RESPONDER PRESENTATION

JACK RABBIT

Catastrophic Releases of Liquefied Compressed Gases

Homeland Security
Science and Technology

U.S. Fire Administration
Working for a fire-safe America

BERKELEY LAB

UVU EMERGENCY SERVICES
UTAH VALLEY UNIVERSITY

Highest Priority TIHs – 2009 Gap Analysis – *Why Chlorine?*

The most widely-shipped toxic inhalation hazard (TIH) chemicals in US by route.

Domestic Shipping Totals by Route (U.S. Tons)

Chemical	Road	Rail	Water	Total	% of Total
Ammonia (NH_3)	5,793,000	3,470,592	1,718,974	**10,982,566**	**52.8%**
Chlorine (Cl_2)	724,000	3,750,372	137,202	**4,611,574**	**22.2%**
Sulfuric Acid (H_2SO_4)	257,000	207,560	2,057,721	**2,522,281**	**12.1%**
Acrylonitrile (C_3H_3N)	29,000	277,200	671,474	**977,674**	**4.7%**
Ethylene Oxide (C_2H_4O)	106,000	671,260	1,132	**778,392**	**3.7%**
Hydrogen Fluoride (HF)	29,000	264,560		**293,560**	**1.4%**
Sulfur Dioxide (SO_2)	72,000	172,480	361	**244,841**	**1.2%**
Hydrogen Chloride (HCl)	2,000	8,400	166,027	**176,427**	**0.8%**
Hydrogen Cyanide (HCN)	33,000	31,600		**64,600**	**0.3%**
Bromine (Br_2)	61,000			**61,000**	**0.3%**
Nitric Acid (HNO_3)	3,000	35,800	44	**38,844**	**0.2%**

~75%

~95%

~99%

- Ammonia and chlorine dominate volume shipped
- Consideration of chlorine's much greater toxicity: Chlorine is TIH of greatest concern in transport

Recent Chlorine Releases

- Festus, MO, 2002
  - Ruptured 1-inch Cl_2 fill line
- Macdona, TX, 2004 (3 dead, 60 tons)
- Graniteville, SC, 2005 (9 dead, 60 tons)
- Iraq Chlorine Attacks, 2007-2008
  - Chlorine 1-ton containers and cylinders
  - Approximately 15 attacks
- Attacks in Syria, Iraq 2014-2015
  - Chlorine 1-ton containers
  - Chlorine "Barrel Bombs"
- New Martinsville, WV, 2016 (90 tons)
  - Stub Sill crack 46" long




- Formula: Cl_2 (Diatomic molecule)
- Physical: Yellow/Green Gas
- Ionization Potential: 11.48 eV
- Four Digit ID Number: UN 1017
- Primary Hazard Class: 2.3 Inhalation Hazard
- Vapor Density: 2.48
- Vapor Pressure: 6.8 ATM @ 70° F
- Expansion Ratio: 460:1
- Solubility: None
- pH: < 1 reacts with water to form HCl
- Flammability: None
- Boiling Point: - 29° F
- Odor Threshold: 0.3 ppm
- TLV/TWA (8 hours): 0.5 ppm
- IDLH: 10 ppm

Index of Jack Rabbit Videos

1. 2015 Release 1 – Release Energy of Compressed Liquefied Chlorine
2. 2016 Release 7 – Detector Response Inside Vehicle
3. 2016 Release 8 – Wind is King - Top and Bottom Release
4. 2016 Release 9 – Wind is King – Little Retrograde Creep
5. 2015 Release 5 – Vehicles Remain Idling in Extreme Chlorine Environment
6. 2010 Trial 5 – Example of Rapid Phase Transition (RPT) @ 21:45
7. 2015 Release 5 – Effect of Liquid Chlorine Exposure on Common Urban Surfaces
8. 2016 Release 6 – Aerial View of Plume
9. 2016 Release 7 – Aerial View of Plume 135 Degrees Down
10. 2016 Release 8 – Aerial View of Plume– Top Release Only
11. 2016 Release 9 – Aerial View of 20 Ton Plume

Jack Rabbit Responder Training Outline

1. Recommended Mitigation Strategies for Public Protection
2. Accuracy of the Current ERG Protective Zone Distances
3. The Effects of Chlorine on Vehicle Infiltration and Performance
4. The ALOHA® Plume Model vs. Data from the JRII Trials
5. Reliability of a PID (11.7eV) During the JRII Trials
6. Significance of UVU Aerial Video During the JRII Trials
7. Auto-refrigeration Behavior and its Impact on the JRII Trials
8. Rapid Phase Transition (RPT) Behavior During the JRII Trials
9. Effect of Chlorine on Common Urban Surfaces

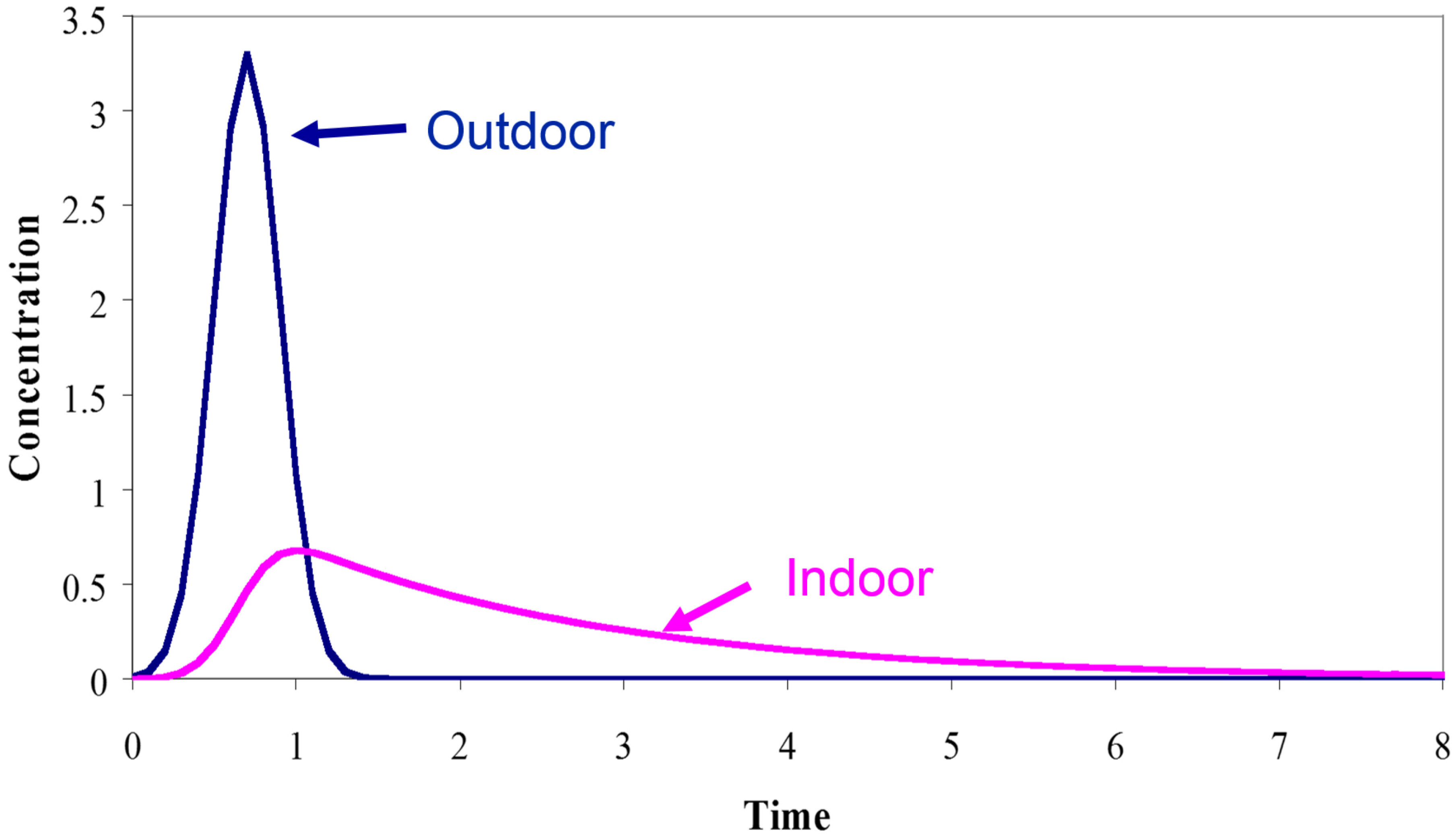
Jack Rabbit Test Control Logs 2015-2016

Trial	Date	Time 1 h:m:s	Stop 1 h:m:s	Time 2 h:m:s	Stop 2 h:m:s	Cl2 Lbs.	Size	Wind from	Wind Speed m/sec	Temp °C	RH %	Pressure mbar
2015												
1	8/24	13:35:45	13:36:43	n/a	n/a	9940	6”	147°	2.0	17.7	39.2	873.5
2	8/28	15:24:21	15:25:10	n/a	n/a	17969	6”	158°	4.2	22.7	33.6	875.12
3	8/29	13:56:55	13:57:31	n/a	n/a	9947	6”	169°	3.9	22.5	30.3	870.97
4	9/1	14:38:50	14:39:33	n/a	n/a	15366	6”	183°	2.3	22.5	26.9	869.26
5	9/3	13:28:19	13:29:09	n/a	n/a	18304	6”	182°	2.7	22.2	26.5	866.53
2016												
6	8/31	14:23:35	14:24:30	n/a	n/a	18460	6”	160°	2.3	22.0	21.6	871.1
7	9/2	13:56:00	13:57:20	14:07:08	14:09:20	19989	6”	160°	4.54	18.88	56.17	868.48
8	9/11	15:01:45	15:04:42	15:17:16	15:26:27	20020	6”	175°	2.18	14.75	26.49	873.31
9	9/17	14:05:30	14:10:21	n/a	n/a	39000	6”	164.6°	3.55	10.48	43.26	875.65

Final Report – Shelter in Place

Sheltering in place is the most survivable option as a primary means of public protection during such an emergency if evacuation is not possible. It is better to be inside a structure or vehicle than outside until the outside chlorine concentration drops and the danger has passed. Gas concentrations will be affected by multiple factors, primarily wind and terrain.

Theoretical Strategy for Sheltering in Place



Shelter in Place?

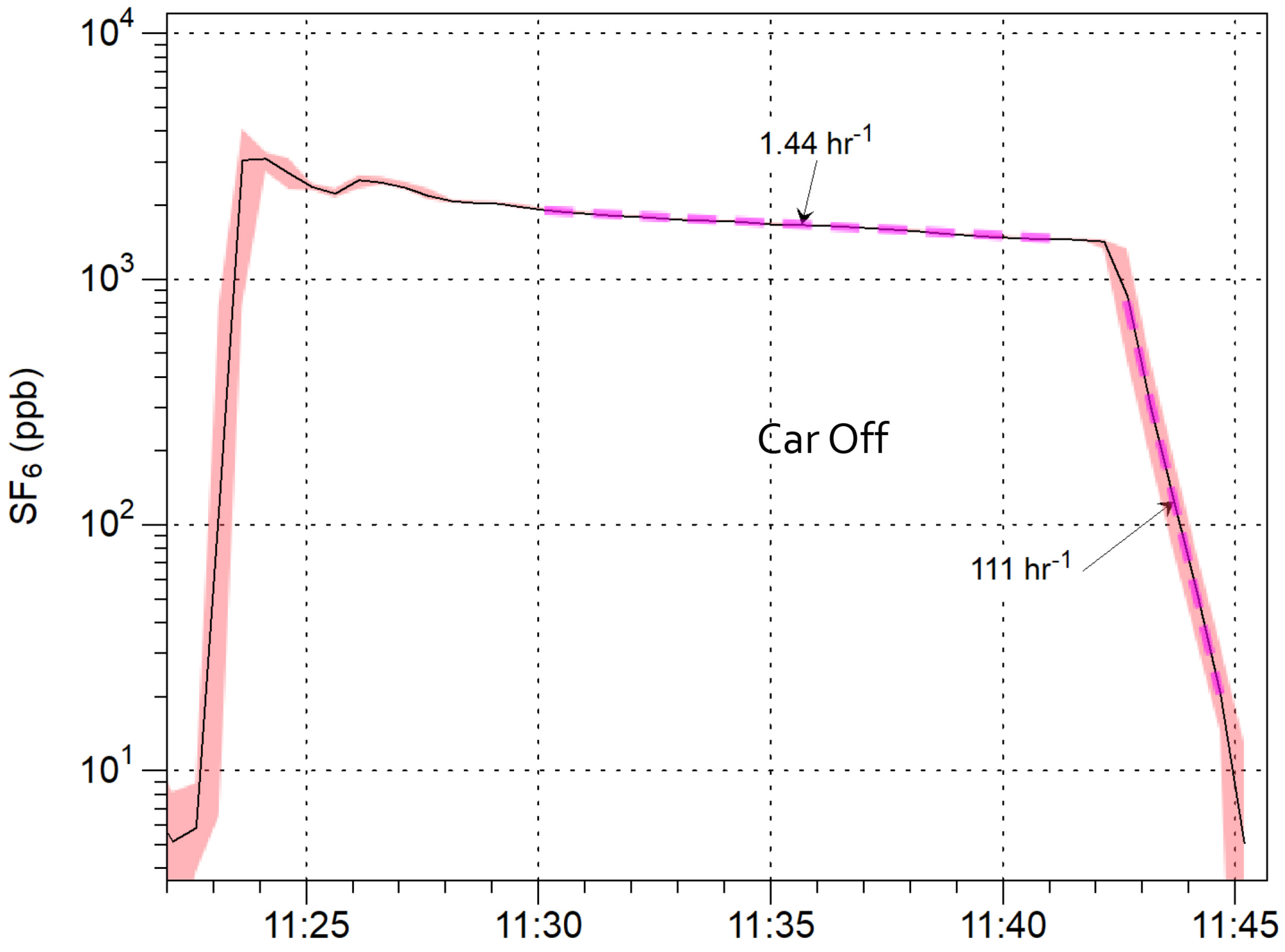
1) It is almost always better to stay inside than go outside.

2) Close exterior openings and stop ventilation systems when feasible.

3) Retreating to an interior room, without windows and away from exterior walls, provides a magnitude of protection. A closet is ideal because all of the fabric hanging has a higher sorption rate than a bathroom with tile and glass surfaces.

4) Stay inside until the outdoor concentration is lower than the inside concentration.

Car AC "fresh air" started at 11:42



Dr. Delp with SF_6

ACH Values	**Off**	**Fresh Air**	**Recirculation**
	1.1 – 1.2	153 (doors open)	N/A
	2.1	81 - 91	81 - 91
	1.6	108 - 152	108 - 152
	2.1	180 - 250	9.3
	1.44	111 - 136	3.9

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Final Report – Rely on the ERG

The 2016 Emergency Response Guidebook's (ERG) Initial Isolation and Public Protective Action distances are consistent with the Jack Rabbit data in both the upwind and downwind environment.

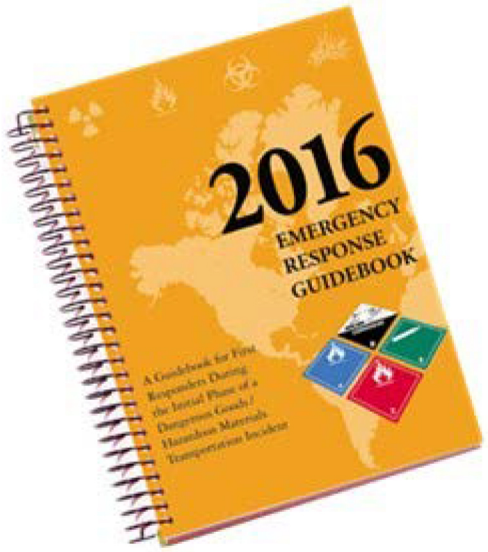
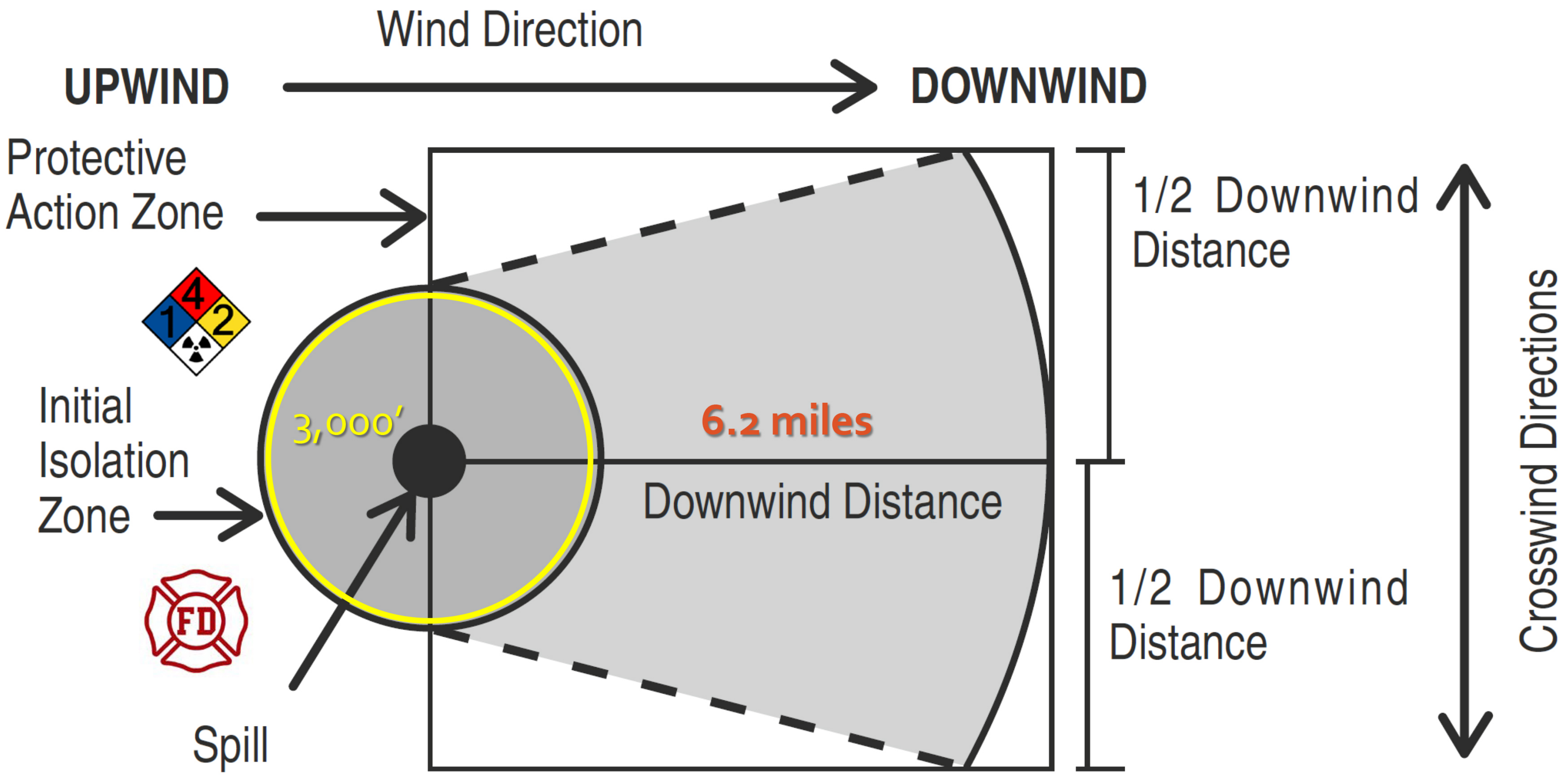
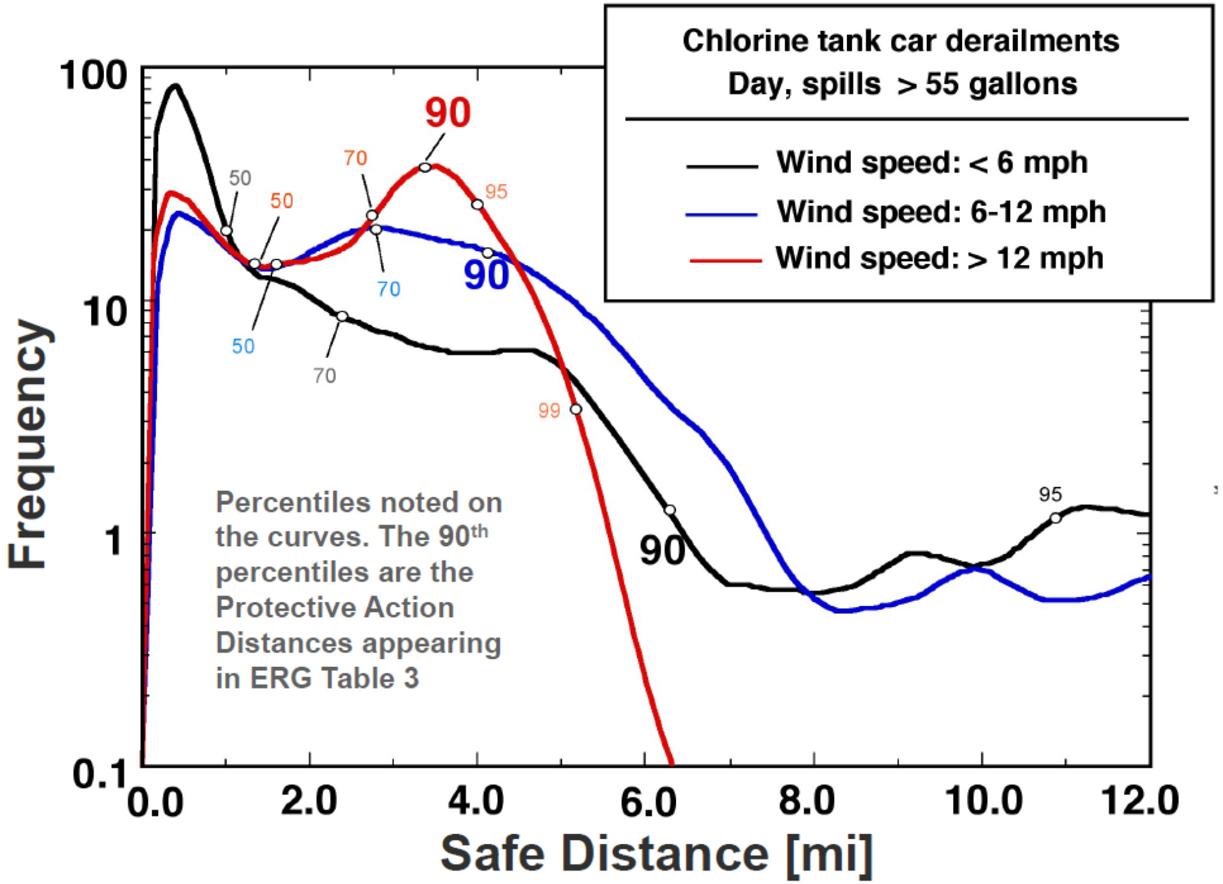


TABLE 3 - INITIAL ISOLATION AND PROTECTIVE ACTION DISTANCES FOR LARGE SPILLS FOR DIFFERENT QUANTITIES OF SIX COMMON TIH (PIH in the US) GASES

	First ISOLATE in all Directions		Then **PROTECT** persons Downwind during											
			DAY						NIGHT					
			Low wind (< 6 mph = < 10 km/h)		Moderate wind (6-12 mph = 10 - 20 km/h)		High wind (> 12 mph = > 20 km/h)		Low wind (< 6 mph = < 10 km/h)		Moderate wind (6-12 mph = 10 - 20 km/h)		High wind (> 12 mph = > 20 km/h)	
	Meters	(Feet)	km	(Miles)	km	(Miles)	km	(Miles)	km	(Miles)	km	(Miles)	km	(Miles)
TRANSPORT CONTAINER	**UN1017 Chlorine: Large Spills**													
Rail tank car	1000	(3000)	9.9	(6.2)	6.4	(4.0)	5.1	(3.2)	11+	(7+)	9.0	(5.6)	6.7	(4.2)
Highway tank truck or trailer	600	(2000)	5.8	(3.6)	3.4	(2.1)	2.9	(1.8)	6.7	(4.3)	5.0	(3.1)	4.1	(2.5)
Multiple ton cylinders	300	(1000)	2.1	(1.3)	1.3	(0.8)	1.0	(0.6)	4.0	(2.5)	2.4	(1.5)	1.3	(0.8)
Multiple small cylinders or single ton cylinder	150	(500)	1.5	(0.9)	0.8	(0.5)	0.5	(0.3)	2.9	(1.8)	1.3	(0.8)	0.6	(0.4)

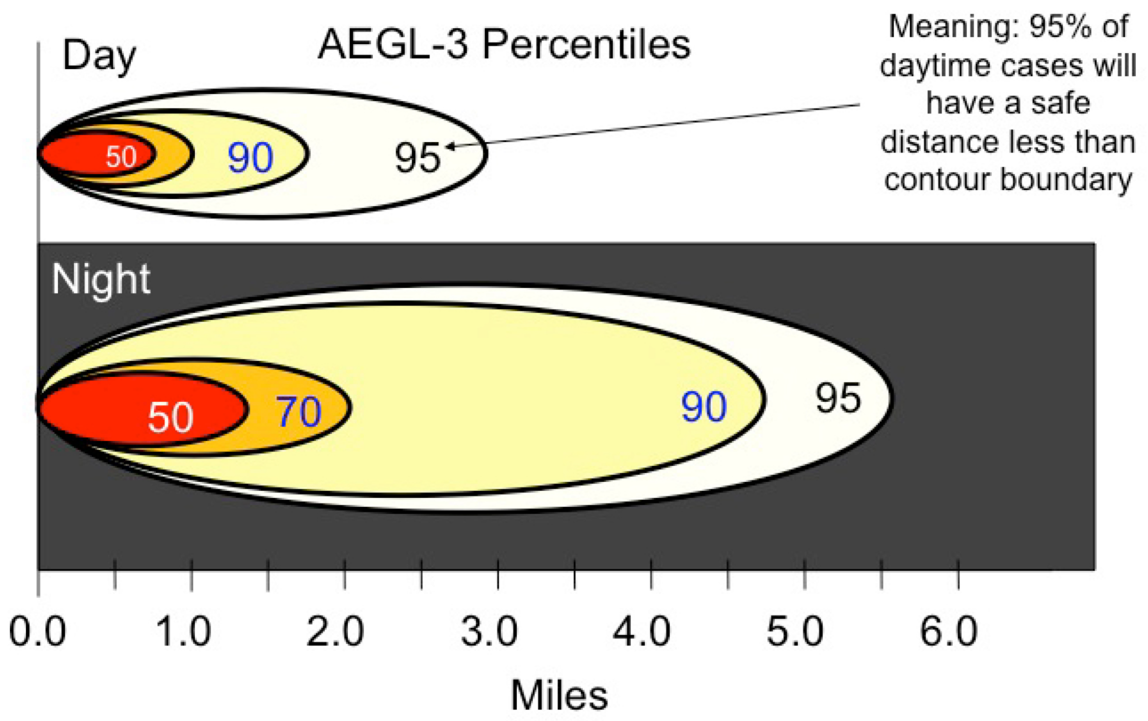


Pg. 295 2016 ERG – Daytime Railcar



Based on one million calculations per chemical

Wind Speed	*Temperature*
Humidity	*Chemical*
Discharge Fraction	*Date*
Time of Day	*Location*
Shipment Mode	*Container*

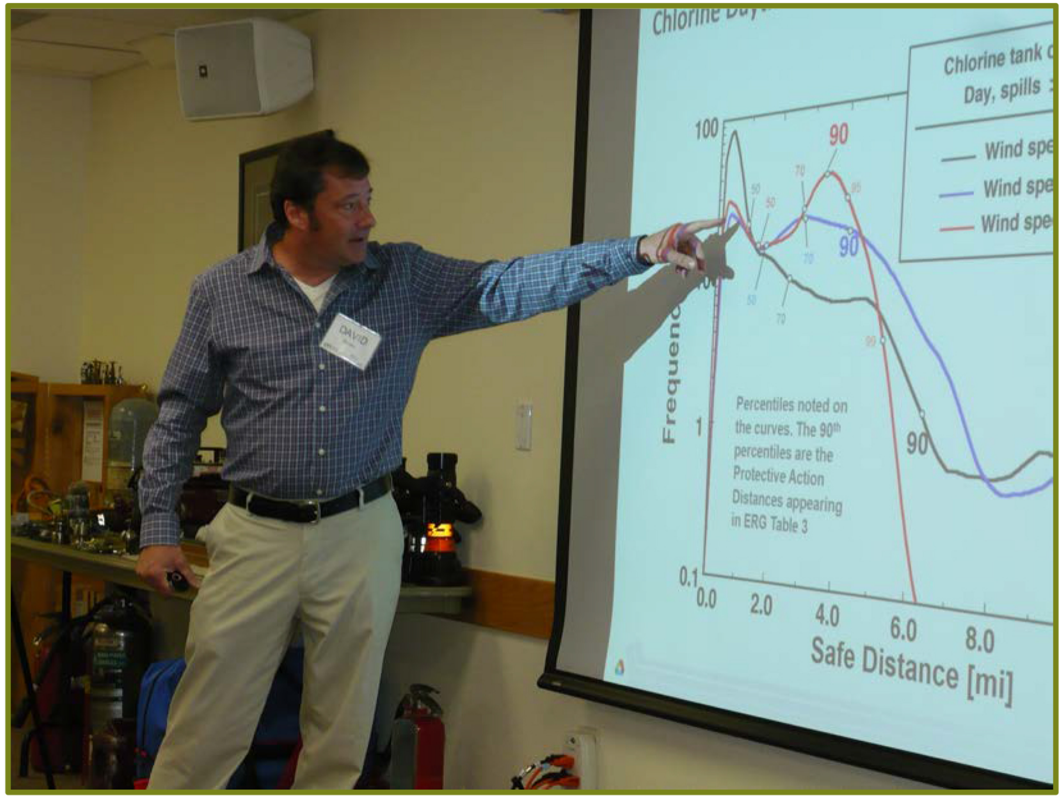


Dr. David Brown – Argonne Labs
DOT - PHMSA

"I would not expect a fatality at 3,000 feet (1,000m) upwind however, environmental and incident variables would indicate caution when deciding to move closer to the release."

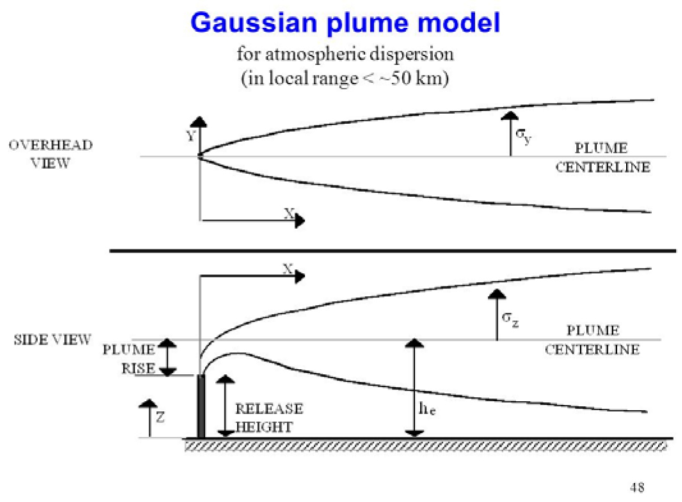
"The problem in determining Protective Action Distances is how to *balance the risk of insufficient protection with the risk of over-response*. The solution lies in a *risk-based approach* where a level of protection is specified using a statistical analysis.

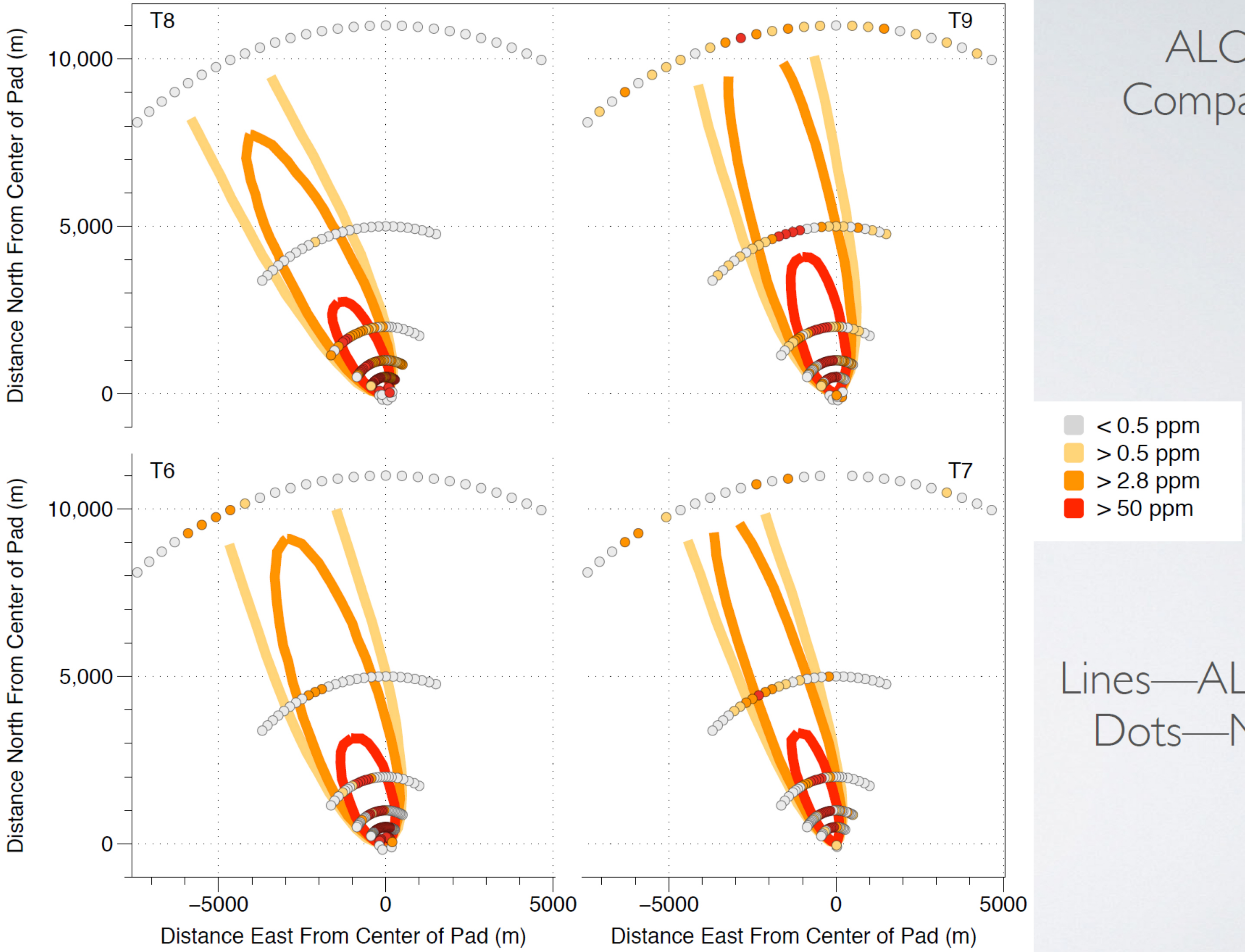
"Conservative isolation and protective action distances are intentional to protect vulnerable populations."



Final Report – Plume Model Limitations

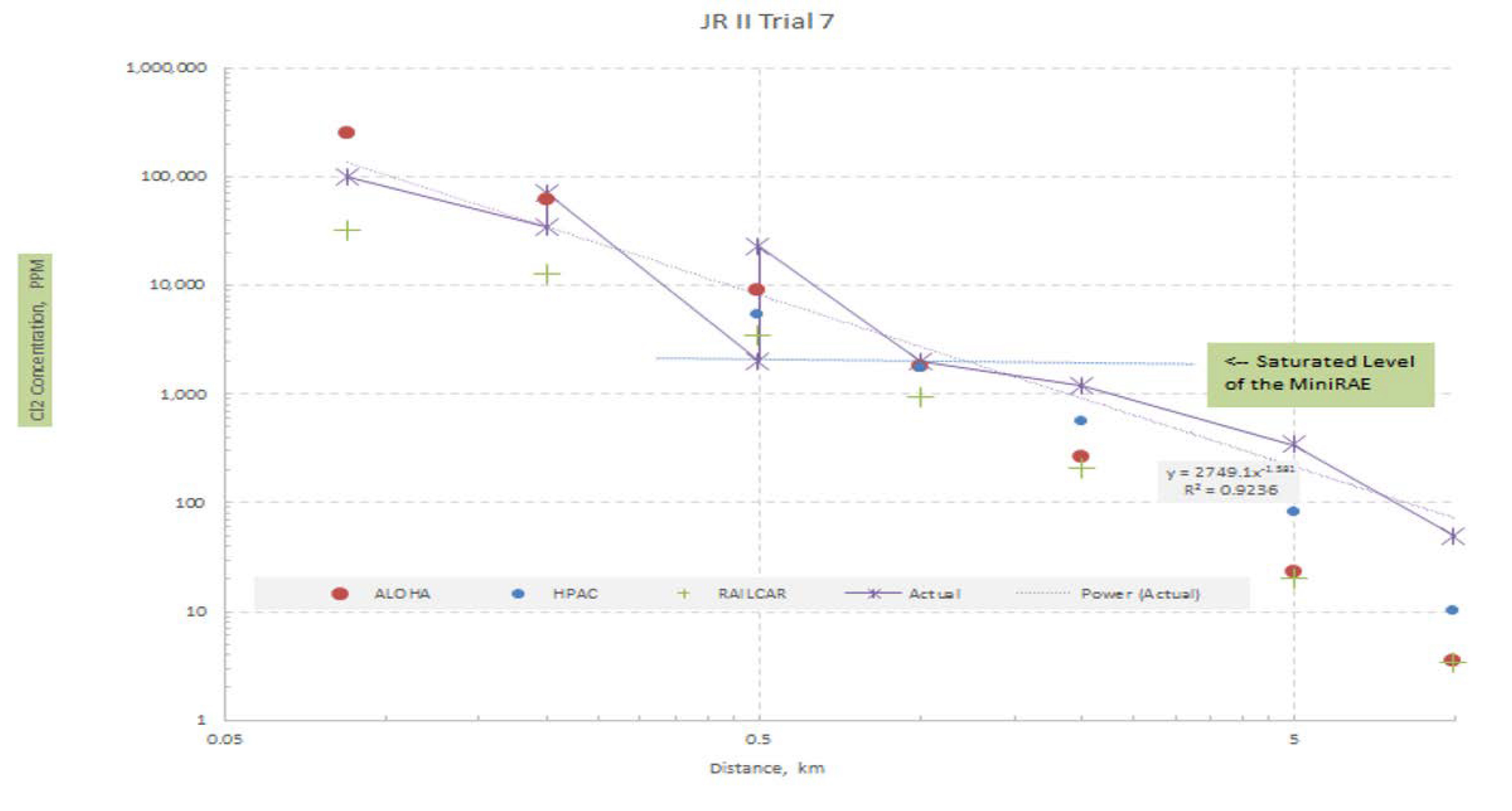
The primary strength of predictive plume models is in their use as planning guidance and/or forecasting tools rather than as emergency response tools due to the real-time uncertainty of some essential source data. First responders need to understand the application, limitations, and capabilities of the plume model they use, including the widely used ALOHA® model.





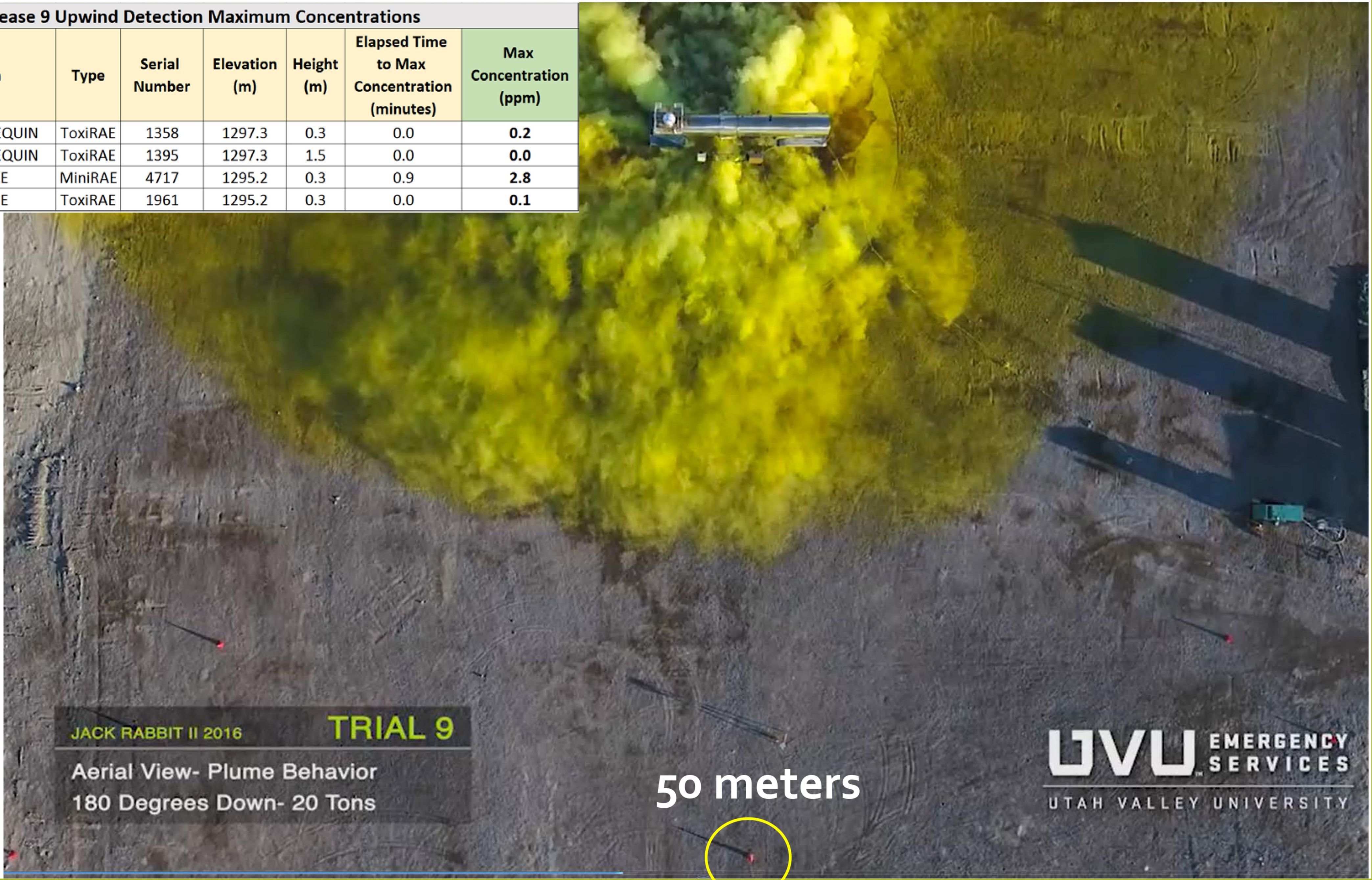
ALOHA Comparisons

Lines—ALOHA contours
Dots—Measurements



JR II Trial 7
Cl2 Concentration, PPM
1,000,000
100,000
10,000
1,000
100
10
1
0.05
0.5
5
Distance, km
<-- Saturated Level of the MiniRAE
y = 2749.1x
R² = 0.9236
ALOHA
HPAC
RAILCAR
Actual
Power (Actual)

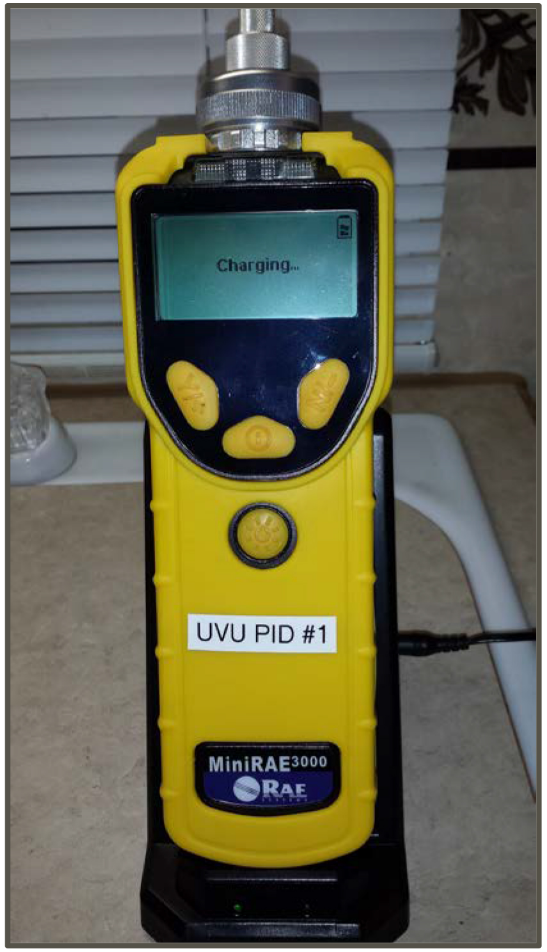
2016 Release 9 Upwind Detection Maximum Concentrations								
Trial	Group	Location	Type	Serial Number	Elevation (m)	Height (m)	Elapsed Time to Max Concentration (minutes)	Max Concentration (ppm)
9	Field	100m MANNEQUIN	ToxiRAE	1358	1297.3	0.3	0.0	**0.2**
9	Field	100m MANNEQUIN	ToxiRAE	1395	1297.3	1.5	0.0	**0.0**
9	Field	50m CONE	MiniRAE	4717	1295.2	0.3	0.9	**2.8**
9	Field	50m CONE	ToxiRAE	1961	1295.2	0.3	0.0	**0.1**



Release 8 Plume Time Lapse

Final Report – Resiliency of 11.7eV PID's

Photo Ionization Detectors (PID) with 11.7eV bulbs detected chlorine with reasonable accuracy and repeatability over broad chlorine concentration ranges.




3
UTAH VALLEY
UVU
UNIVERSITY
DURANGO SLT
DODGE


UVU #8


INTERSTATE
TR1


MORNING PRIDE
UVU #5

Release 7 Detectors

Final Report – Vehicle Operations

Vehicles continued to be operational even when exposed to ultra-high concentrations of chlorine. Escaping a chlorine plume lateral to the wind in a vehicle is the best course of action if the public or emergency responders find themselves in that position.

Combustion Engine Performance in Cl_2

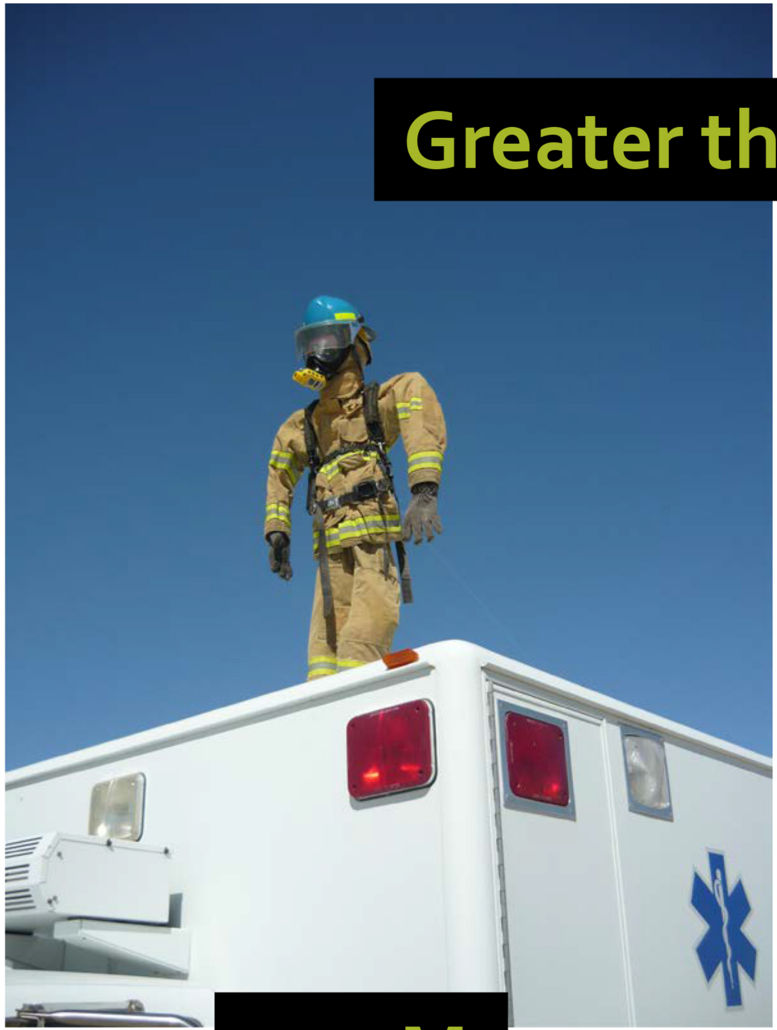
50,000 ppm @ 100 M downwind

234,000 ppm @ 15 M


09-03-2015 07:29:37
IPC

Emergency Procedures for Responders

Greater than 50.0 ppm



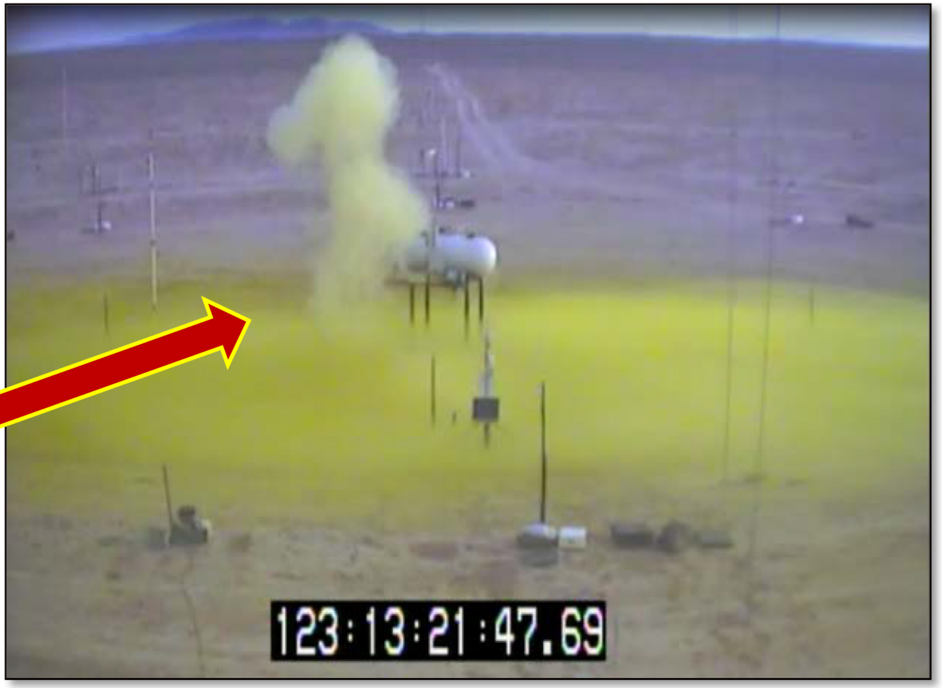
500 M

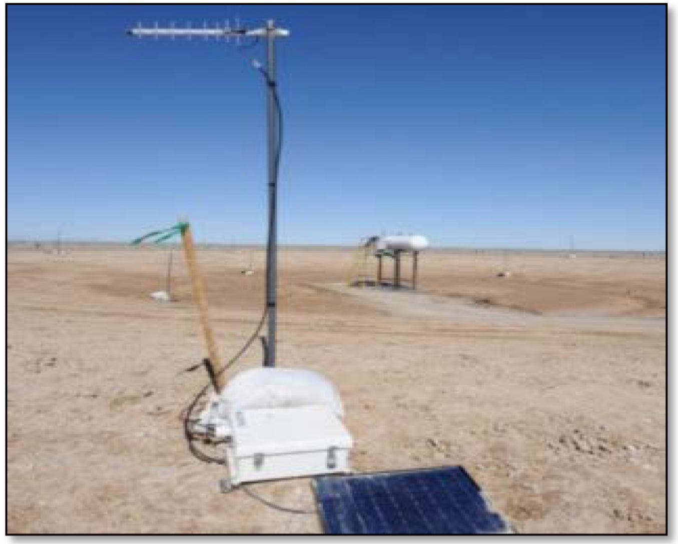
100 M

Jack Rabbit I – 2010 - Results

- Turbulent mixing is initially resisted by dense gas, resulting in cloud persistence near release in low wind conditions
- Cold, dense gas is held up near release site and collects in low-lying areas
- **Rapid Phase Transition** (RPT) eruptions were *previously undocumented hazard.*
- Chemical reactivity of chlorine can result in significant removal via soil, vegetation, and other organics
- Up to 50% of a 2-ton Cl_2 release could be removed within 20 m for soil with high organic matter and water content.

* Journal of Hazardous Materials 252– 253 (2013) 107– 114.

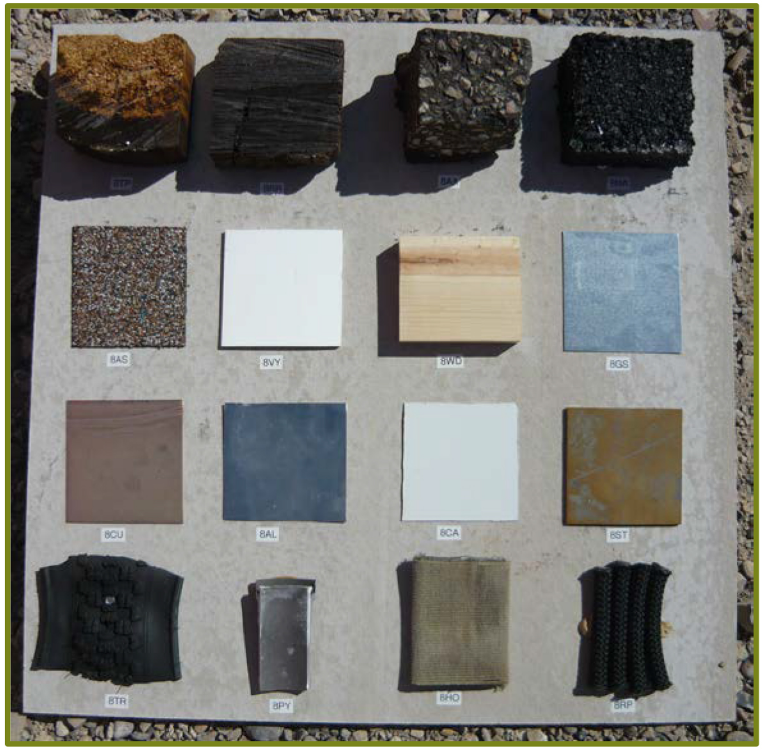




21:45

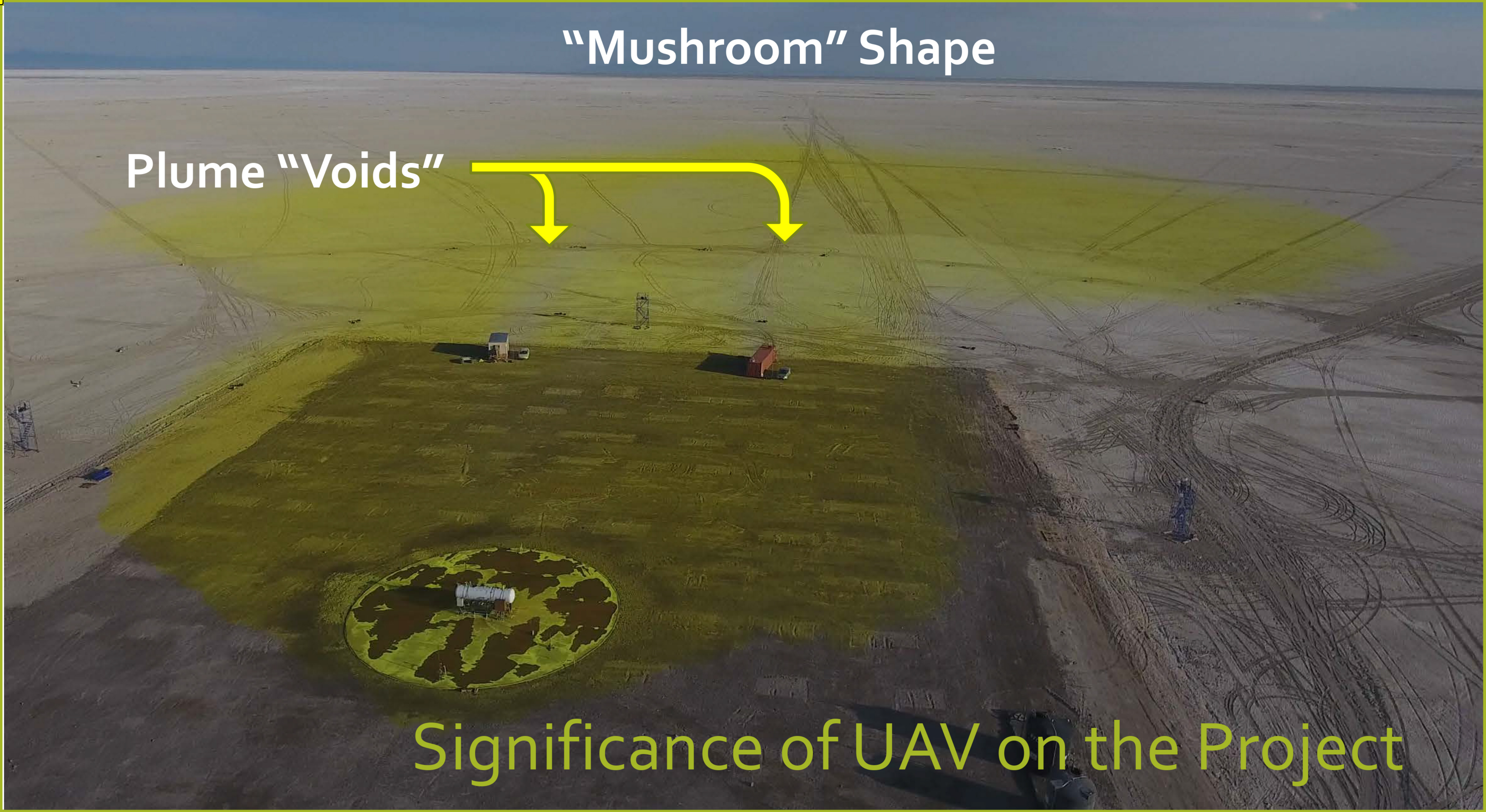
Final Report – Effect on Urban Surfaces

Common urban surfaces and materials were not greatly affected, even by direct liquid exposure to chlorine. Heavy hydrocarbons dissolved and metal surfaces were immediately corroded. Electronics continued to operate after exposure, however, long term operability was erratic. No residual chlorine contamination was noted.

Witness Board

Utility Pole
RR Tie
Aged Asphalt
New Asphalt
Asphalt Shingle
Vinyl
Bare Wood
Galvanized Steel
Bare Copper
Bare Aluminum
Coated Aluminum
Bare Steel
Rubber Tire
Hose Coupling
Fire Hose
Kernmantle Rope



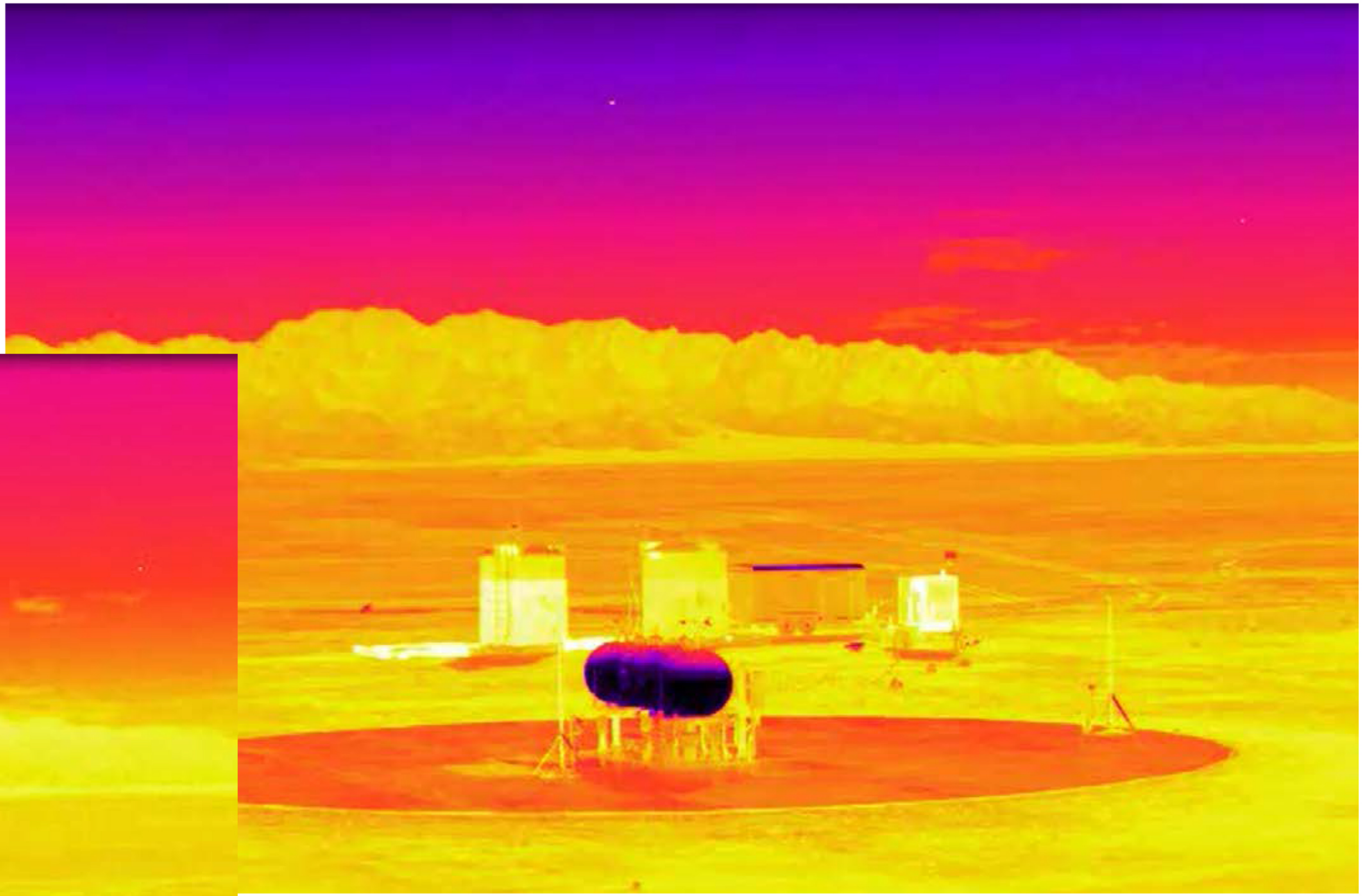
Significance of UAV on the Project

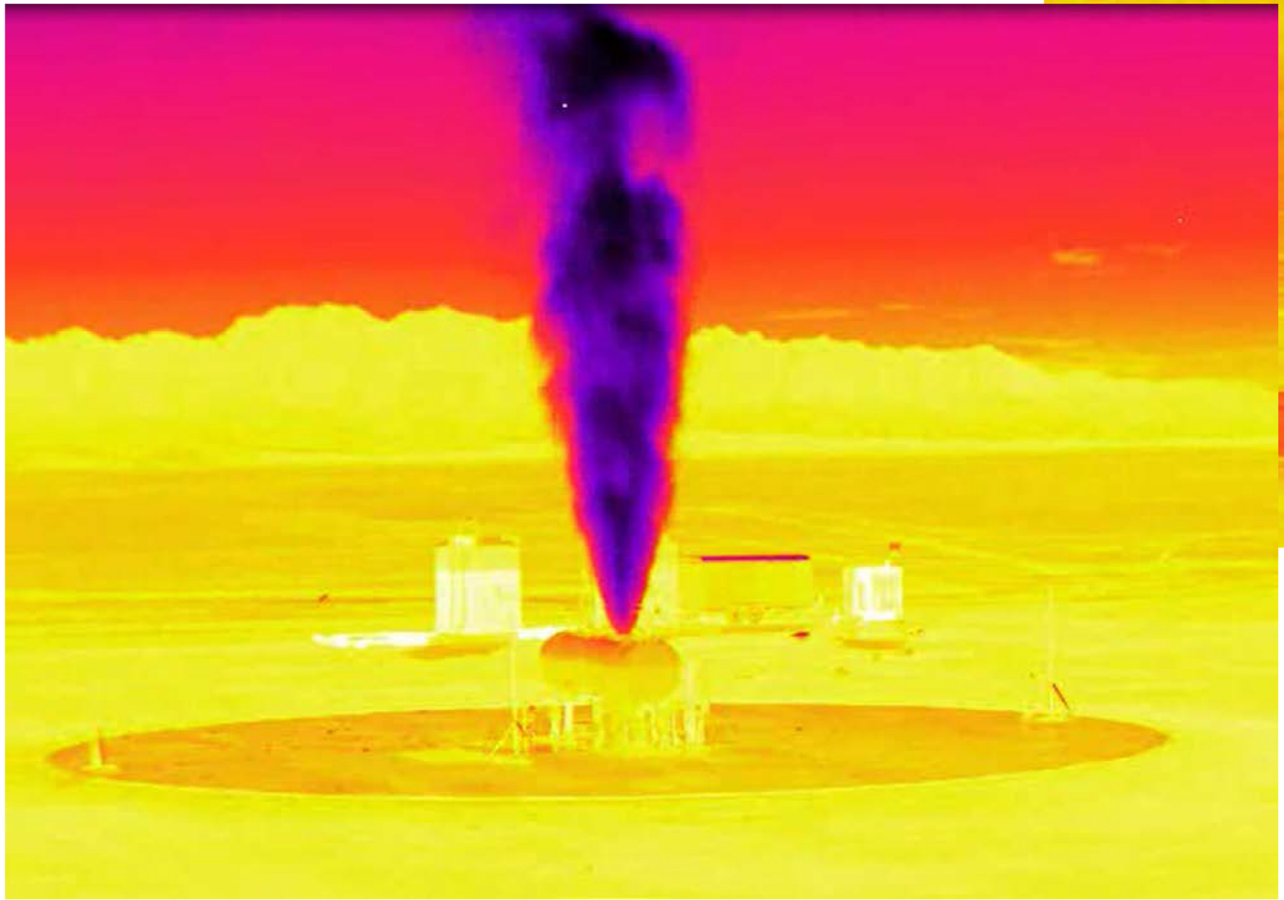
Release 6 Plume

Release 7 Plume

Release 8 Plume

Auto Refrigeration





Release 9 Plume

www.uvu.edu/esa/jackrabbit

2013

JACK RABBIT TRIALS I:

TRAINING VALUE ANALYSIS MEETING

Monday, February 11th – Thursday, February 14th, 2013
Saint Anthony's Parish Hall, Emmitsburg, MD

DRAFT REPORT

For Final Participant Review

ATEC

PREPARED FOR:
National Fire Academy
16825 S Seton Ave
Emmitsburg, MD 21727

PREPARED BY:
Advanced Technical and Educational Consultants
2875 Jupiter Park Drive, Suite 500
Jupiter, FL 33458

Contract # HSFE20-12-P-0289

2015

JACK RABBIT II PHASE 1 TRIALS:

TRAINING NEEDS ASSESSMENT AND ANALYSIS

Monday, April 4 – Friday April 8, 2016

National Fire Academy, Emmitsburg, MD

Final Report

August 1, 2016

PREPARED FOR:
National Fire Academy
16825 S Seton Ave
Emmitsburg, MD 21727

PREPARED BY:
McKinley Group
9210 Corporate Blvd., Suite 360
Rockville, MD 20850

2016

Jack Rabbit II Phase II 2016 Trials – Findings and Observations

JACK RABBIT II Phase II 2016:

Findings and Observations

Friday November 11, 2016

Prepared by: Andy Byrnes & David Matthew

Final Report on 2016 Trials

PREPARED FOR:

McKinley Group
9210 Corporate Blvd., Suite 360
Rockville, MD 20850

2017

Final Report

The Jack Rabbit II Project's Impacts on Emergency Responders

Catastrophic Releases of Liquefied Compressed Chlorine 2015 – 2016

At U.S. Army Dugway Proving Ground, Utah

Utah Valley University
Emergency Services Department
September 30, 2017

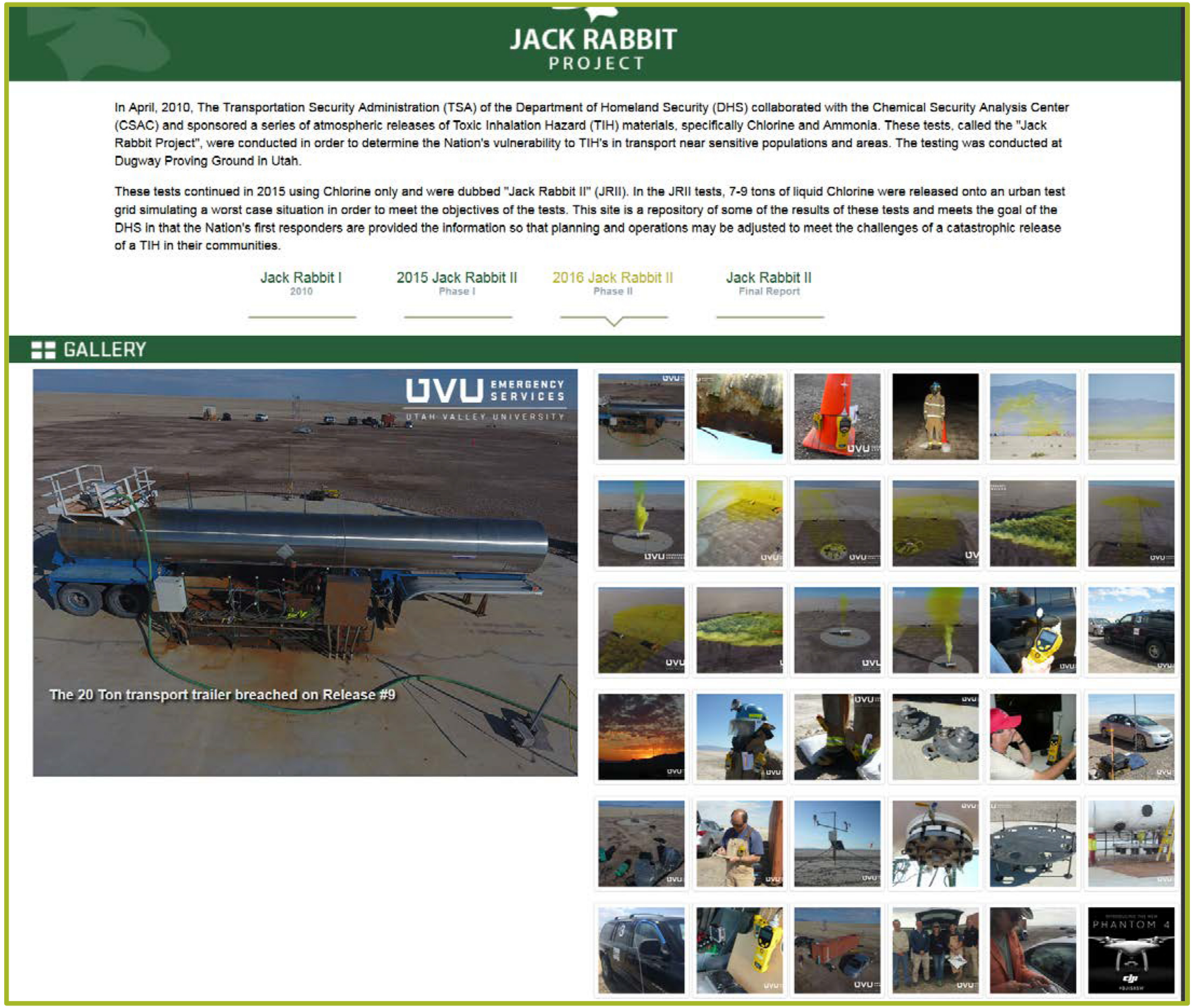
UTAH VALLEY UNIVERSITY 1941

UVU Emergency Responder SME Team:

Andy Byrnes, Utah Valley University, Orem, UT.
Hank DuPont, Office of the State Fire Marshal, Topeka, KS.
David Matthew, Independent Researcher, Wichita, KS.
Jack McCartt, ATEC Inc., Jupiter, FL.
Gregory Noll, South Central (PA) Task Force & The Interagency Board (IAB), Lancaster, PA.
Wayne Yoder, National Fire Academy, Emmitsburg, MD.

Website: http://www.uvu.edu/esa/jackrabbit

www.usfa.fema.gov/current_events/



JACK RABBIT PROJECT

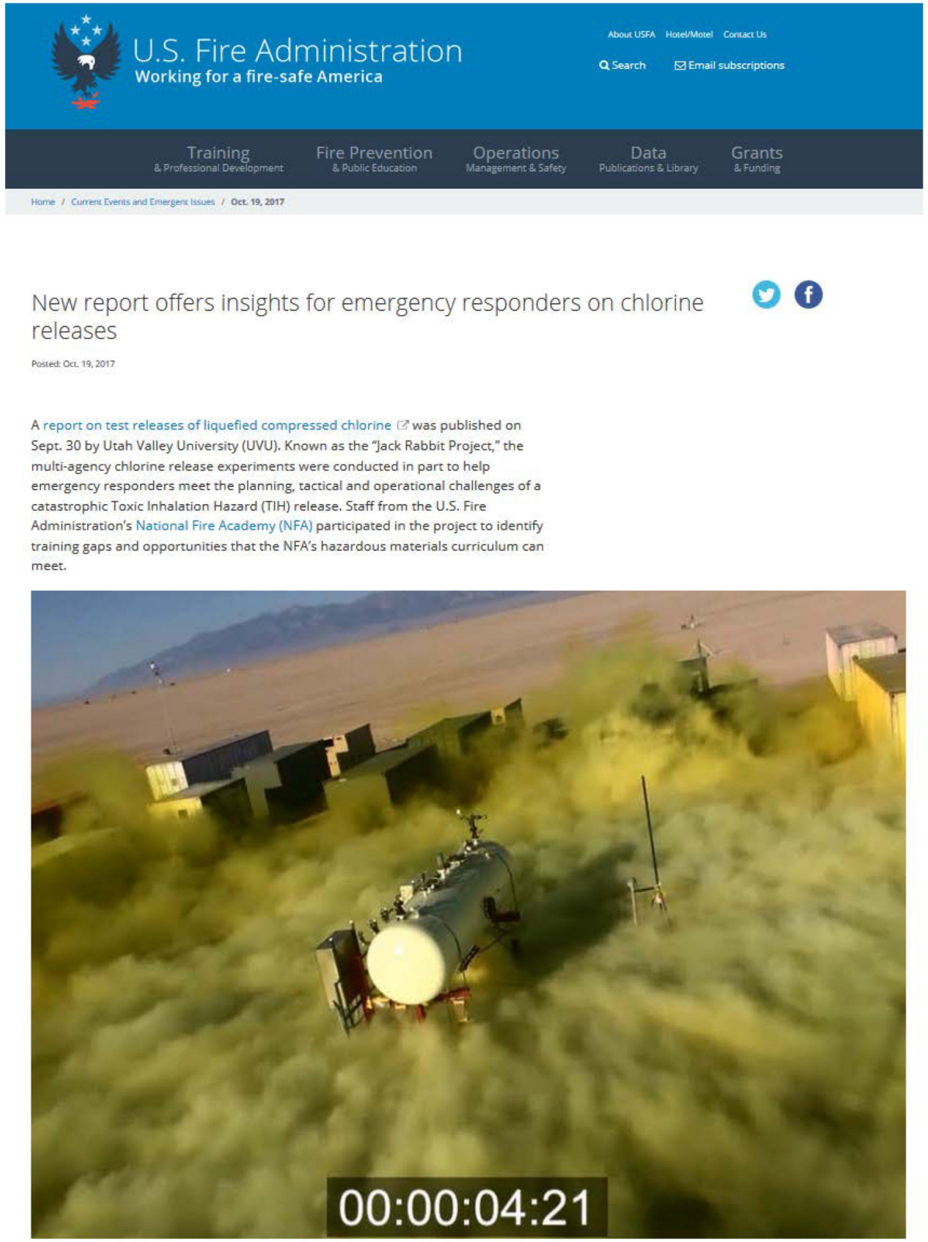
In April, 2010, The Transportation Security Administration (TSA) of the Department of Homeland Security (DHS) collaborated with the Chemical Security Analysis Center (CSAC) and sponsored a series of atmospheric releases of Toxic Inhalation Hazard (TIH) materials, specifically Chlorine and Ammonia. These tests, called the "Jack Rabbit Project", were conducted in order to determine the Nation's vulnerability to TIH's in transport near sensitive populations and areas. The testing was conducted at Dugway Proving Ground in Utah.

These tests continued in 2015 using Chlorine only and were dubbed "Jack Rabbit II" (JRII). In the JRII tests, 7-9 tons of liquid Chlorine were released onto an urban test grid simulating a worst case situation in order to meet the objectives of the tests. This site is a repository of some of the results of these tests and meets the goal of the DHS in that the Nation's first responders are provided the information so that planning and operations may be adjusted to meet the challenges of a catastrophic release of a TIH in their communities.

Jack Rabbit I 2010 | 2015 Jack Rabbit II Phase I | 2016 Jack Rabbit II Phase II | Jack Rabbit II Final Report

GALLERY

The 20 Ton transport trailer breached on Release #9



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New report offers insights for emergency responders on chlorine releases

Posted: Oct. 19, 2017

A report on test releases of liquefied compressed chlorine was published on Sept. 30 by Utah Valley University (UVU). Known as the "Jack Rabbit Project," the multi-agency chlorine release experiments were conducted in part to help emergency responders meet the planning, tactical and operational challenges of a catastrophic Toxic Inhalation Hazard (TIH) release. Staff from the U.S. Fire Administration's National Fire Academy (NFA) participated in the project to identify training gaps and opportunities that the NFA's hazardous materials curriculum can meet.

http://www.uvu.edu/esa/jackrabbit/