)	5.6 (7+))	4.2 (4.4)
Highway tank truck or trailer	2000 (3000)	3.6 (6.6)	2.1 (2.3)	1.8 (1.8)	4.3 (7+)	3.1 (3.4)	2.5 (2.6)
Multiple ton cylinders	1000 (1250)	1.3 (2.5)	0.8 (0.9)	0.6 (0.7)	2.5 (4.9)	1.5 (1.7)	0.8 (0.9)
Multiple small cylinders or single ton cylinder	500 (800)	0.9 (1.6)	0.5 (0.6)	0.3 (0.5)	1.8 (3.5)	0.8 (1.1)	0.4 (0.5)

Tables also developed for

- Ammonia
- Sulfur dioxide
- Hydrogen chloride
- Hydrogen fluoride
- Ethylene oxide

Outline

- Background on Protective Action Distances
- Analysis procedure
- Reactivity considerations

How Do We Determine PADs?

- Problem: **How to balance risk of insufficient protection with risk of over-response**

- Solution: **Risk-based approach where a Level of Protection is specified using a statistical approach**

Level of Protection → **Percentage of time a Protective Action Distance will be sufficient**

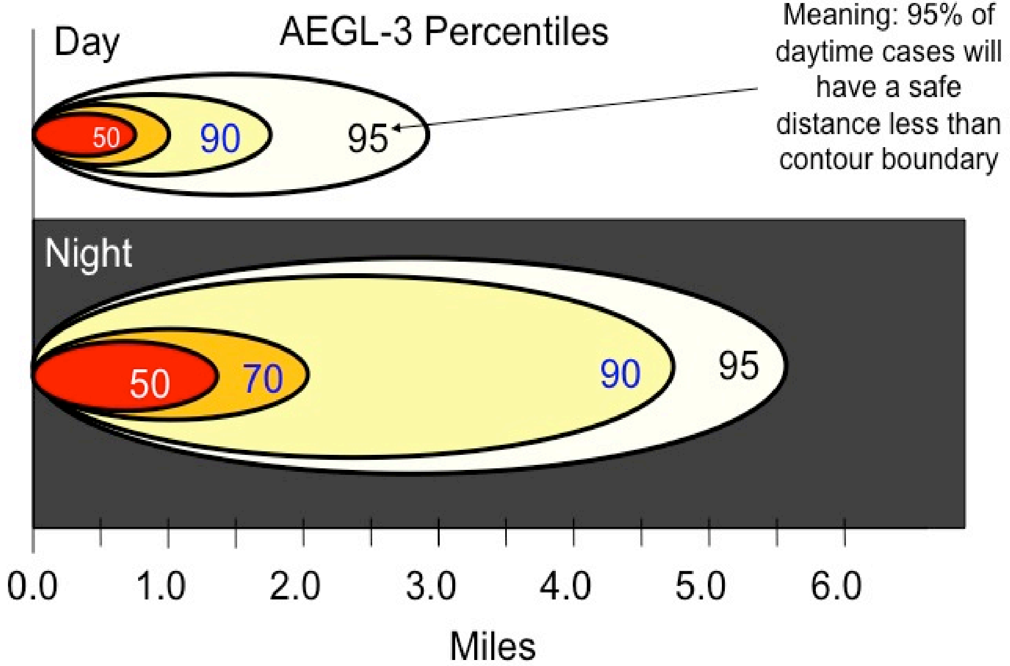
Consequence Model: CASRAM

Chemical Accident Statistical Risk Assessment Model

- Primary transportation risk assessment (TRA) tool in the ERG analysis
- Monte Carlo based approach to risk estimation
- Key CASRAM components
  - Emission rate models
  - Dispersion models (dense gas and passive dispersion)
  - Ignition, thermal radiation and blast overpressure algorithms
  - Meteorological database (5 years, 100 cities)

Statistical Approach Application

- Tools/Data
  - Transportation regulations
  - Historical accident data
  - Detailed commodity flow for high volume chemicals
  - Meteorological data
  - Chemical property data
  - Source, dispersion and health effects models



- Analysis
  - Simulate 1,000,000+ accidents for each chemical
  - Sort results into small and large spill, and day and night
  - Set the Protective Action Distance as the 90th %-tile
  - For six major chemicals – container (and transportation mode) specific information listed for Large Spills

Protective Action Health Criteria – Recap of 2016

- Acute Exposure Guideline Level 2 (AEGL-2) used as the baseline for PAD definition
  - Short definition: Threshold for serious, long-lasting effects or an impaired ability to escape
  - Applies to sensitive populations
  - Interim and Final AEGL's used in ERG analysis
  - ERPG-2* used as a surrogate when available (*Emergency Response Planning Guideline – Level 2)
- LC_{50} (Lethal Concentration for 50% or population) used if AEGL and ERPG are unavailable PAHC = 0.01 x LC_{50}
- For 2016 (2012 in parentheses)
  - AEGL-2's available for 93 (80) chemicals on TIH list
  - ERPG-2's available for 30 (41) additional TIH chemicals
  - LC_{50} or LC_{LO} based values used for remaining 25 (27) chemicals

Outline

- Background on Protective Action Distances
- Analysis procedure
- Reactivity considerations

Reactivity Considerations

- Reactivity and surface deposition of materials recognized as a gap in current understanding of hazardous material releases
- Multiple studies have shown that distances to AEGL-3 concentration thresholds are significantly reduced if simple surface deposition (reactivity with surface matter) is included
- Much of this effect driven by vegetation uptake – an effect strong enough to lead some to suggest that greenbelts and other vegetation around potential release sites
- Deposition is conceptually easy to implement and has been incorporated is CASRAM for the 2016 ERG. This utilizes many surface parameters already included in our scenario analyses
  - Land use/season
  - Vegetation parameters such as leaf area index
  - Atmospheric boundary layer properties

Key Application Issues

- Surface reactivity is not well characterized, even for major commodities
  - Appears important for many materials, though saturation or destruction of organic material at high chemical concentrations may limit reactivity in the near field
  - Values in the literature are often anecdotal
  - Additional mitigation effects include photolysis and other atmospheric chemical reactions – can expressed in terms of a chemical half life which can be 20 min or less
- Another key issue: 170 separate chemicals and mixtures considered in our ERG analysis. Will eventually like a method that addresses not just major commodities but all TIH materials
  - Uniform methodologies across the range of materials in the ERG analysis would be ideal – only 4 materials considered for 2016 ERG
  - Like other aspects of the problem, could be treated statistically

Key Application Issues (cont.)

- Basis for experiments and use of data acquired
  - Calculate a deposition velocity v_d using a ***surface depletion resistance*** R_c

$$v_d = \frac{1}{R_a + R_b + R_c}$$

  - R_a is atmospheric resistance , R_b is surface boundary layer resistance (these are readily estimated using atmospheric turbulence parameters already used within the modeling framework)
  - R_c could be roughly estimated for highly reactive, moderately reactive, etc. (e.g., Jonsson et al. 2005; Dillon, 2009) – we have derived these values experimentally

Key Application Issues (cont.)

- **Basis for experiments and use of data acquired**
  - Calculate a deposition velocity v_d using a ***surface depletion resistance*** R_c

Vessel well mixed

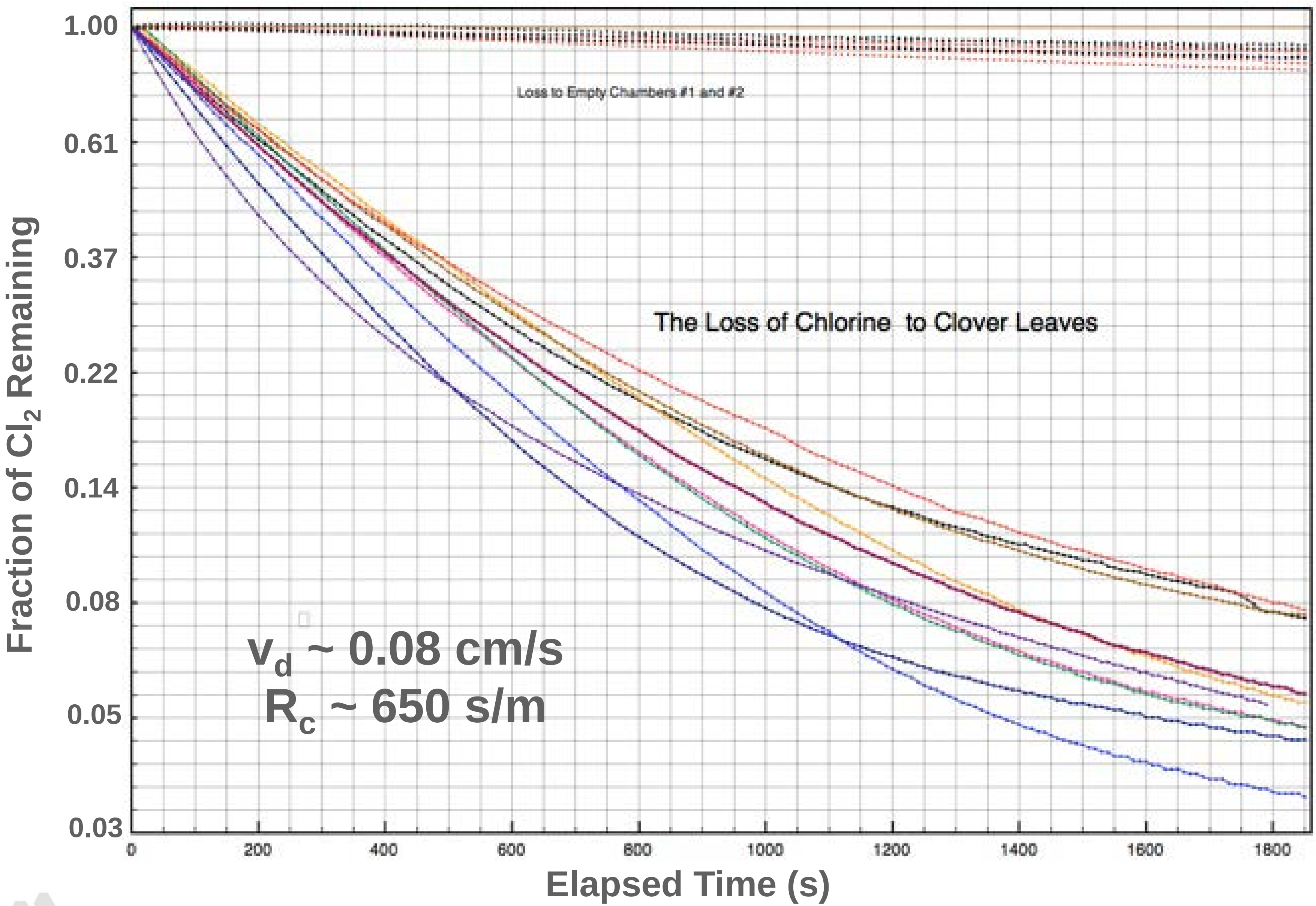
$$v_d = \frac{1}{\underbrace{\cancel{R_a}}_{\sim 0} + \underbrace{\cancel{R_b}}_{\sim 0} + R_c}$$

  - R_a is atmospheric resistance , R_b is surface boundary layer resistance (these are readily estimated using atmospheric turbulence parameters already used within the modeling framework)
  - R_c could be roughly estimated for highly reactive, moderately reactive, etc. (e.g., Jonsson et al. 2005; Dillon, 2009) – we have derived these values experimentally

Experimental Apparatus

Two identical set-ups including glass chamber, Draeger chemical sensor, tubing, and syringe for injection of gas.

Data Summary - Clover



Final Results from 2014/2015 Experiments

Surface depletion resistance R_c

Vegetation/soil type	Chlorine	SO2	HCl	Ammonia
Broadleaf evergreen forest	1023	9208	1592	8801
Broadleaf deciduous forest	1023	9208	1592	8801
Broadleaf and needleleafed mixed	869	9164	1378	4992
Needleleaf deciduous forest	1023	9208	1592	8801
Needleleaf evergreen forest	930	8887	1392	1985
Tundra	220	490	147	166
Broadleaf shrubs	1266	10929	1989	11038
Grassland/Prairie	295	4045	401	2089
Field crops	618	6333	929	5067
Surburban areas	618	6339	930	5072
Urban areas	618	6339	930	5072
Bare areas	174	354	106	135
Water	821	660	102	297
soil low moisture	128	217	66	104
soil high moisture	220	490	147	166

Next Steps

- Proposal into DOT for second series of tests in support of the 2020 guidebook
- Two analysis options:
- Consider a few different materials not evaluated in first series
  - Hydrogen sulfide
  - Bromine
  - Methyl mercaptin
  - Phosgene
  - Carbon monoxide
- Conduct additional experiments on chlorine and ammonia
  - Higher concentrations
  - Wider variety of vegetation types

Questions

David F. Brown

dbrown@anl.gov

608-442-1249 (o)

Argonne National Laboratory

9700 S. Cass Avenue

Lemont, Illinois 60439