Protective Action Distance Estimation in the Emergency Response Guidebook

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DOT ERG Workshop
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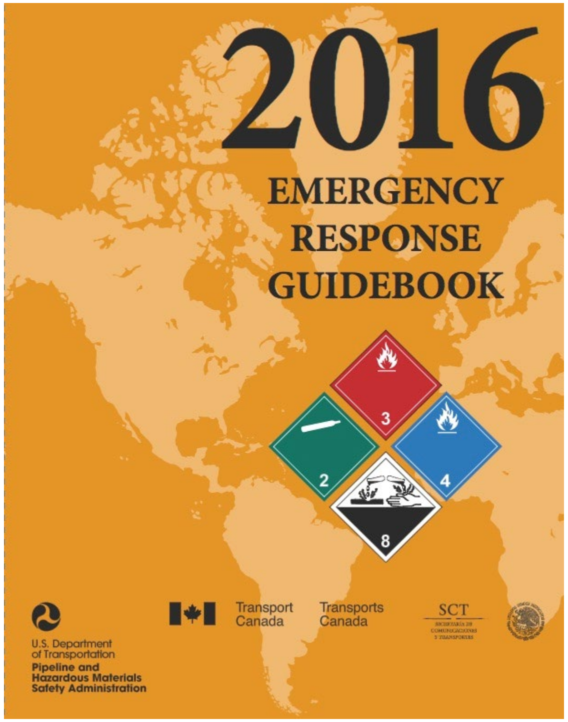
Outline

- Background on Protective Action Distances
- Consequence assessment modeling
  - Data used
  - Health effects
  - Reactivity considerations
- Sample Statistical Results (Cl2, NH3)
- Benefits of Sheltering

- Part II: Placing JRII Results in the Context of Green Page PAD Estimates

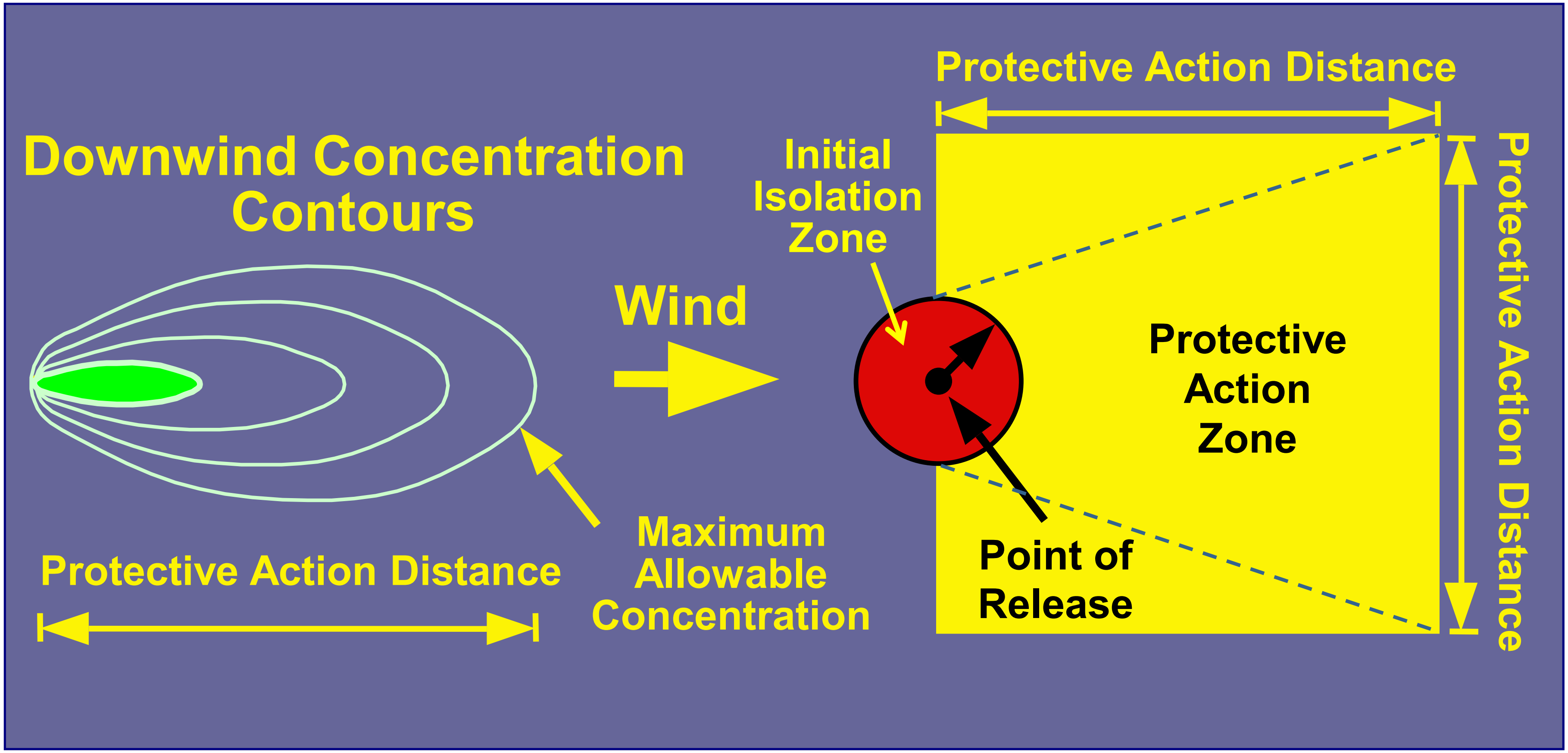
ERG Background

- 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.)

ERG Green Page Distance Application



Key Definition: "Protective Actions are those steps taken to preserve the health and safety of emergency responders and the public."

A Few Key TIH Entries (2016 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**

TABLE 1 - INITIAL ISOLATION AND PROTECTIVE ACTION DISTANCES

			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	
ID No.	Guide	NAME OF MATERIAL	Meters (Feet)	DAY Kilometers (Miles)	NIGHT Kilometers (Miles)	Meters (Feet)	DAY Kilometers (Miles)	NIGHT Kilometers (Miles)
1005 1005	125 125	Ammonia, anhydrous Anhydrous ammonia	30 m (100 ft)	0.1 km (0.1 mi)	0.2 km (0.1 mi)	Refer to table 3		
1008 1008	125 125	Boron trifluoride Boron trifluoride, compressed	30 m (100 ft)	0.1 km (0.1 mi)	0.7 km (0.4 mi)	400 m (1250 ft)	2.2 km (1.4 mi)	4.8 km (3.0 mi)
1016 1016	119 119	Carbon monoxide Carbon monoxide, compressed	30 m (100 ft)	0.1 km (0.1 mi)	0.2 km (0.1 mi)	200 m (600 ft)	1.2 km (0.7 mi)	4.4 km (2.8 mi)
1017	124	Chlorine	60 m (200 ft)	0.3 km (0.2 mi)	1.1 km (0.7 mi)	Refer to table 3		
1026	119	Cyanogen	30 m (100 ft)	0.1 km (0.1 mi)	0.4 km (0.3 mi)	60 m (200 ft)	0.3 km (0.2 mi)	1.1 km (0.7 mi)

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

Table 3 Distances for Ammonia

2016 Distances (2012 in parentheses)

Transport container	First ISOLATE in all Directions m (ft)	Then PROTECT persons Downwind during					
		Day (mi)			Night km (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	1000 (700)	1.1 (1.6)	0.8 (0.9)	0.6 (0.7)	2.7 (3.7)	1.4 (1.8)	0.8 (1.0)
Highway tank truck or trailer	500 (300)	0.6 (0.7)	0.3 (0.3)	0.3 (0.3)	1.3 (1.6)	0.5 (0.5)	0.4 (0.4)
Agricultural nurse tank	200 (120)	0.3 (0.4)	0.2 (0.2)	0.2 (0.2)	0.8 (0.9)	0.2 (0.2)	0.2 (0.2)
Multiple small cylinders	100 (60)	0.2 (0.2)	0.1 (0.1)	0.1 (0.1)	0.5 (0.5)	0.2 (0.2)	0.1 (0.1)

Tables also developed for

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

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

How Do We Determine PADs?

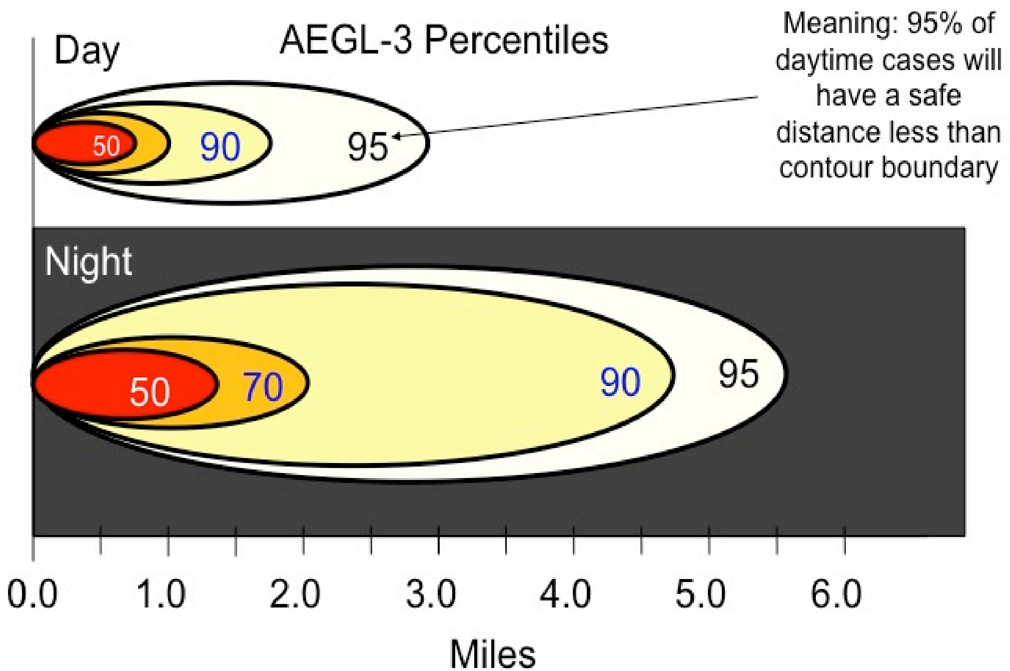
- Problem: How to balance risk of insufficient protection with risk of over-response

- 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

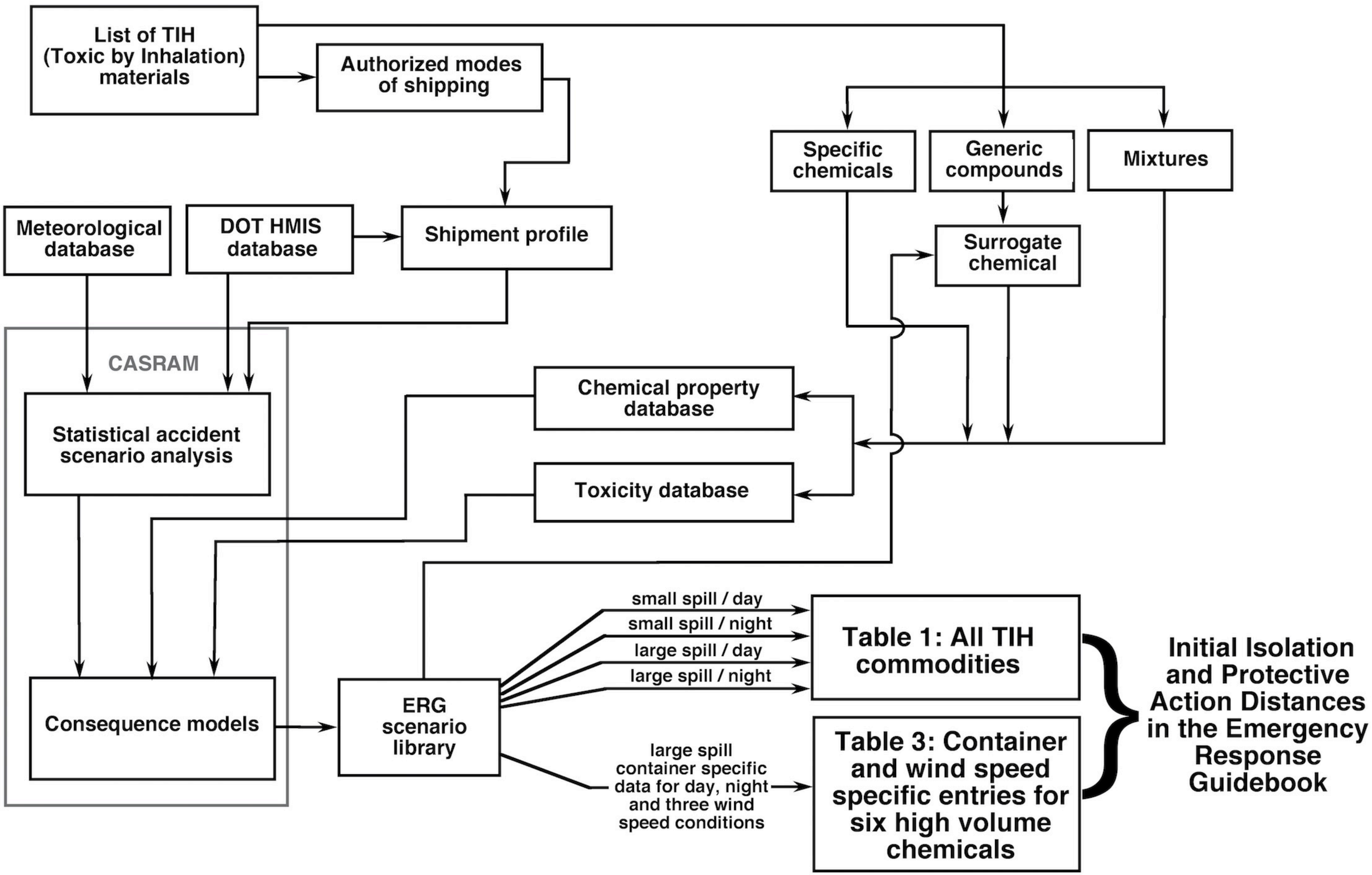
Statistical Approach Application

- **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

Analysis Steps



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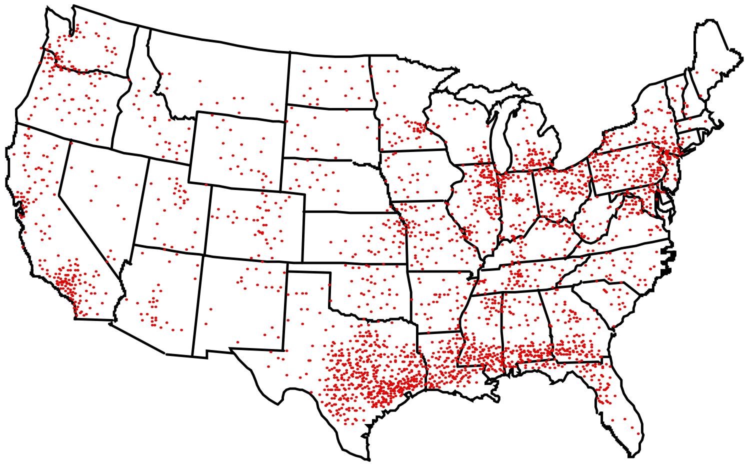
Consequence Model: CASRAM

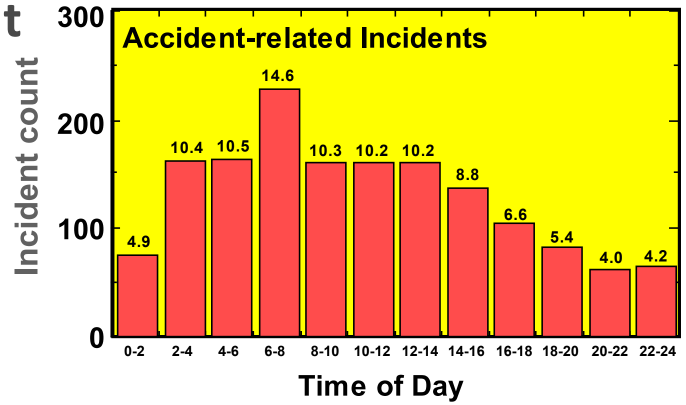
Chemical Accident Statistical Risk Assessment Model

- 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 (10 years, 200 cities)

Incidents Evaluated

- Types of incidents
  - Accident-related
  - En route / nonaccident
- Geographical distributions
  - Highway
  - Rail
  - Urban/rural factors considered (important in dispersion)
- Temporal distributions
  - Time of day
  - Month

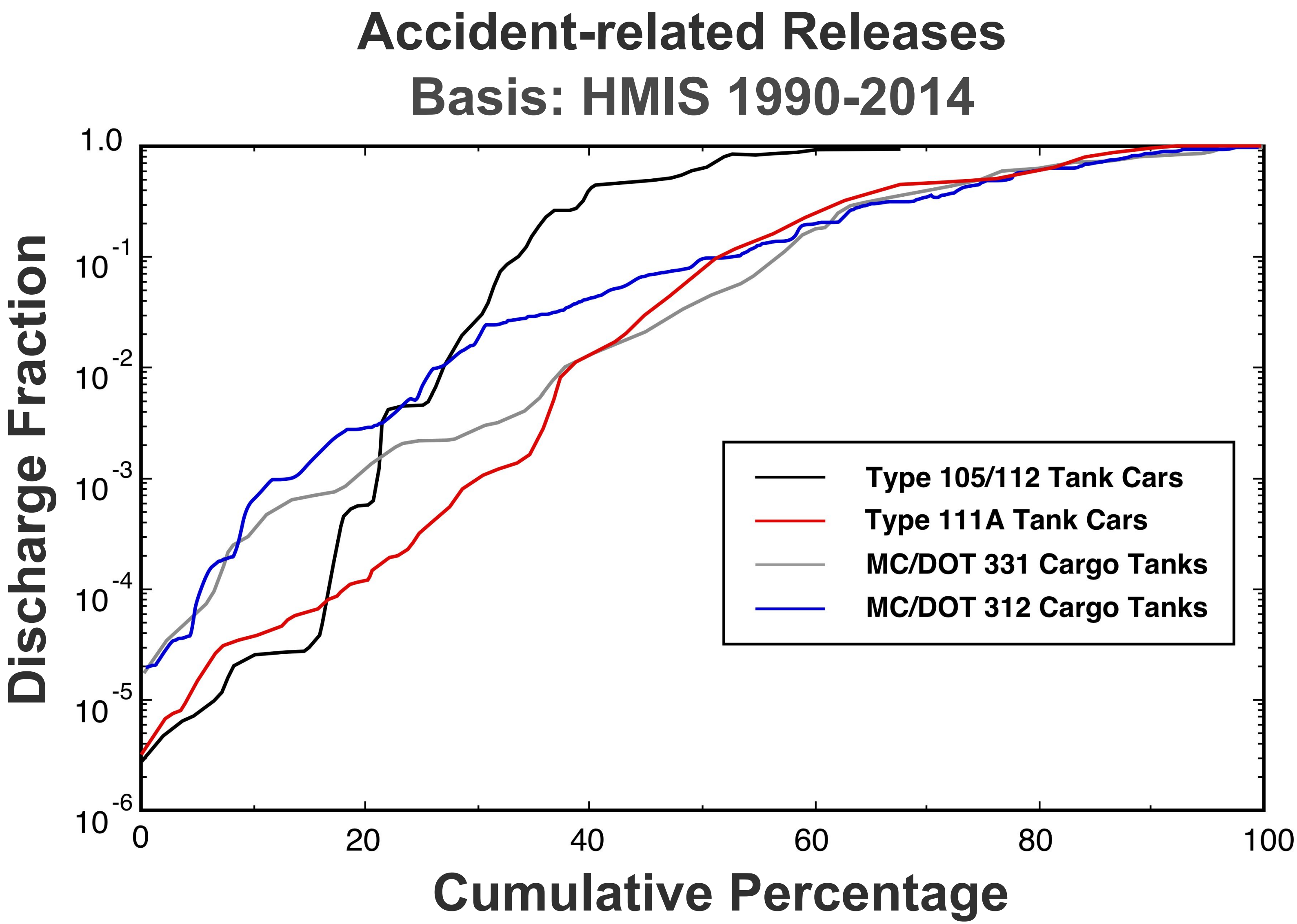




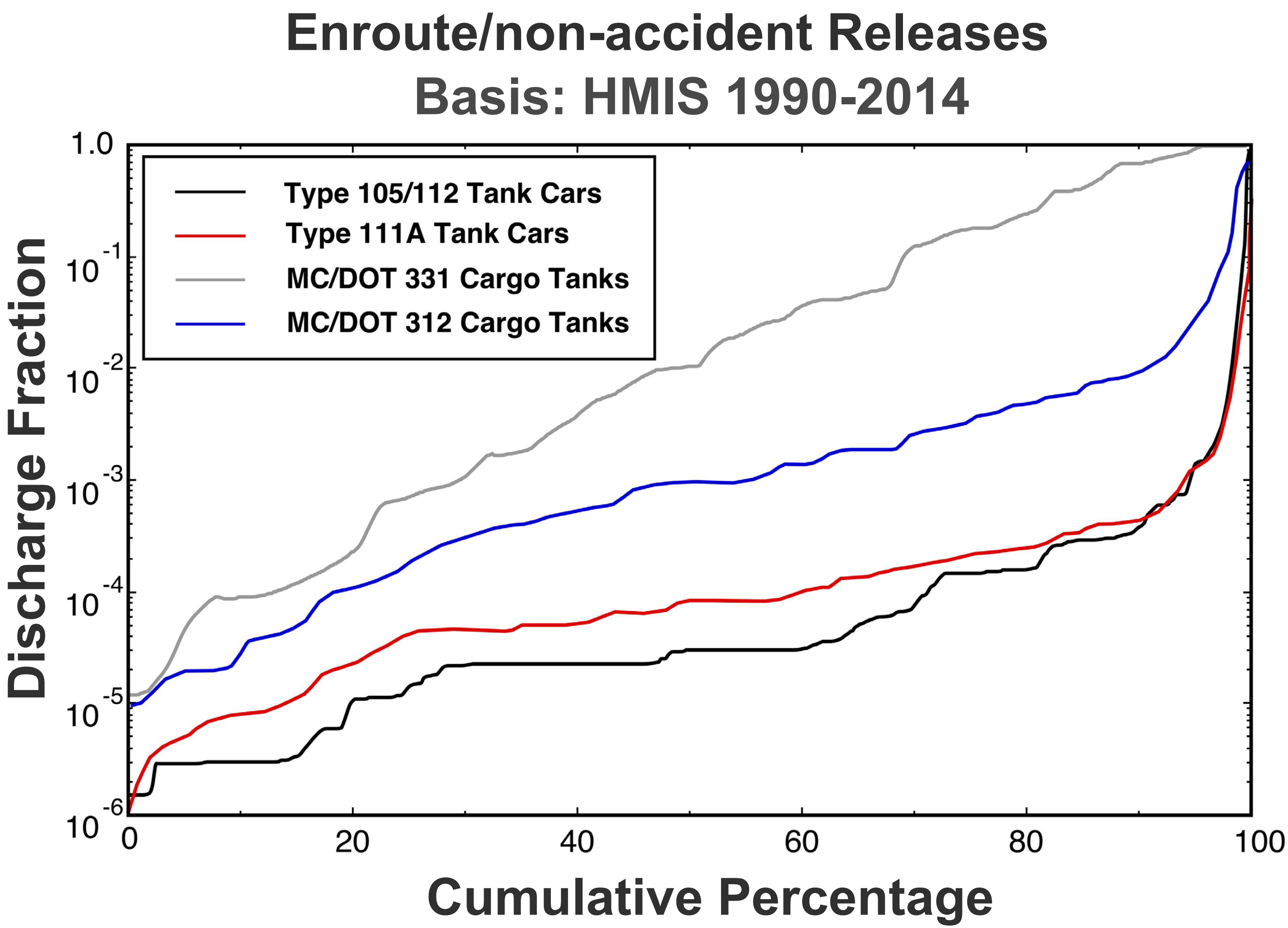
HMIS Data Utilized

- DOT HMIS (Hazardous Materials Information System)
  - Data used: 1990 – 2014 (for 2016)
  - Provides
    - Spill amount
    - Location and time
    - Transportation mode (highway, rail, waterway, air)
    - Container type and capacity
    - Number of containers
    - Type of incident
      - accident-related
      - en route/nonaccident
      - loading/unloading
    - Details on container failure
- Discharge fraction = Spill amount/ Container(s) capacity

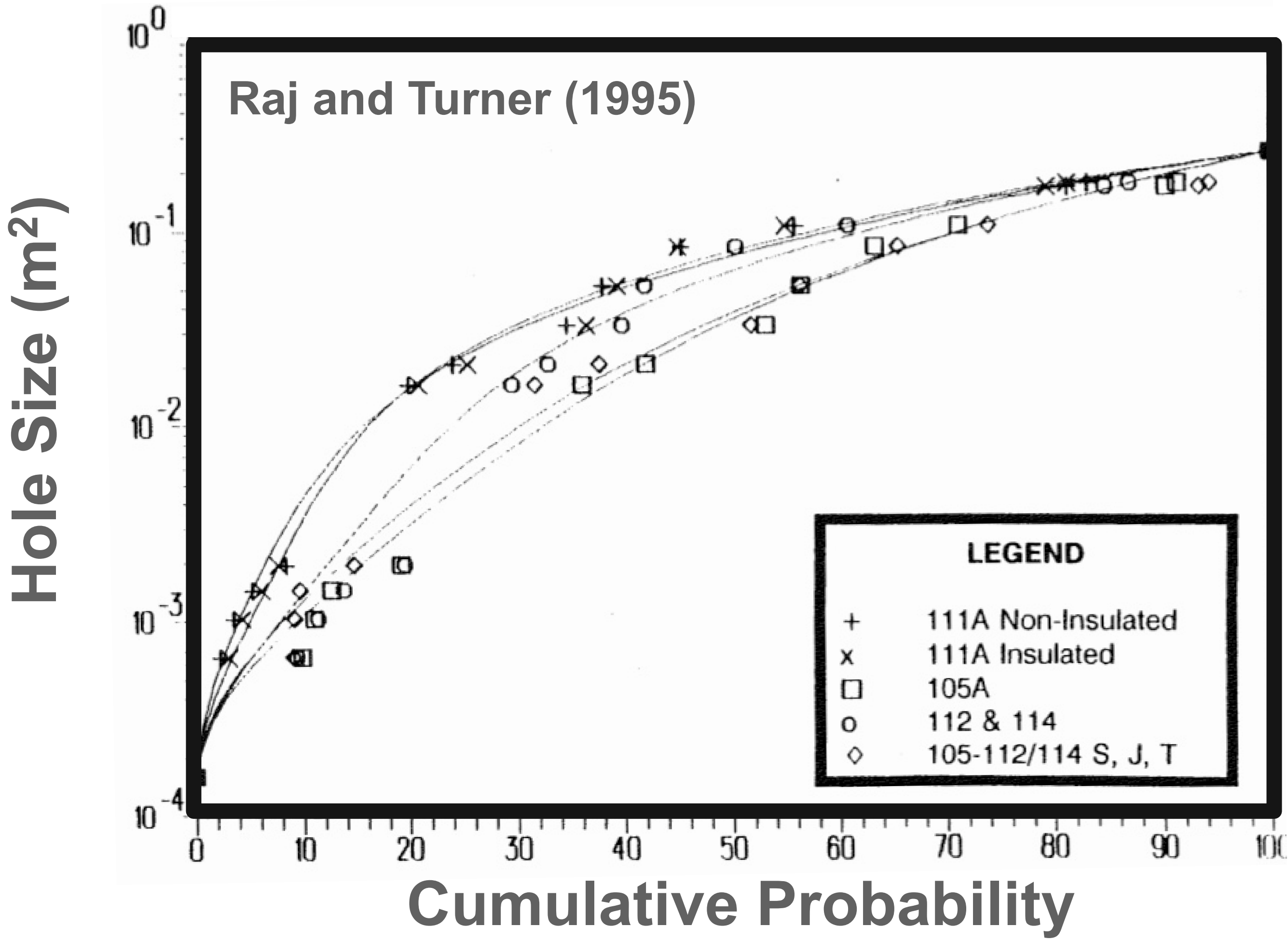
Discharge Fraction Example



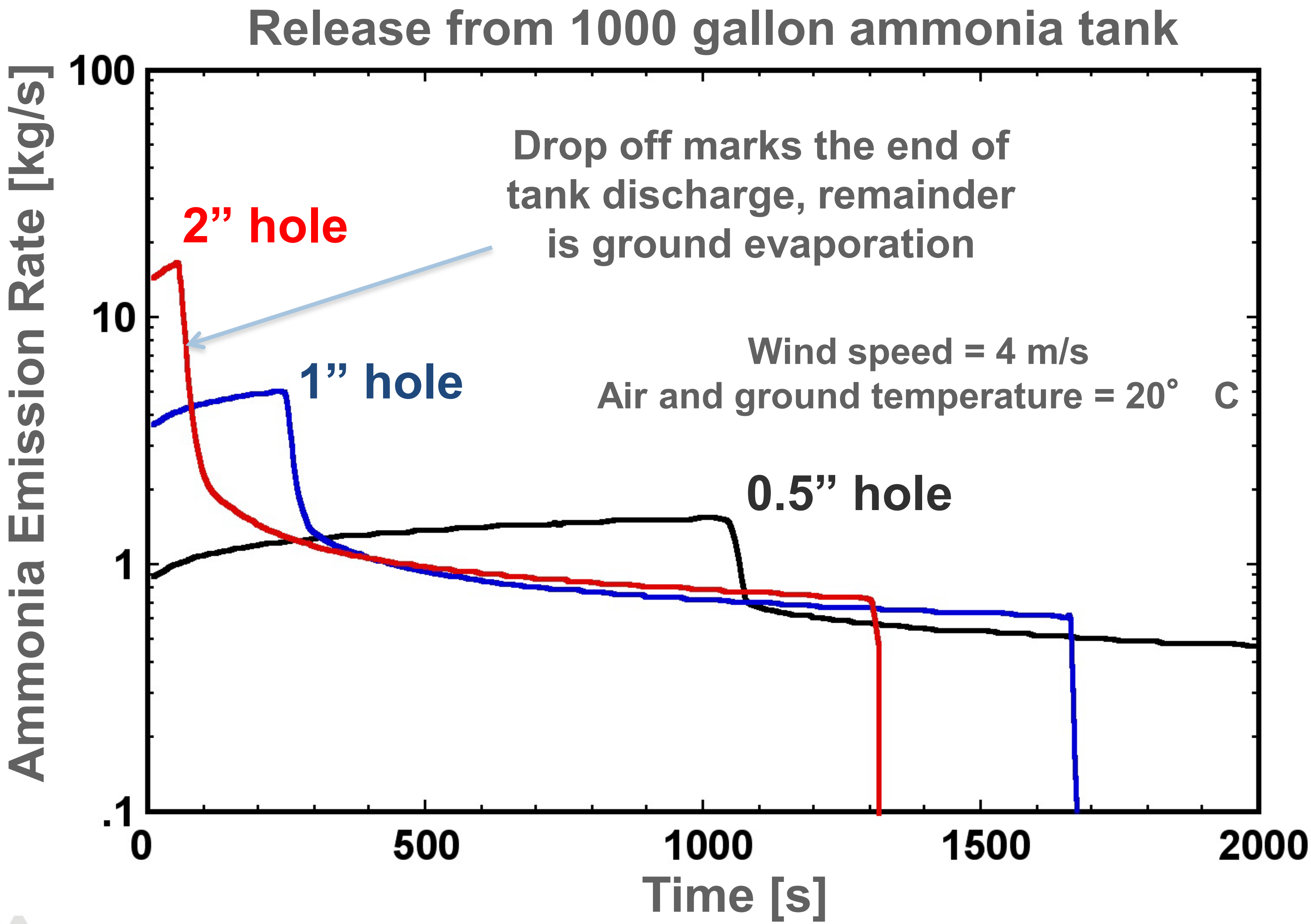
Discharge Fraction Example



Tank Car Hole Size Distributions

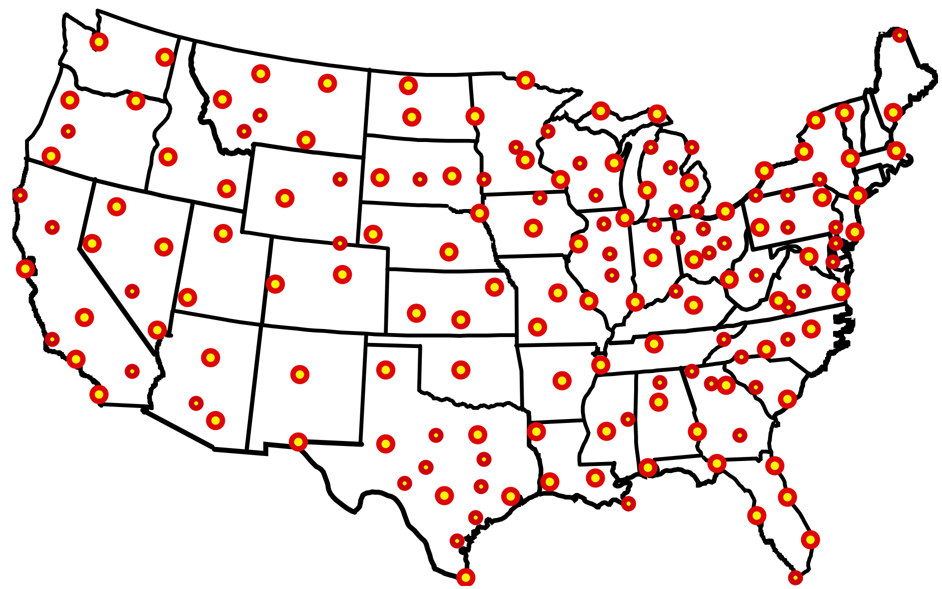


Emissions Example for Ammonia



Meteorological Data

- **Observational data**
  - 204 Cities (US), 5 Canada
  - 10 Yrs. data (1996-2005)
  - Surface observations
    - wind speed/direction
    - temperature
    - cloud cover
    - humidity
    - pressure
    - precipitation
  - Upper-air temperature profiles
  - Land use and vegetation information
  - Soil properties



- **Calculated parameters**
  - Friction velocity
  - Surface heat flux
  - Ground and pavement temperature profiles
  - Mixing height

Key Point Concerning Shipment Information

- The shipment amounts considered in the ERG analysis are chemical dependent per CFR 49 and available shipment information
- Result: For large spill entries, representative release quantities for Hazard Zone A gases are typically much lower than for materials authorized for bulk transportation
- In other words: large spill Protective Action Distances for materials like arsine or hydrogen selenide are representative of much smaller releases than for materials like chlorine or ammonia
  - 5-10 cylinders typical “large” spill for Hazard Zone A gases
  - Rail tank cars or tank trucks typical “large” spills for other materials

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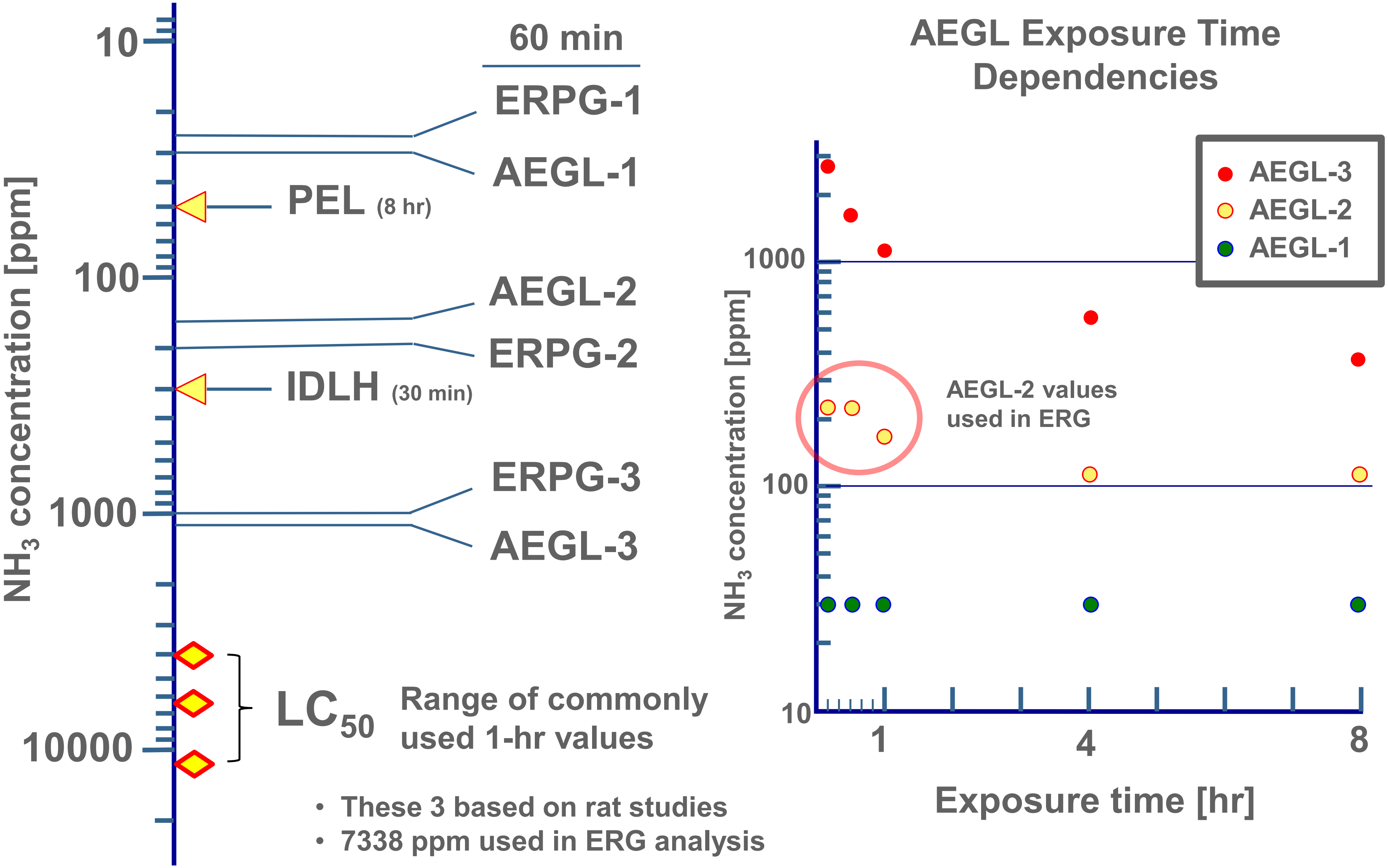
Protective Action Health Criteria - recap of 2016

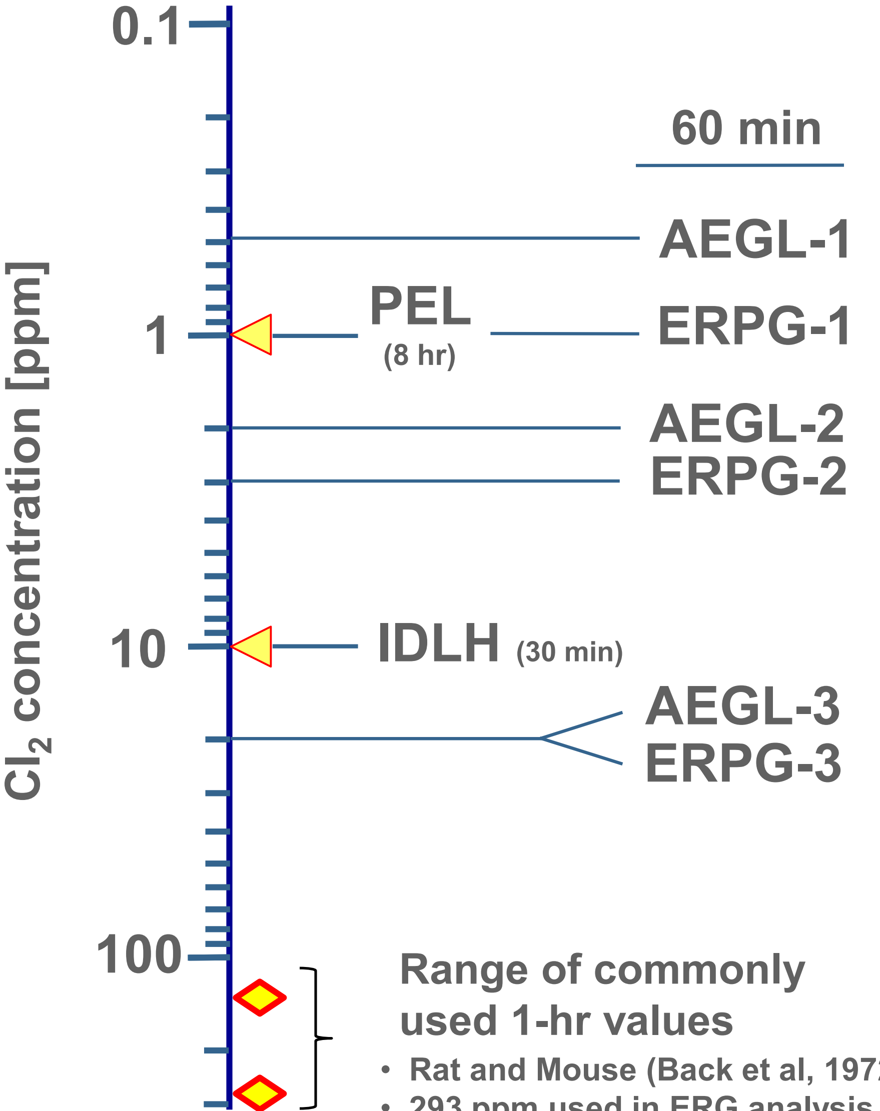
- Acute Exposure Guideline Level 2 (AEGL-2) used as the baseline for PAD definition
  - Short definition: Threshold for serious, long-lasting effects or an impaired ability to escape
  - Applies to sensitive populations
  - Interim and Final AEGL's used in ERG analysis
  - ERPG-2* used as a surrogate 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

Ammonia Health Criteria



- These 3 based on rat studies
- 7338 ppm used in ERG analysis

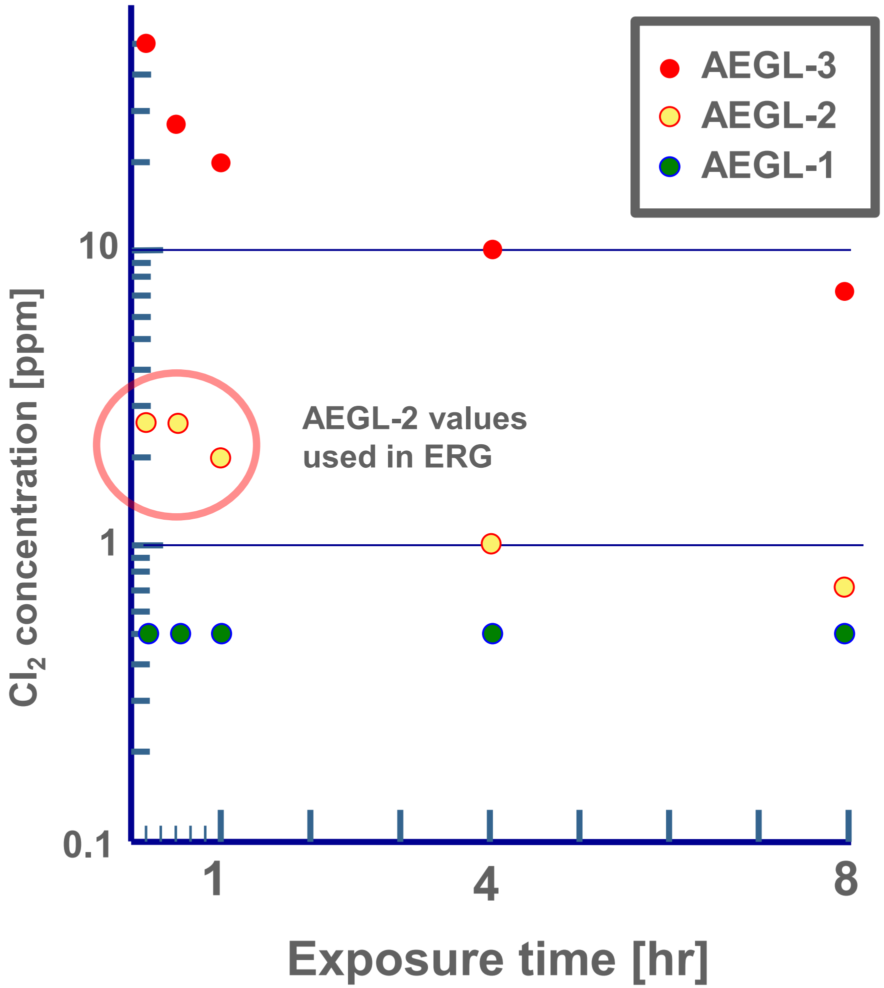
Chlorine Health Criteria



Range of commonly used 1-hr values

- Rat and Mouse (Back et al, 1972)
- 293 ppm used in ERG analysis

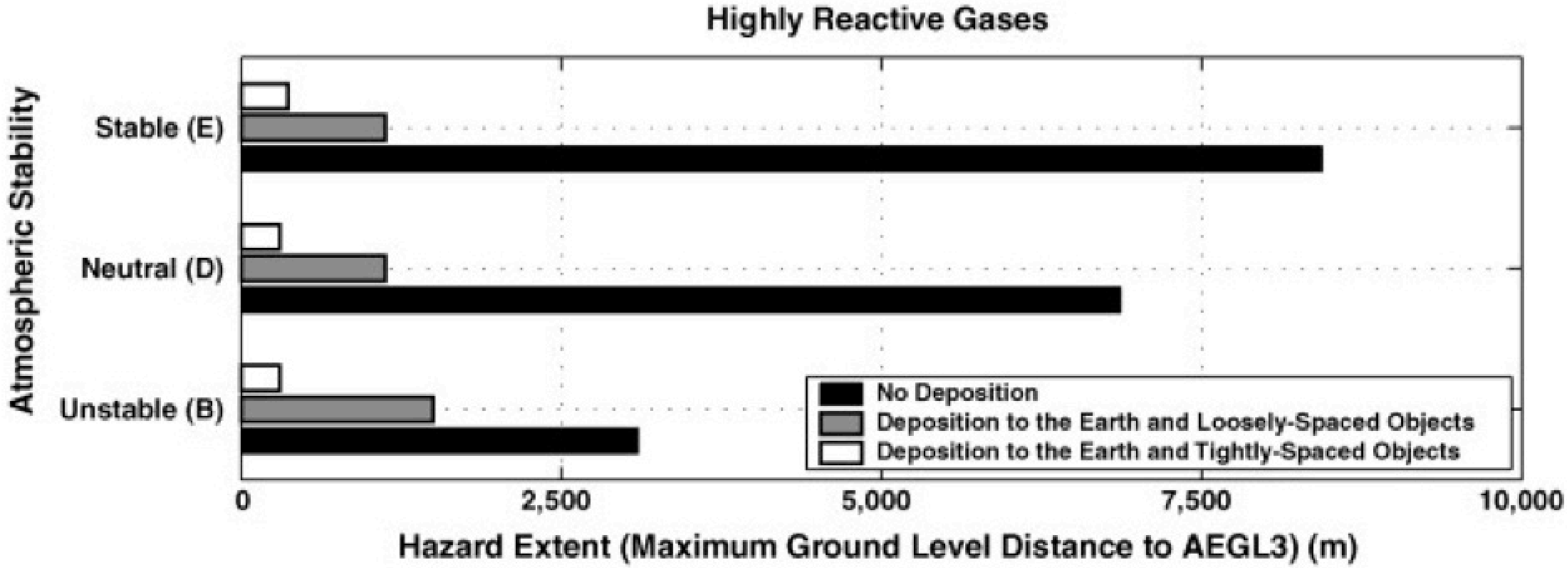
AEGL Exposure Time Dependencies

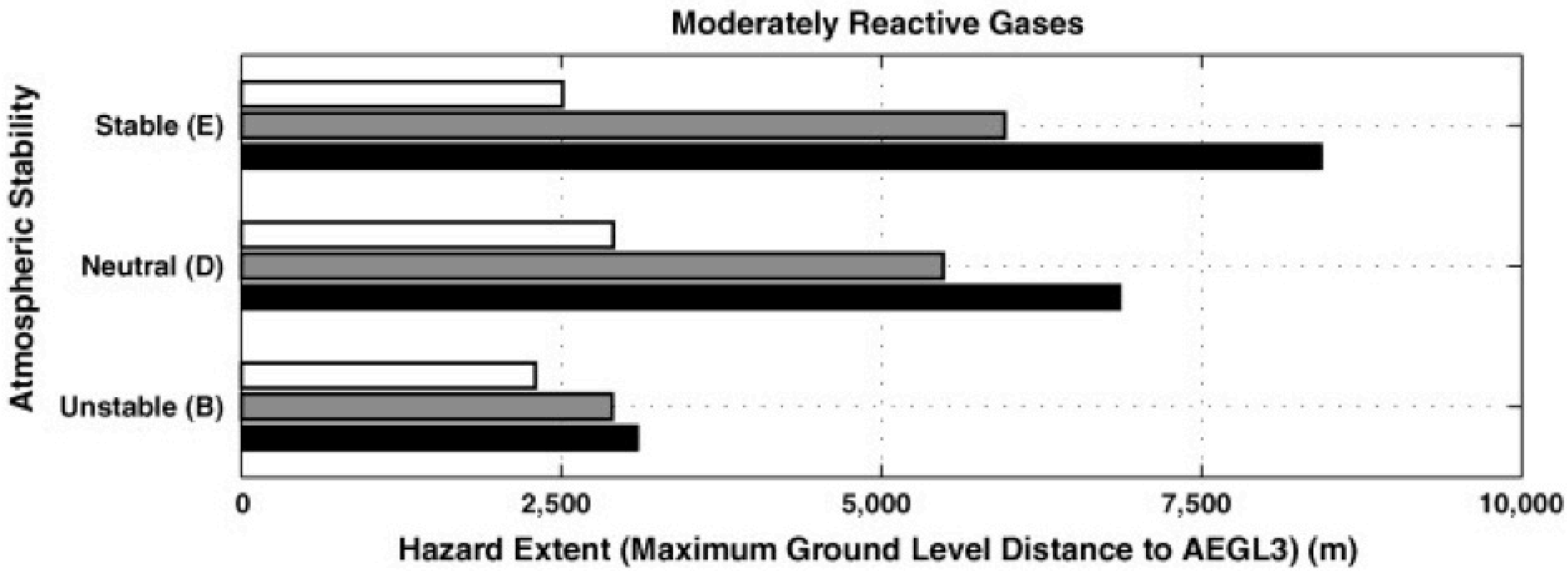


Reactivity Considerations

- 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

Example Results from Literature





From: Michael Dillon, *Role of Deposition in Limiting the Hazard Extent of Dense Gas Plumes,* Journal of Hazardous Materials, 2008

Final Results from Experimental Program

Surface depletion resistance R_c (s/m)

Vegetation/soil type	Chlorine	SO2	HCl	Ammonia	CO	H2S
Broadleaf evergreen forest	1023	9208	1592	8801	114942	49650
Broadleaf deciduous forest	1023	9208	1592	8801	114940	49650
Broadleaf and needleleafed mixed	869	9164	1378	4992	72400	28566
Needleleaf deciduous forest	1023	9208	1592	8801	114940	49650
Needleleaf evergreen forest	930	8887	1392	1985	56883	29431
Tundra	220	490	147	166	75000	19753
Broadleaf shrubs	1266	10929	1989	11038	93670	39108
Grassland/Prairie	295	4045	401	2089	73500	37878
Field crops	618	6333	929	5067	88567	18765
Surburban areas	618	6339	930	5072	88567	18765
Urban areas	618	6339	930	5072	88567	18765
Bare areas	174	354	106	135	75187	20661
Water	821	660	102	297	75230	25864
soil low moisture	128	217	66	104	77562	27633
soil high moisture	220	490	147	166	75000	19753

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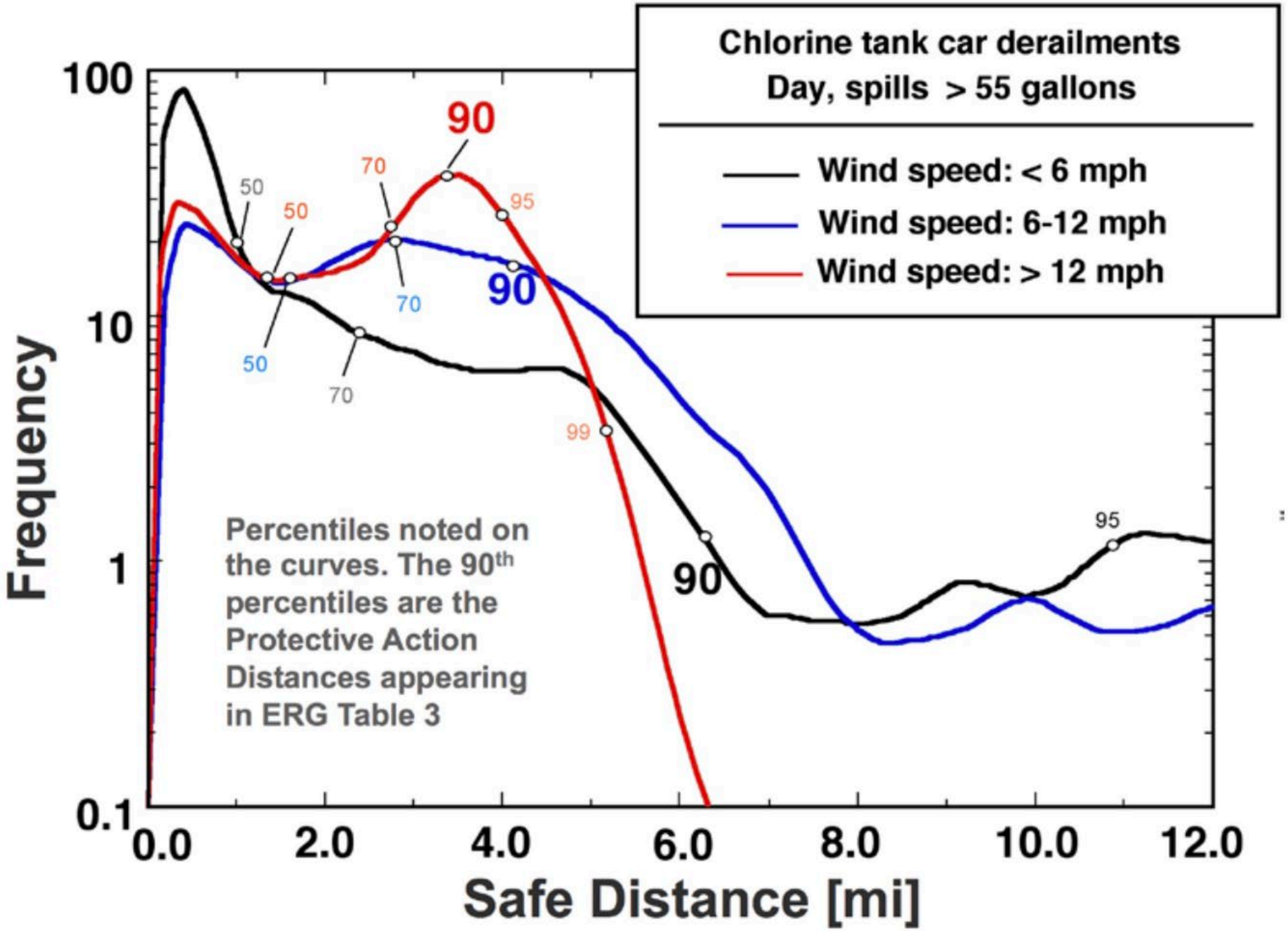
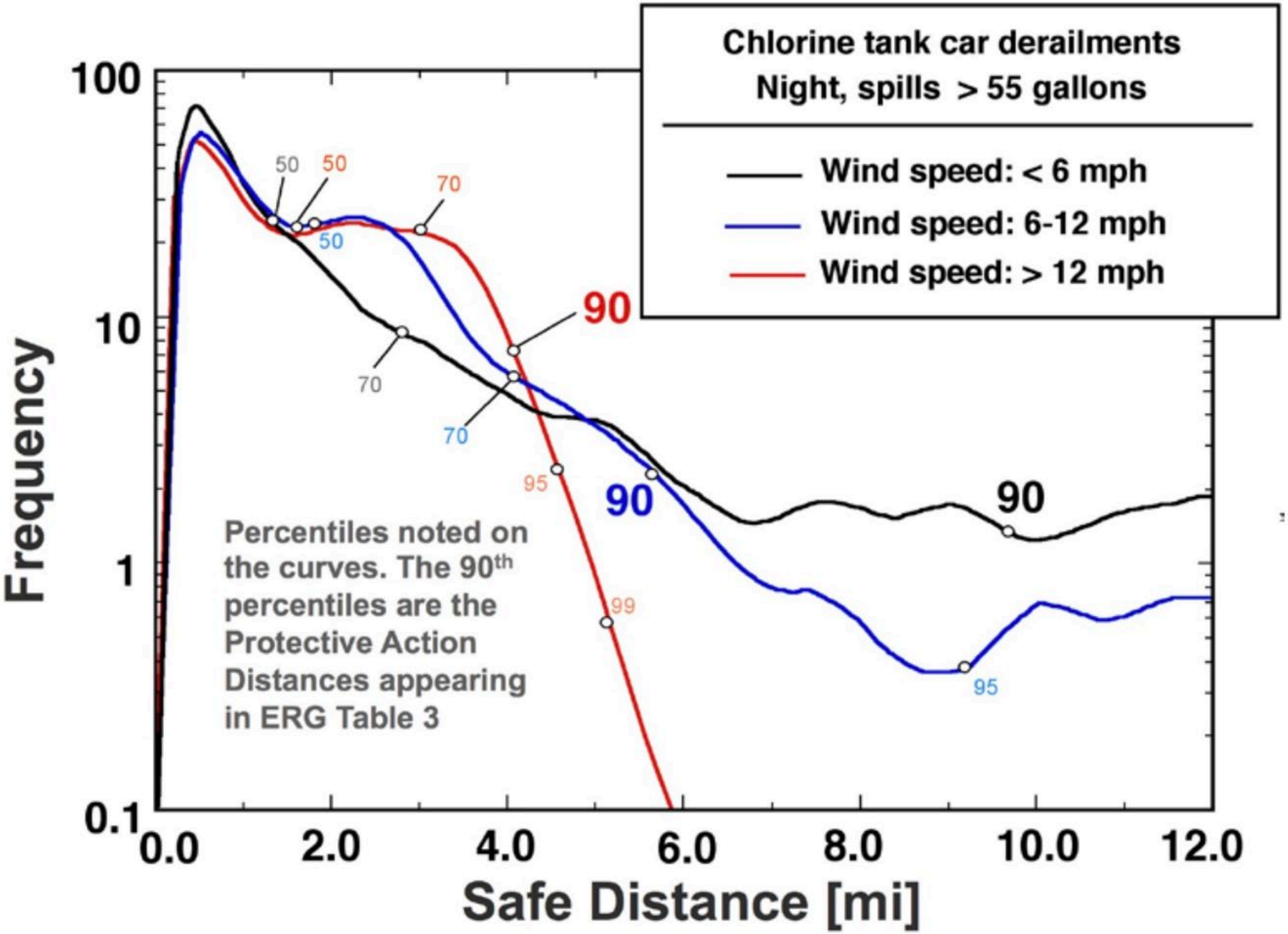
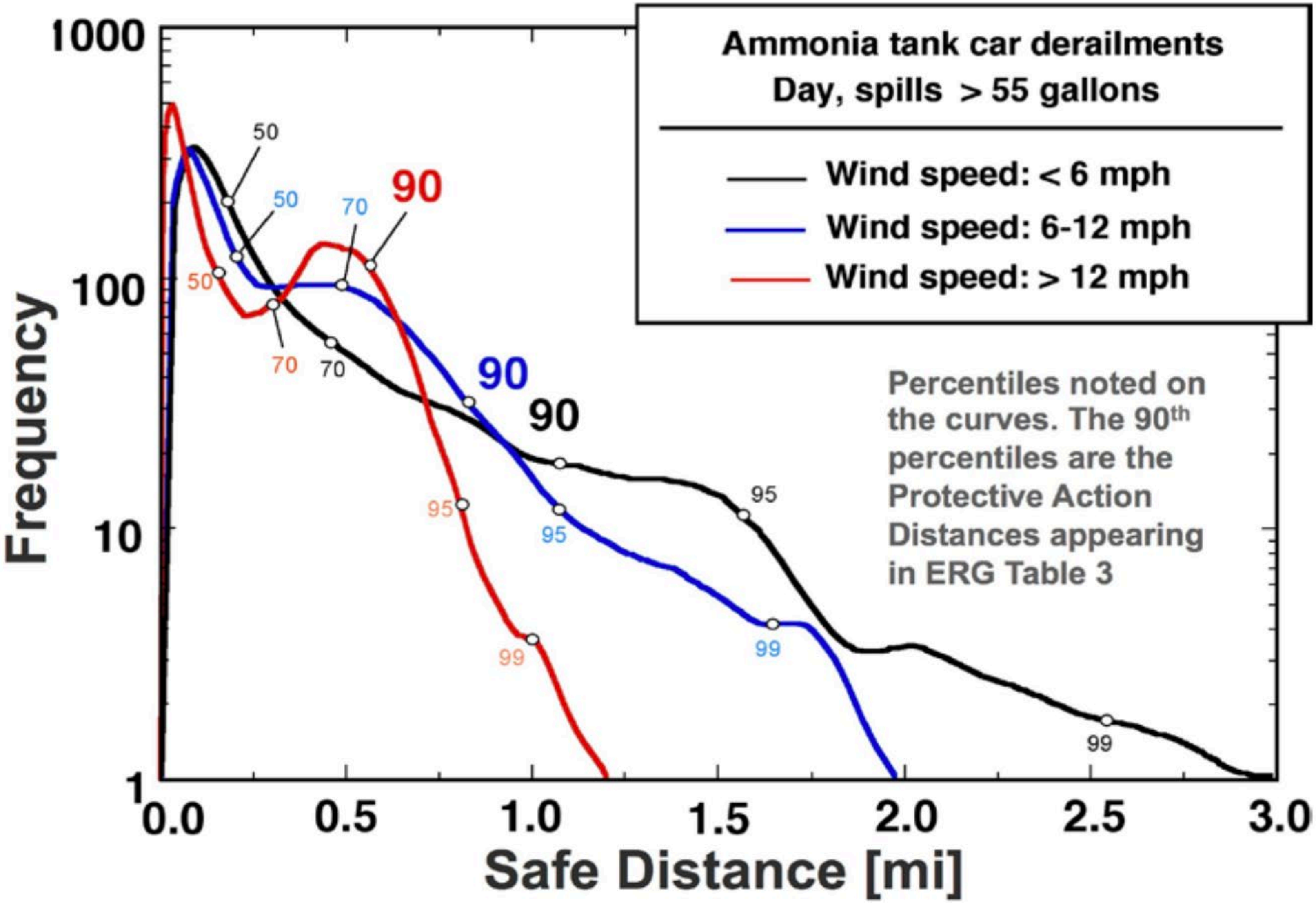
Level of Protection Example: Large Day Chlorine Spills



Level of Protection Example: Large Night Chlorine Spills



Level of Protection Example: Large Day Ammonia Spills



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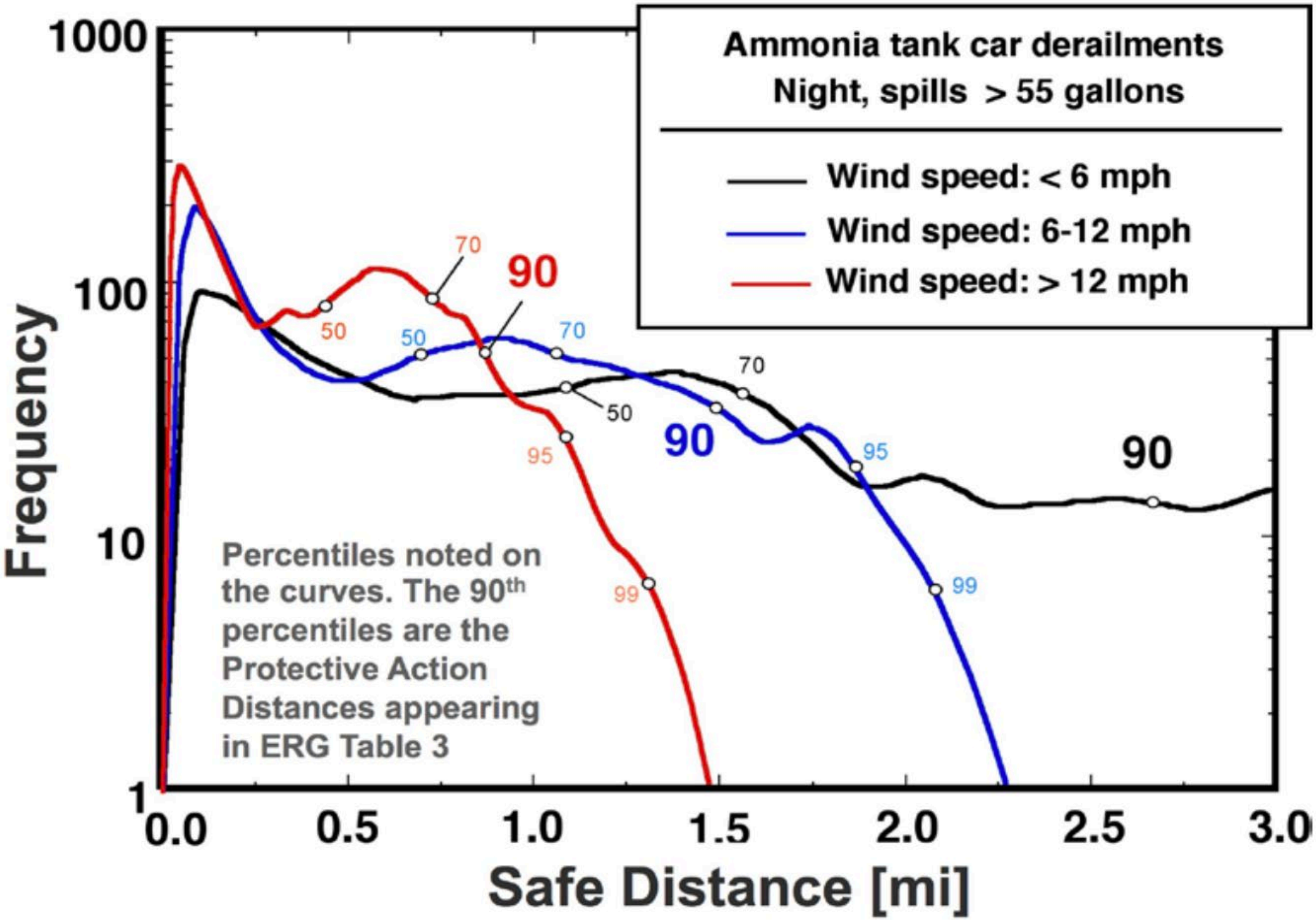
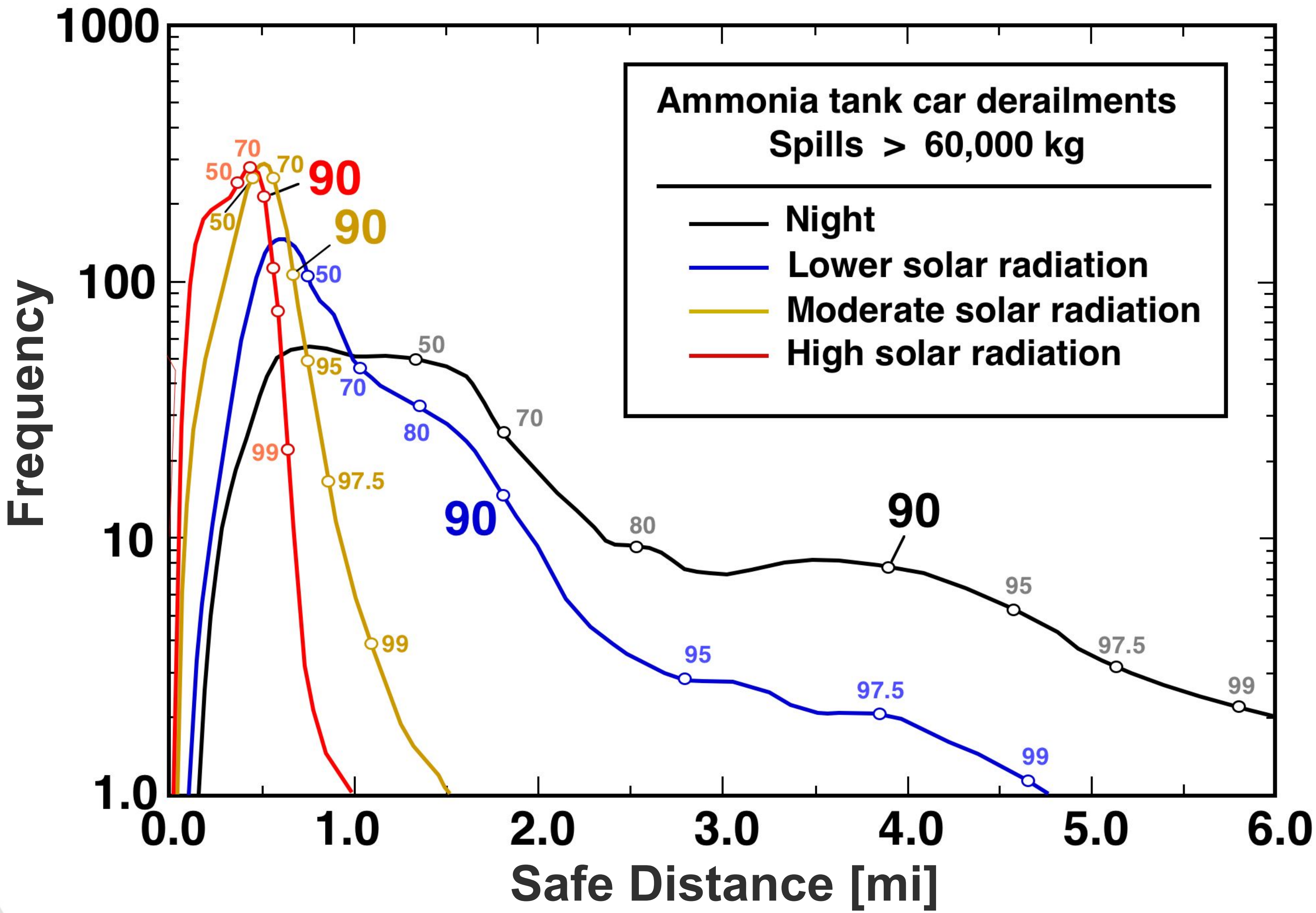


Benefit of Detailed Data (Example)



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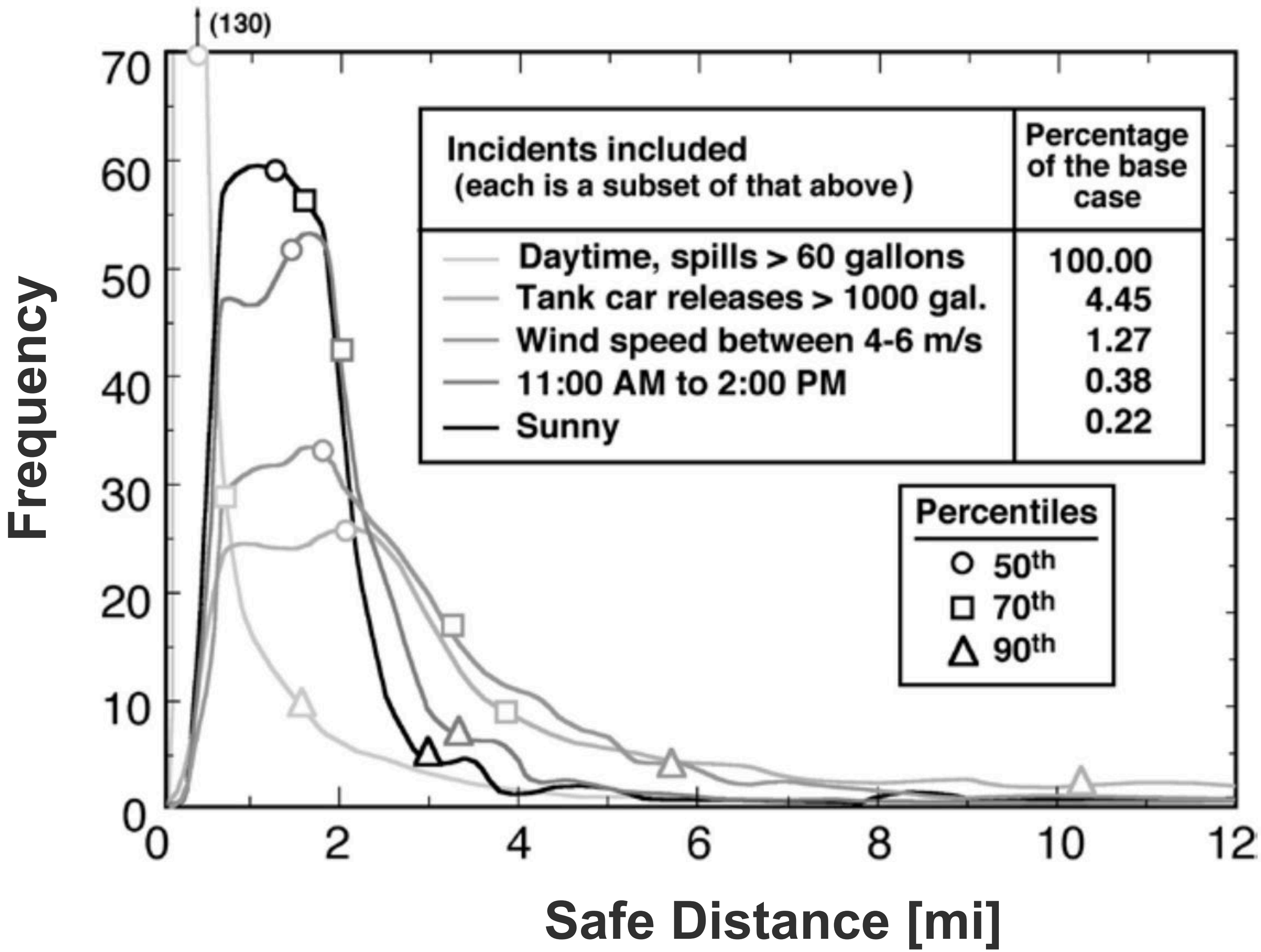

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Benefits of Sheltering

- Sheltering dramatically reduces toxic effects
  - For most chemicals, the toxic load is much worse for brief high concentration exposures than if the dosage was spread over a longer time

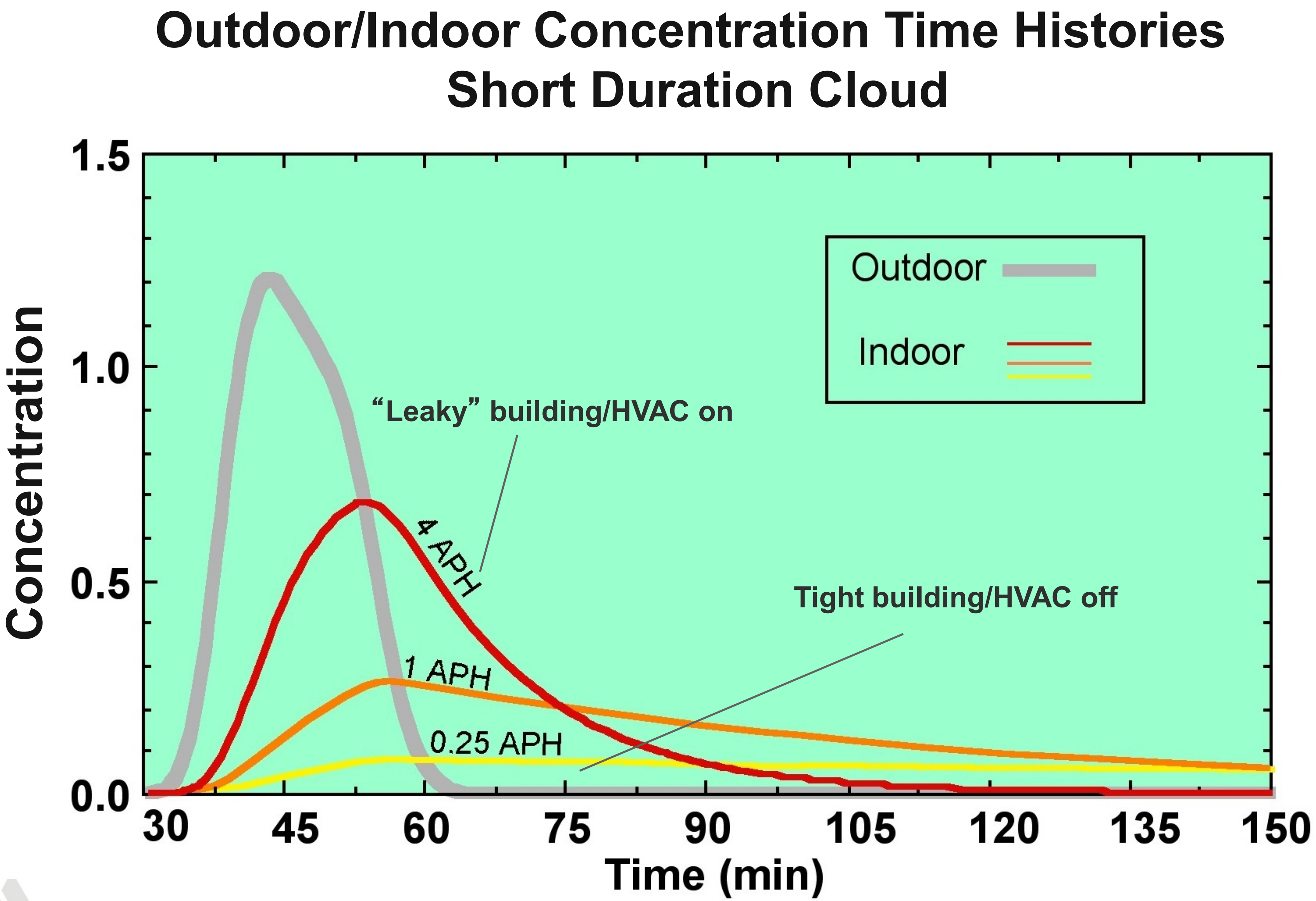
$$\text{Toxic load} = C^{n} \times \text{time}$$

n = 1.3	phosgene
n = 2	ammonia
n = 4	hydrogen sulfide

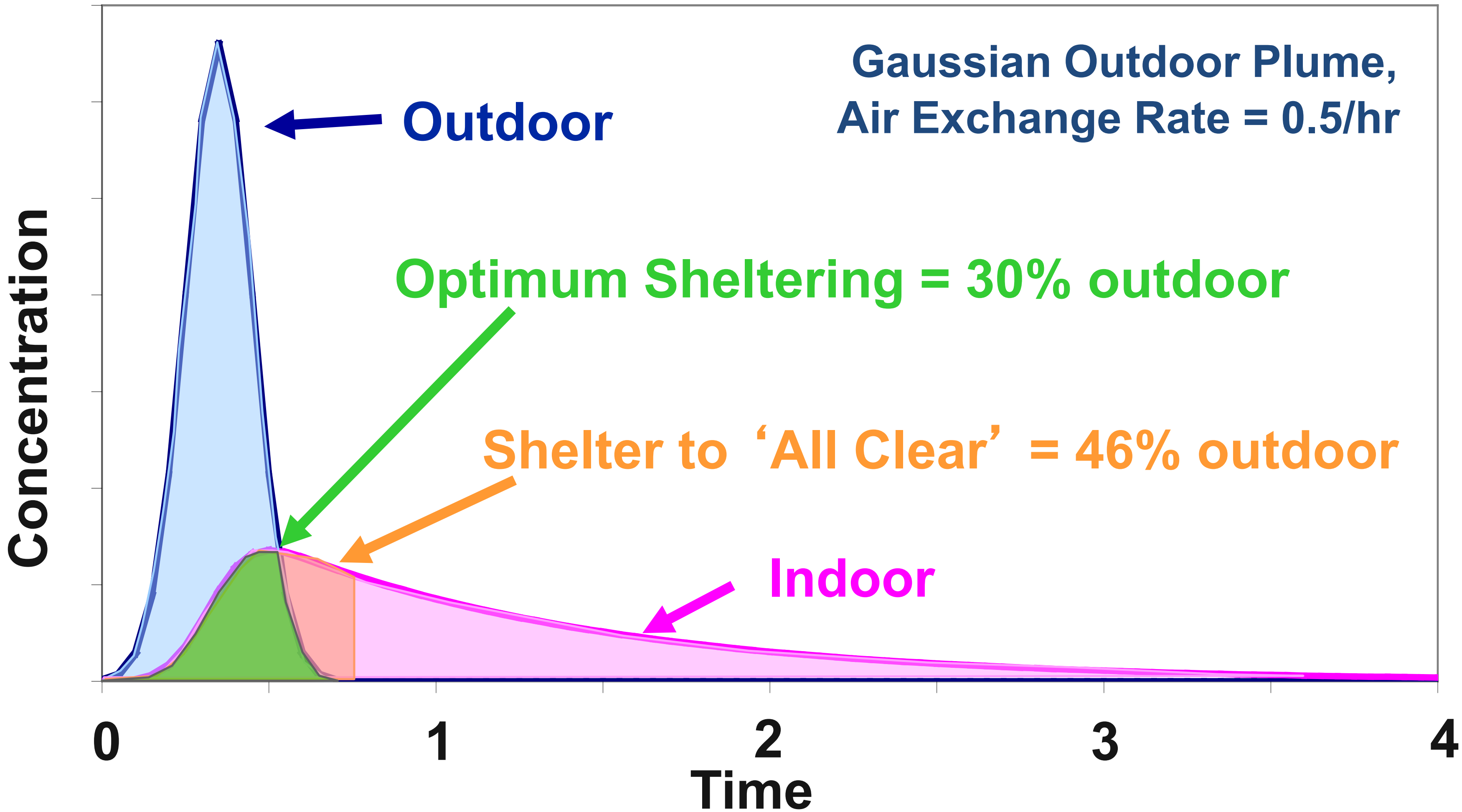
  - These benefits are very significant even for long duration chemical plumes
  - Indoor exposures often further reduced by chemical absorption and degradation once indoors

- Sheltering is usually far safer than evacuation
- Considerable operational experience exists in training and notifying vulnerable offsite populations

Benefits of Sheltering



Terminate Shelter in Place (TSIP)



For conservative species indoor = outdoor exposure

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Key Issues

- JRII data is the only dataset involving multi-ton releases of chlorine in a well instrumented field study
- Almost all JRII releases had peak concentrations well above the AEGL-2 level at 7 mi (11 km)
- This has led to criticisms that PAD estimates are way too small; whereas prior to JRII they were viewed as far too conservative
- How do we resolve this in light of a very solid state-of-the-science dataset?
- And … does this call for a complete re-evaluation of the entire methodology of the ANL approach?

Key Issues

- Full statistical model evaluation of CASRAM against JRII is ongoing – full dataset has (very) recently been finalized
- What we will show here is a comparison of maximum values and how those would vary under more typical surfaces
- Surface types evaluated:
  - JRII Dugway salt flats
  - Flat lightly vegetated surfaces
  - Typical low cropland
  - Rural areas with scattered trees
  - Suburban areas with many trees
  - Forested areas
  - Urban areas (or winter forests w/o active vegetation

Key Land Surface Parameters

Land Use	Z_o (m)	Leaf area index	Soil Moisture
JRII Dugway salt flats	0.0005	0	Dry
Flat lightly veg. surfaces	0.005	1	Dry
Typical low cropland	0.025	3	Moderate
Rural areas with sct. trees	0.01	5	Moderate
Suburban w/many trees	0.3	3	Moderate
Forested areas	1	7	Moderate
Urban areas/winter forests	1	1	Moderate

Key Meteorological Variables

Test #	Wind Speed[1] [m/s]	Temp. [K]	Friction Velocity [m/s][2]	Monin Obukhov Length [m]	Mixing Height [m]
1	2.0	291	0.094	8.1	50
2	5.2	297	0.19	-17	250
3	3.8	294	0.13	21	100
4	2.3	294	0.080	20	80
5	2.1	295	0.072	60	200
6	2.7	296	0.097	18	100
7	3.7	291	0.17	33	175
9	2.5	284	0.11	18	100

[1]PWIDS 2m Tower 3 – generally 30 min average

[2]Calculated based on roughness, wind speed and L

Comparisons of Peak Concentrations [ppm]

Test #	Release amount	JRII Data [peak]	CASRAM [60 sec]	CASRAM [600 sec]	CASRAM [3600 sec]
1	4509	20	15.5	12.8	2.8
2	8151	13	11.1	3.7	0.8
3	4512	0.3	9.8	5.4	1.0
4	6970	22	21	13	2.9
5	8303	6.5	7.5	6.3	1.4
6	8373	50	29	22	4.7
7	9607	50	26	20	3.4
9	17690	106	58	41	7.8

Comparisons of 600 s Avg Concentrations [ppm]

1000 m

Land Use	Trial 5	Trial 7	Trial 9
JRII Dugway salt flats	1324	996	1929
Flat lightly veg. surfaces	670	286	1176
Typical low cropland	351	171	651
Rural areas with sct. trees	155	142	398
Suburban w/many trees	57	93	287
Forested areas	18	67	107
Urban areas/winter forests	27	130	165

Comparisons of 600 s Avg Concentrations [ppm]

5000 m

Land Use	Trial 5	Trial 7	Trial 9
JRII Dugway salt flats	46	64	128
Flat lightly veg. surfaces	12	6.5	48
Typical low cropland	2.6	2.2	14
Rural areas with sct. trees	0.69	1.8	3.7
Suburban w/many trees	0.48	0.33	2.8
Forested areas	0.10	0.25	0.34
Urban areas/winter forests	0.42	1.6	1.7

Comparisons of 600 s Avg Concentrations [ppm]

11,000 m

Land Use	Trial 5	Trial 7	Trial 9
JRII Dugway salt flats	11.5	20	41
Flat lightly veg. surfaces	0.55	0.30	2.20
Typical low cropland	0.10	0.083	0.50
Rural areas with sct. trees	0.019	0.072	0.22
Suburban w/many trees	0.032	0.30	0.11
Forested areas	0.015	0.075	0.022
Urban areas/winter forests	0.028	0.092	0.085

Conclusions and Next Steps

- Analysis to data shows no systematic biases in the CASRAM transport and dispersion model
- Translation to more realistic surfaces suggests chlorine concentrations would be much smaller in most instances
- Full statistical analysis with final data set will be performed

Questions

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