



AMERICAN METEOROLOGICAL SOCIETY (AMS) EXTENDED ABSTRACT FOR THE JACK RABBIT TEST PROGRAM TRIAL SUMMARY

BRIEFING 1.2 PRESENTED DURING SPECIAL SYMPOSIUM ON APPLICATIONS OF AIR POLLUTION METEOROLOGY ON 27 JANUARY 2011

LEAD AUTHOR: DONALD P. STORWOLD, JR. CO-AUTHORS: EDWARD ARGENTA JR., JOHN W. WHITE, JOHN C. PACE, AND SHANNON B. FOX

> WEST DESERT TEST CENTER U.S. ARMY DUGWAY PROVING GROUND DUGWAY, UT 84022-5000

> > FEBRUARY 2011

PREPARED FOR: American Meteorological Society 45 Beacon Street Boston, MA 02108-3693

APPROVED FOR PUBLIC RELEASE; DISTRUBUTION IS UNLIMITED

ABSTRACT – As submitted to AMS Conference on 02 August 2010

The Jack Rabbit test program was conducted at Dugway Proving Ground (DPG), UT in April/May 2010. The program was sponsored by the Department of Homeland Security (DHS) Transportation Security Administration (TSA) with program oversight provided by the Chemical Security Analysis Center (CSAC) and test execution provided by the Meteorology Division of DPG. During the field campaign, 10 trials were conducted – 2 pilot trials and 8 record trials with releases of either anhydrous ammonia or chlorine. This presentation will describe the Jack Rabbit field campaign and provide results for several of the test objectives. Individual trials will be discussed with video footage and photos from select trials. The Jack Rabbit trial naming convention will be presented along with dissemination information. Lastly, a brief overview of the database and website will be provided.

BACKGROUND

The Department of Homeland Security (DHS) / Transportation Security Administration (TSA) tasked the Chemical Security Analysis Center [CSAC, Aberdeen Proving Ground Edgewood Area, (APGEA), Maryland], part of the DHS Science and Technology (S&T) Directorate, to study and improve the understanding of rapid large-scale releases (60 to 90 tons) of pressurized, liquefied toxic inhalation hazard (TIH) gases from a railcar. It is critical for DHS and TSA to understand the nature of such releases because of the potential for catastrophic accidents. A containment breach in a railcar transporting these materials, and the subsequent release of toxic gases, has the potential to cause significant numbers of fatalities and injuries. Furthermore, railcars transporting TIH materials could be attractive targets to terrorists.

Currently, the expected behavior of large-scale releases of many toxic industrial chemicals (TICs) is extrapolated from experiments involving other gases, using different (non-validated) scaling, or with objectives that differ from the current needs of TSA. Therefore, TSA directed that experimental field releases of TIH materials be conducted to study and improve understanding of the behavior and associated phenomena. As such, the Jack Rabbit field test program was conducted at U. S. Army Dugway Proving Ground (DPG) during April/May 2010 under the direction of the West Desert Test Center (WDTC) Meteorology Division.

The objectives of the Jack Rabbit test program were as follows:

- Execute a reduced-scale test of each of two chemicals (chlorine and anhydrous ammonia) to identify potential vulnerabilities before full test conduct.
- Develop and evaluate a mechanism for the controlled, rapid release of liquefied, pressurized gases from containment to approximate the conditions hypothesized to generate a persistent vapor-aerosol cloud in a 90-ton railcar release.
- Characterize the vapor/aerosol cloud movement, behavior, and physiochemical characteristics and compare those characteristics with known observations and testing of large-scale releases of the testing materials.

- Determine if anhydrous ammonia and/or tetra fluoroethane (R-134a) can potentially act
 as less expensive and less dangerous dense gas for studying the component phenomena of
 large scale releases of dense gas TIH materials. <u>NOTE</u>: Before the test program, it was
 determined that R-134a was too expensive to use as a potential surrogate for chlorine;
 therefore, R-134a was not disseminated.
- Field and evaluate instrumentation that can be used for the study of the large-scale release of the testing materials, and develop and evaluate testing methodology for future additional and potentially larger-scale tests.

TEST GRID

The Jack Rabbit test was conducted at WDTC on the Insensitive Munitions (IM) Test Grid. The center of the IM test grid is located at 40.20661577 latitude/-113.2657215 longitude. DPG constructed a depression at the center of the test grid to contain the chemicals being released, limit the air entrainment during dissemination, and restrict the initial cloud movement. The depression was 2-m deep with a 25-m radius and the depression served as the focal point of the test. Concentric rings with radii of 50 m, 100 m, 150 m, 200 m, 250 m, 500 m, 1250 m, and 2500 m also had instrumentation deployed. The safety standoff distance was set at 2500 m, and the control point (CP) for test operations was approximately 2835 m from grid center. A graphic depiction of the excavated depression is provided in Figure 1. An illustration of the general test area is provided in Figure 2.

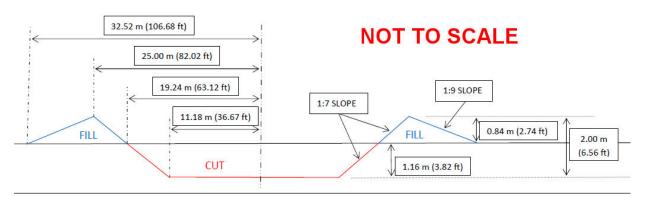
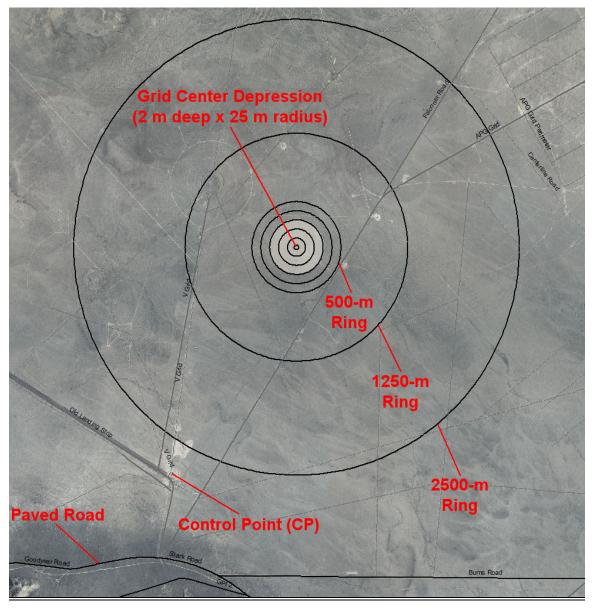


Figure 1. Graphic Depiction of Jack Rabbit Depression; Jack Rabbit Test Program.



<u>NOTE</u>: The dimensions provided for the concentric rings are the radius of the ring, which is also the standoff distance from grid center.

Figure 2. General Jack Rabbit Test Area; Jack Rabbit Test Program.

INSTRUMENTATION

Instrumentation for the Jack Rabbit Test Program falls into one of three basic categories: photonic, chemical, or meteorological. Each category consists of multiple types of instrumentation. In both the photonic and chemical categories, a further division is required for either the chlorine or the anhydrous ammonia detection.

Photonic support consisted of recording visual spectrum footage for both anhydrous ammonia and chlorine disseminations, but IR footage was used only for anhydrous ammonia releases. Chemical detection falls into one of two categories: point detection or stand-off detection. All chemical detection occurred within a 500-m radius of the grid center. WDTC provided the majority of chemical detection; however, CSAC contracted with Center for Toxicology and Environmental Health (CTEH) and Signature Science, Limited Liability Corporation (LLC) (SSLLC) to augment the WDTC dataset. Several types of chemical detection sensors were colocated to support instrument inter-comparison. An extensive meteorological dataset was collected during Jack Rabbit consisting of surface data, vertical profiles up to 32 m, sonic anemometer data, and thermocouple data. Figure 3 is a collage of some of the instrumentation used on the Jack Rabbit test program. Table 1 lists most of the deployed instrumentation and Table 2 lists the non-DPG Jack Rabbit test participants.



Figure 3. Collage of Deployed Instrumentation; Jack Rabbit Test Program.

Table 1. Deployed Instrumentation; Jack Rabbit Test Program.

Instrumentation	Quantity	Type	Detection
UV Canary	20	Chemical	Chlorine
UV Sentry	3	Chemical	Chlorine
JAZ Detectors	17	Chemical	Ammonia/Chlorine
miniRAE	40	Chemical	Ammonia/Chlorine
FTIR Spectrometer	5	Chemical	Ammonia
Bubblers	35	Chemical	Chlorine
Thermocouple	168	Meteorological	Temperature
Tripod PWIDS	16	Meteorological	WD, WS, Temp, RH, Pressure
32m Tower PWIDS	15	Meteorological	WD, WS, Temp, RH, Pressure
Tripod Sonics	2	Meteorological	WD, WS, Turbulence
32m Tower Sonics	15	Meteorological	WD, WS, Turbulence
SD Berm Camera	2	Photonic	Visual Spectrum (Ammonia/Chlorine)
SD Tower Camera	2	Photonic	Visual Spectrum (Ammonia/Chlorine)
Standoff HD Camera	3	Photonic	Visual Spectrum (Ammonia/Chlorine)
Standoff IR Camera	3	Photonic	IR Spectrum (Ammonia)

Table 2. Non-U.S. Army Dugway Proving Ground (DPG) Participating Organizations and Systems Deployed; Jack Rabbit Test Program.

	Organization	Deployed	
Organization	Location	System	Manufacturer
Signature Science, Limited Liability Corporation (LLC) (SSLLC)	Austin, TX	Jaz ultraviolet visible (UV-VIS) sensor	Ocean Optics Inc.; Dunedin, Florida
Center for Toxicology and Environmental Health (CTEH)	Little Rock, AR	AreaRAE (CTEHowned) and miniRAE (DPG-owned)	RAE [®] Systems; San Jose, California
SAFER Systems	Camarillo, CA	Chemical risk management software	SAFER Systems; Camarillo, California
Air Force Research Laboratory (AFRL)	Tyndall Air Force Base (AFB); Panama City, FL	Soil core sampling	Not applicable (NA)
Naval Surface Warfare Center (NSWC) - Dahlgren	Dahlgren, VA	Electronics sampling	NA
METSS Corporation	Westerville, OH	Coupon sampling	NA
NSWC – Dahlgren	Dahlgren, VA	Hazard prediction modeling	NA
Norwegian Defence Research Establishment	Oslo, Norway	Computational fluid dynamics (CFD) modeling	NA

DISSEMINATORS

Two types of custom disseminators were designed and constructed by WDTC. One type of disseminator was built for anhydrous ammonia and another type was built for chlorine releases. Two identical disseminators of each type were built for a total of four disseminators. The anhydrous ammonia disseminator used a modified 1,000-gal propane tank, and the chlorine disseminators consisted of a modified 500-gal propane tank. The dissemination height was 2 m above ground level (AGL). A stand was constructed to mount the disseminator at the desired height at the center of the depression. The jet from the disseminator impinged against a 12-ft \times 8-ft \times 1-in steel plate, which served as the base for the metal disseminator stand Photographs of the ammonia disseminator are provided in Figure 4.

The dissemination valve assembly consisted of two valves: a manual knife gate valve and a remotely controlled ball valve. The knife gate valve provided increased safety for the WDTC dissemination crew because it separated the tank from the remotely controlled valve, and it remained closed until the disseminator was staged and ready to trigger. A 4-in diameter valve assembly was used on the anhydrous ammonia disseminator, while a 3-in diameter valve assembly was used on the chlorine disseminator. A restricting orifice was attached to the outlet of each valve assembly to lessen the likelihood that flashing would occur during the rapid release of chemicals. The restricting orifice was used on the first four trials, but later removed for the last six trials. The differences in tank sizes and valve assemblies allowed for approximately the same mass flow, whether the release was anhydrous ammonia or chlorine.

Tank pressure was monitored in the chemical liquid at the bottom of the dissemination tank and in the vapor head space at the top of the tank. Temperature within the tank was also monitored. Software was written to control the dissemination and valve operation from the CP site and record the pressure and temperature data.



Figure 4. Ammonia Disseminator and Underneath of Disseminator Showing Remotely Controlled Valve Assembly; Jack Rabbit Test Program.

DISSEMINATION SCHEDULE

The ammonia and chlorine pilot trials were conducted on 07 April 2010 and 08 April 2010, respectively. After a three-week break, record test conduct began on 27 April 2010 and continued through 21 May 2010. The dissemination matrix is provided in Table 3 and a data summary is provided in Table 4.

Operational hours spanned across three different meteorological regimes. The night regime is defined as sunset plus 2 hours to sunrise plus 1 hour. Morning is defined as sunrise plus 1 hour to sunrise plus 4 hours. Afternoon is defined as sunrise plus 4 hours to sunset minus 1 hour. Disseminations were conducted during the night regime and trial data were collected throughout the morning regime. Disseminations occurred as close to sunrise as possible because of the meteorological conditions that exist at that time of day. In most cases, wind speeds at the time of dissemination were calm or light with neutral or stable atmospheric conditions. As meteorological conditions changed from one regime to another, calm or light winds often occur, and this phenomenon was used throughout the test program. Disseminating at sunrise provided the daylight needed to record video coverage

Tubic 3. Dissemination Frank Public Test Frogram.						
Test Phase	Trial Name ^a	Chemical	Quantity	Date	Time (UTC)	
Pilot Test	01-PA	Anhydrous Ammonia	1 ton	07 April 2010	1400	
	02-PC	Chlorine	1 ton	08 April 2010	1345	
Record Test	03-RA	Anhydrous Ammonia	2 tons	27 April 2010	1315	
	04-RA	Anhydrous Ammonia	2 tons	01 May 2010	1420	
	05-RC	Chlorine 2 ton		03 May 2010	1320	
	06-RC	Chlorine 2 tons		04 May 2010	1340	
	07-RC	Chlorine	2 tons	05 May 2010	1405	
	08-RC	Chlorine	2 tons	07 May 2010	1250	
	09-RA	Anhydrous Ammonia	2 tons	20 May 2010	1245	
	10-RA	Anhydrous Ammonia	2 tons	21 May 2010	1250	

Table 3. Dissemination Matrix; Jack Rabbit Test Program.

Table 4. Data Summary; Jack Rabbit Test Program.

	1		T-4-1		17:1	T-4-1 C:
			Total		Video	Total Size
Trial	Number of	Number of	Number of	Data Dataset	Dataset	of All Data-
Name ^a	Data Files	Video Files	Files	Size (MB ^b)	Size (MB)	sets (MB)
01-PA	67	199	266	140	200,922	201,062
02-PC	88	150	238	190	260,482	260,672
03-RA	108	246	354	382	37,446	37,828
04-RA	112	444	556	423	86,363	86,786
05-RC	110	172	282	348	155,476	155,824
06-RC	109	207	316	334	146,546	146,880
07-RC	111	237	348	348	243,778	244,126
08-RC	111	285	396	367	304,340	304,707
09-RA	96	350	446	302	450,927	451,229
10-RA	95	300	395	297	381,443	381,740

^aTrial names are identified as follows: the first two digits are the trial sequence number; the first letter is the trial type (P − pilot, R − record); the second letter is the chemical type (A − ammonia, C-chlorine).

PILOT TRIALS

An apparent observation relating to the dense gas behavior of both anhydrous ammonia and chlorine is that they behave very differently when released to the atmosphere. This observation was most obvious during the ammonia and chlorine pilot tests conducted on 07 and 08 April 2010, respectively. The meteorological conditions on those two days differed so slightly that they can be considered the same. Because the conditions were similar, a good comparison can be made between the chemicals that were disseminated. Table 5 is a comparison of those days at the time of each release.

 $^{^{}a}$ Trial names are identified as follows: the first two digits are the trial sequence number; the first letter is the trial type (P – pilot, R – record); the second letter is the chemical type (A – ammonia, C-chlorine).

^bMegabyte.

Table 5.	Pilot Trial N	Meteorology	Comparison:	Jack Rabbit	Test Program.
I doic 5.	I HOU I HUI I	*10t001010 <u>6</u>	Companioon,	Juck Rubbit	I Cot I I Calum.

	07 April 2010	08 April 2010	
Parameter	(Ammonia Release)	(Chlorine Release)	Difference
Wind Speed	0.31 m/s	0.64 m/s	0.33 m/s
Temperature	-0.09° C	-0.35° C	0.26° C
Relative Humidity	81%	74%	7%
Dew Point	-3.51° C	-4.36° C	0.85° C

The easiest way to analyze the difference between anhydrous ammonia and chlorine releases is to review time slices of each chemical at the same time during the dissemination. Figures 5 through 9 show time slices from trials 01-PA (ammonia) and 02-PC (chlorine) under nearly identical meteorological conditions.



Figure 5. Ammonia and Chlorine Releases 5 Seconds Into Dissemination; Jack Rabbit Test Program.



Figure 6. Ammonia and Chlorine Releases 15 Seconds Into Dissemination; Jack Rabbit Test Program.



Figure 7. Ammonia and Chlorine Releases 30 Seconds Into Dissemination; Jack Rabbit Test Program.



Figure 8. Ammonia and Chlorine Releases 60 Seconds Into Dissemination; Jack Rabbit Test Program.



Figure 9. Ammonia and Chlorine Releases 90 Seconds Into Dissemination; Jack Rabbit Test Program.

The visible chemical clouds in Figures 5 through 9 are in a gaseous state. These images clearly illustrate a difference between the more buoyant gas, ammonia, as opposed to the less buoyant gas, chlorine. By comparing the two releases in the Jack Rabbit test, both DPG and CSAC determined that ammonia cannot serve as a surrogate for chlorine.

AMMONIA ANOMILIES

The record ammonia trials produced unexpected results that differed from the ammonia pilot trial. After each trial, small pockmarks were observed in the soil wherever liquid ammonia had been present. Video footage was collected of the soil and standing water immediately after a trial, showing small bubbles bursting from the surface. In the standing water, the bubbles looked similar to the bubbles in a soft drink. Figure 10 shows the pockmarks created after an ammonia trial.

Another anomaly witnessed during the ammonia disseminations occurred during the pilot trial. Several minutes after the dissemination terminated, two plumes rose out of the depression and eventually joined into a single, 30 m high plume. Although wind speeds were minimal during other ammonia trials, this phenomenon only occurred during the calm meteorological conditions of the pilot trial.



Figure 10. Ammonia Trial Soil Pockmarks; Jack Rabbit Test Program.

CHLORINE ANOMILIES

During the 2-ton record chlorine trials, small explosions occasionally occurred within the depression. These explosions were believed to be caused by one of two phenomena. The first theory was that the chlorine reacted with residual ammonia impregnated in the soil from previous trials. After two record ammonia trials had been conducted, the soil had become saturated with the ammonia prior to the four record chlorine trials. The reaction between the ammonia and chlorine was thought to have produced nitrogen trichloride (NCl₃), which is highly unstable. The second theory for the explosions was rapid phase transition (RPT) as the chemical quickly transitioned from a liquid state to a gaseous state upon contact with ground moisture. RPT is a fairly well documented occurrence with liquid natural gas spills. Hours after the chlorine disseminations, witnesses heard popping sounds similar to cooking popcorn within the Jack Rabbit depression. Figure 11 shows one of the many explosions during the first record chlorine trial (05-RC).

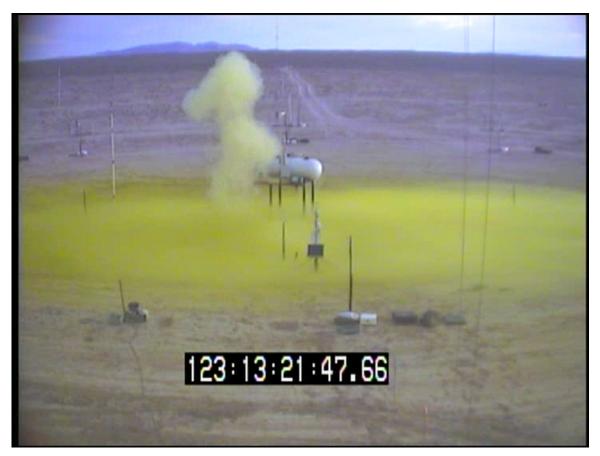


Figure 11. Explosions Occurring During Record Chlorine Trials; Jack Rabbit Test Program.

Another notable anomaly occurred during trial 07-RC, which was also the chlorine VIP day. Approximately 20 minutes after the dissemination of chlorine, a flock of birds landed on the disseminator and remained perched there for roughly 2 minutes. What makes this event so peculiar is that the birds were within 7 feet of a visible chlorine cloud for a significant period of time and they suffered no ill effects.

FINAL TRIAL COMMENTS

Two record trials, 05-RC (chlorine) and 10-RA (ammonia), had wind speeds higher than desired for the Jack Rabbit test program. Despite being out of the range of desired wind speeds, the decision was made to conduct the trials. Even under conditions that were less than ideal, these two trials provided information that was not available from the other trials. In both cases, test participants were able to witness the affects of stronger winds on the released chemicals and at the end of the dissemination, the liquid pooling of the chemicals was easily seen. Figure 12 shows the Jack Rabbit test grid and disseminator 10 seconds after the dissemination ended.



Figure 12. Final Ammonia Trial; Jack Rabbit Test Program.

CONTACT INFORMATION

Mr. Donald P. Storwold Jr. served as the test officer for the Jack Rabbit test program and was the lead author for the Jack Rabbit Test Program Trial Summary, which was presented on 27 January 2011 at the AMS Annual Meeting in Seattle, WA. His contact information follows:

Donald P. Storwold Jr. TEDT-DPW-MEM MS#6 4034 2nd Street Dugway, UT 84022-5006

Email: donald.storwold@us.army.mil

Office: 435-831-5496 Cell: 435-830-8963