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

Table of Contents

Introduction

In August and September of 2016, Department of Homeland Security (DHS), in collaboration with the Chemical Security Analysis Center (CSAC), sponsored a series of follow-on tests called the Jack Rabbit II 2016 Trials at Dugway Proving Ground (DPG), UT. In the trials, multiple releases of 10 & 20 ton amounts of chlorine were performed in various release angles and wind speeds from a release container and within a standardized outside test area. The purpose of the tests was to continue the research from 2015 and answer the gaps in the results that were identified by the April 2016 panel at the NFA. The results of that meeting were published in a document entitled *Training Value Analysis Meeting, August 1, 2016* available through distribution from the National Fire Academy.

The Report identified gaps which the 2016 Phase II Trials were designed to answer. Working with scientists from DHS's Chemical Safety Analysis Center (CSAC), Lawrence Berkeley National Labs (LBNL), Dugway Proving Ground (DPG), and other partnering agencies, the Utah Valley University (UVU) SME Team assisted in designing and conducting field experiments to collect data designed to provide conclusions to support emergency response needs. The following is a description of the effort and recommendations for further study and recommendations for the next steps.

Jack Rabbit II 2016 Test Design with Observations, Questions and Recommendations

1. Rapid Phase Transitions (RPT)

Trial #8 included a designed experiment to test the RPT phenomena found in the 2010 testing. A metal rack with 5-gallon plastic drums filled with different types of soil was placed under the 3" dump value. Trial #8 was a Zero-degree (top) release causing auto-refrigeration to occur. Approximate 15 minutes' post release, the bottom value was opened dumping ~1,000 gallons of cooled, liquefied Cl_2 (-29F) onto the rack and into the soil contained buckets. The liquid Cl_2 quickly filled the buckets causing a percentage of the soils to float outside the buckets. It was determined that the design of the study did not allow for acceptable data to determine if a RPT did occur.

On November 8, 2016, Dr. Mark Whitmire DHS-Chemical Security Analysis Center (CSAC) was asked the following questions regarding the RPT study:

1-1. What is the likelihood of occurrence of RPT if liquefied Cl2 is released into soil?

1-2. What types of soil would most likely produce RPT?

1-3. Since rail cars carry the largest amounts of liquefied Cl2, are rail beds, made up of rock and raised likely able to produce a RPT?

1-4. What is the likely force that may be experienced in RPT phenomena?

1-5. What is the likely impact to the emergency response community if we are able to answer these questions?

Dr. Whitmire suggested that it is very unlikely to experience RPT phenomenon only under special conditions. He stated that wet permeable soil, in that the chlorine can percolate into the subsurface and then freeze the surface of the soil effectively capping the expanding gas is the most likely mechanism. The sudden release of the expanding gas pressure would lift soil and liquid into the air. The type of soil was not as important as the moisture content. Due to the fundamental design of the raised rail bed and the drainage designed into them, the conditions are not likely to exist there to support an RPT. When discussing the likely force he related that the force was closer to an M-80 than a firecracker, however, the actual force might be calculated from the 2010 Jack Rabbit I video data. (Figure 1).

Figure 1. *Rapid Phase Transition event from Jack Rabbit 2010.*

From the UVU SME Team perspective the impact of further testing of RPT's may be low as it is difficult to imagine a scenario where responders would be exposed to this phenomenon.

2. Identify mitigation strategies for the public

The indoor air studies should offer significant data to confirm sheltering-in-place strategies. Different air monitoring devices were deployed inside structures and vehicles to determine differences between outside and inside concentrations of Cl_2. The factors of weather, tightness of containers, measured in air exchanges per hour (ACH), and amounts of Cl_2 released need to be evaluated. (Figure 2).

Figure 2. *ToxiRAE and MiniRAE with Canary in Vehicles with GoPro Camera.*

On November 8, 2016 while meeting with Dr. Mike Sohn and Dr. Woody Delp of Lawrence Berkeley National Labs (LBNL), the following questions were discussed:

2-1. What were the outside concentrations for the releases?

2-2. What were the interior concentrations for the containers on the grid?

2-3. Does the data match the predicted concentrations?

2-4. Of the factors the effect mitigation strategies? (Product released, amounts, air changes per hour (ACH), toxic load component, temperature, humidity, wind conditions, etc...)

2-5. Does the mathematical equation match the data?

2-6. What is the so what of the data?

Dr. Sohn and Delp were very happy with the quality of their data. They are awaiting the scrubbing and the subsequent release of data from the Dugway team. They stated that the data was aligning with the predicted concentrations. Dr. Sohn was extremely confident that their mathematical models are matching the corresponding data. Of the mitigation strategies that may have been verified is that home HVAC should be disabled and inside a vehicle, it is always better to shut off the air in the case of an atmospheric release. Other factors that might affect mitigation strategies were the duration of the exposure, the distance from the source of the release and the type of structure. Dr. Sohn stated that a mathematical equation could be created that would take these factors into account however, they need to better understand how this equation would be utilized.

The UVU SME Team recommends a meeting of SME's to review the Jack Rabbit II data as presented by LBNL representatives to gain consensus on its impact on the emergency response community.

3. PPE – sorption on exposure

No PPE studies were conducted. Dr. Christina Baxter indicated that there was already an abundance of information on Chlorine's effect on PPE.

4. Upwind categorization up to 500 m (verify ERG for upwind)

The 2016 data seems to indicate that winds in excess of 2 m/s (~5 mph) will not allow retrograde creep greater than 100 meters. The Dugway team provided detection at 50 m however, that data has not been released. It is apparent, using the 2016 Utah Valley University (UVU) Unmanned Aerial Vehicle (UAV) video that no visible plume was observed upwind past 35 m and UVU SME Team provided detection at 100 m upwind was negative (0 ppm) for all four trials in 2016. Other detection provided upwind by the Dugway team (at 200 m) has not been released. There is a need to review the wind conditions for trial 5 (2015) where retrograde creep (visible plume) was documented at greater than 100 meters. (Figure 3)

Figure 3. *Trial 5, 2015 Retrograde Creep greater than 100 m.*

4-1. Does the data confirm that the ERG upwind guidance is too conservative?

4-2. How does terrain and/or obstructions impact this upwind discussion?

The visible plume in trial 5 was beyond 100 m upwind while no visible plume made it past 35 m upwind in trials 6 thru 9 at similar wind speeds and identical release points (180 degrees).

It is recommended that CSAC review and provide analysis of the upwind data from all nine of the Jack Rabbit II trials (2015 & 2016). On November 8, 2016 Dr. Shannon Fox DHS-CSAC

explained that his office would be looking into the comparison of trial 5 (2015) and trial 6 & 9 (2016) in regards to the wind speed and direction vs. the visible cloud moving against the wind.

5. Interior vehicle concentration & infiltration studies in several conditions

On August 24, 2016 all five vehicles (Figure 4) established current air exchanges per hour (ACH) through injection of SF_6 with exfiltration tracked with infrared (IR) detectors. In addition, on September 14, 2016 all five vehicles were tested by injecting Cl_2 at concentrations greater than 1,000 ppm to compare exfiltration rates. During trials 6 thru 9, data was collected on the interior of the vehicles using three separate detectors in all conditions. There appears to be a greater than 10 to 1 ratio from exterior concentrations to interior concentrations.

5-1. How does the Canary data compare with the PID and electrochemical cell data?

5-2. Does the SF_6 and Cl_2 data align with the model equation?

5-3. Did the vehicles ACH rate change from August 24 to September 14?

5-4. Do we have data to confirm that the ACH with air/off, vehicle running is about the same as air/off, vehicle off?

5-5. What is the "so what" of the data?

5-6. What is the impact to the electronic systems due to repeated exposure to high levels of Cl_2?

During the November 8th meeting with LBNL, Dr. Sohn and Dr. Delp stated that the preliminary data seems to be consistent between the different detection technologies. The control gas data using SF_6 on August 24 and September 14 provided high confidence in the accuracy of the model equation. They stated there was no noticeable changes in ACH of the vehicles. When discussing the different condition in which the vehicles were tested they stated the data is clear that the air should be turned off as it greatly reduces ACH and infiltration rate. It was noted that the electronic systems (Air, fans, radio, dash lights, etc…) in several of the vehicles were exhibiting erratic functioning during the last few trials.

The UVU SME Team recommends a meeting of National SME's to review the Jack Rabbit II data as presented by LBNL representatives to gain consensus on its impact on the emergency response community.

Figure 4. *Jack Rabbit II Vehicle Air Changes per Hour (ACH) under three conditions.*

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

6. Assess the auto-refrigeration behavior for further guidance

There were two tests that may provide data on auto-refrigeration of Cl_2. Trial 7 was a 135 degree release in which it appeared little to no auto-refrigeration occurred. Trial 8 was a 0 degree (top) release where it was allowed to release for 15:35 minutes at which time a dump valve was opened on the bottom of the tank. After the initial 0 degree pressurized liquid release, the vapor rate seemed to slow and the temperature of the liquid remaining in the tank dropped.

6-1. Is there useful data from trials 7 & 8 related to auto-refrigeration?

6-2. Would the data allow for linear calculations for different degrees of releases?

6-3. Can predictions be made about auto-refrigeration of Cl_2 from the data?

It is recommended that CSAC review and provide analysis of the auto-refrigeration data from trials 7 & 8 during Jack Rabbit II 2016. On November 8, 2016 Dr. Shannon Fox DHS-CSAC explained that his office would be looking into the data.

7. Determine the field application of PID with 11.7 eV bulbs for TIH's

The research questions below were taken from the August 2016 Training Analysis Report from the National Fire Academy as broad research questions. The subset of questions are provided to answer these broader research questions.

- Does current PID technology provide useful data to support the emergency responder's efforts to protect the community at the large-scale releases of chlorine gas?

- Does PID technology offer a practical means of detecting chlorine below Immediately Dangerous to Life and Health (IDLH) conditions?
- Does current PID field technology prove to be resilient to repeated exposures to low concentrations (50 ppm or less) of chlorine?

During the 2016 releases a single RAE Systems® Photoionization Detector (PID) with an 11.7 eV bulb, standard calibration, was placed inside vehicles with the condition of air/off, vehicle not running (Table 1). An electrochemical cell detecting from 0-50 ppm (ToxiRAE II®) was placed at the same height with a GoPro® camera filming the instrument responses. Between each trial, data was downloaded and a standard calibration performed. In addition, the same PID was placed inside the vehicles during the infiltration studies conducted September 14th.

Table 1. *Condition of the vehicles and detector numbers for each trial.*

Trial #	Veh ID	Veh cond	PID Y/N	ToxRae #
6	Honda-5	on/air off	N	1 & 2
6	Sebring-1	off/off	Y	3 & 4
7	Honda-5	on/recerc	N	1 & 2
7	Durango-3	off/off	Y	3 & 4
8	Honda-5	off/off	Y	1 & 2
8	Durango-3	on/air off	N	3 & 4
9	Honda-5	off/off	Y	3
9	Durango-3	off/off	N	4

During trial 8, the interior concentrations in the Honda remained below 50 ppm for approximately 15 minutes.

The same PID was exposed to greater than 4,000 ppm more than 10 times and was still functioning upon returning to the RAE Systems. There was noticeable discoloration to the wand (Figure 5) and a battery error (Figure 6) appeared after trial 8. Dr. Norman Lian from Dugway Proving Ground (DPG) has offered to provide data on their use of the RAE PID detectors. During the exfiltration studies on September 14th, the exposed PID was used side-by-side with a never exposed PID with a new 11.7 eV bulb (Figure 7) to measure the exfiltration rates leaving the Durango. Both detectors were provided standard calibration prior to exposure and post exposure (Figure 8).

Figure 5. *Discoloration typical of metal surfaces exposed to high concentrations of chlorine.*

Figure 6. *Battery Error*.

Figure 7. *Three detectors aligned during interior vehicle chlorine tests.*

Figure 8. *Field calibration of the RAE Systems PID.*

7-1. Does the data offered by the PID during trials 6 thru 9 correlate with the electrochemical cell and the Canary data?

7-2. Is the data offered by the PID during the September 14th exfiltration studies correlate with the UV data?

7-3. What does the trial 8 data show and how does that data correlate with the GoPro video?

7-4. How did the PIDs perform during the exfiltration studies when compared to an electrochemical detector?

7-5. Will DPG offer useful data and observations in support of answering this question?

7-6. Is the PID data taken from this single instrument useful and repeatable?

7-7. Are there indicators that the data became less accurate after each exposure?

7-8. How did the single PID perform compared to a never exposed PID with an 11.7 eV bulb?

There is significant data to support the application and limitations of PIDs with 11.7 eV bulbs when exposed to various concentrations of Cl_2. This data needs to be evaluated by interested parties and presented to National SME's as to its usefulness to the emergency response community.

8. UAV – Aerial plume behavior video capture

The restrictions established by DPG on August 25 impacted the ability to efficiently operate the UVU drone to capture video. With the cooperation of the test team, alterations in the drone operations plan allowed for aerial video to be captured and shared with stakeholders.

All liquid releases were captured on aerial video with the exception of the first release (Trial 6) which went off without the drone in position. All downwind plumes were captured. The video was processed by a UVU media team creating the long versions, titled "Science" and the five minute versions titled "Training". Most videos can be found on the UVU Jack Rabbit website at www.uvu.edu/esa/jackrabbit.

8-1. Which drone video provides the most impactful information to stakeholders?

8-2. What are the probable outcomes from review of the drone video?

8-3. What are the approximate concentrations at the edge of the visible cloud seen on the drone video?

It is recommended that CSAC provide analysis of the aerial video in comparison with the data collected from the grid. This data can then be used to further explore implications for the emergency response communities.

9. Application of the data to the current ALOHA plume modeling program

Data from the Jack Rabbit I trials was used to make changes to ALOHA plume model relating to a new rail car release algorithm. The 2015/2016 Jack Rabbit II trials have provided additional data to be evaluated.

9-1. How does the current ALOHA plume modeling depict the nine releases?

9-2. How does the data from JR II trials 1 thru 9 align with the ALOHA data?

9-3. What is the most interesting differences in the actual data compared to the ALOHA data?

9-4. What data is most likely to impact changes to ALOHA plume modeling program?

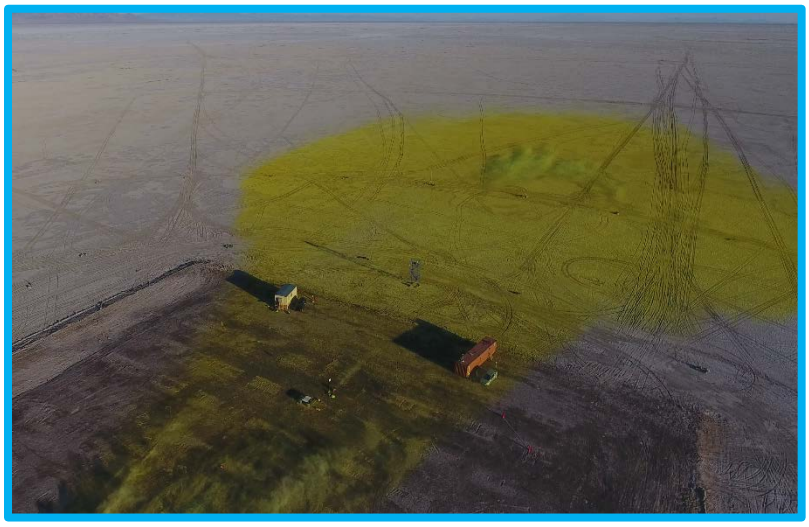
9-5. Does ALOHA calculate a catastrophic release accurately?

9-6. Is there an acceptable range within ALOHA for a catastrophic release rate?

9-7. Does ALOHA use the JR II area of the opening in its calculation for rate of release?

9-8. Why does the plume shape in the video look so different from the model?

It is recommended that the UVU SME Team and CSAC collaborate in sharing and evaluating the modeling data. The UVU SME group has been working with Chief Hank Dupont (Kansas State Fire Marshal's Office) to get the current ALOHA data from the nine JR II trials. Once the data has been evaluated a presentation to National Public Safety SME's on its impact should occur.



Report Summary

During the 2015 Trials, emergency response personnel functioned in coordination with the DPG test team providing an effective response capability. The April 2016 panel at the NFA distinctly supported a command post and ICS integration in alliance with current OSHA regulations, NFPA standards, and NIMS guidance for control of hazardous materials. The Command and Control elements were not a focus of the 2016 Trials. The lack of resources required the UVU SME Team to fill advisory roles only to the DPG Test Team Officers during the trials.

As of the writing of this report, all nine assessment areas are actively being pursued by partner agencies with CSAC, LBNL and United States Fire Administration (USFA) as lead agencies. The UVU SME Team continues to seek opportunities to support this effort through collaboration which includes the hosting of the Jack Rabbit Trials information on their website www.uvu.edu/esa/jackrabbit. As the data is received and analyzed it is

believed that future training requirements for emergency responders will be impacted by the findings.