

Attachment A

OEM Data on Refrigerant Distribution in AC System Components (Example 1)

Refrigerant Distribution Analysis

Updated Jun 25, 2013

Refrigerant Distribution for Three Configurations

	Refrigerant Distribution HEV Sedan		
Component Description	System Off (10°C)	System On High Load (30°C/80%RH)	System On Low Load (10°C/60%RH)
Discharge Line	11%	2%	1%
Condenser/Receiver	47%	72%	70%
Liquid Line	6%	20%	22%
Evaporator	3%	4%	5%
Suction Line	31%	1%	2%
Compressor	2%	<1%	<1%
Total	100%	100%	100%

	Refrigerant Distribution Van Front Only		
Component Description	System Off (10°C)	System On High Load (30°C/80%RH)	System On Low Load (10°C/60%RH)
Discharge Line	12%	2%	1%
Condenser/Receiver	39%	74%	73%
Liquid Line (Main)	4%	14%	15%
Evaporator (Main)	5%	7%	9%
Suction Line (Main)	29%	2%	2%
Compressor	11%	1%	1%
Total	100%	100%	100%

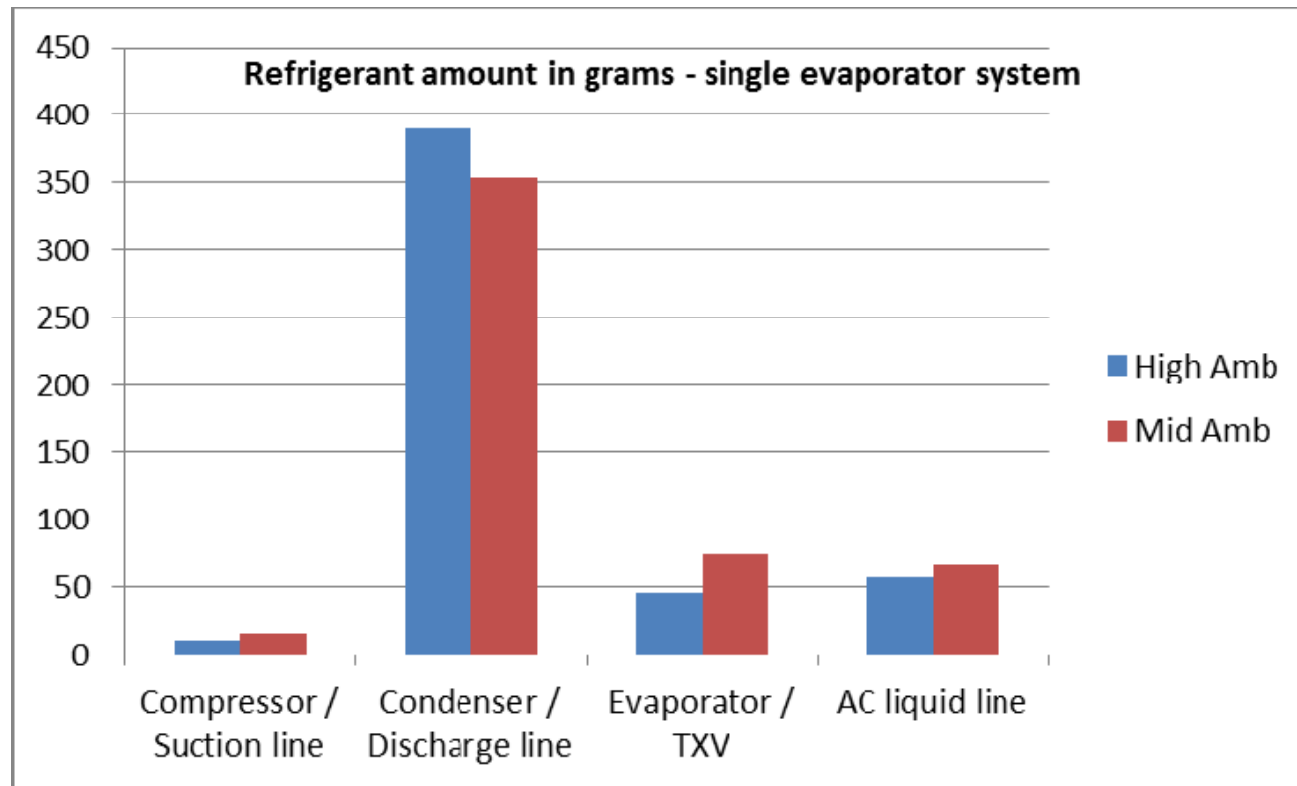
- System On data from A/C Simulation software and bench data
- System off data assumes Evaporator ambient is 12°C and is the refrigerant is superheated
 - All other components/lines are saturated at 10°C ambient

	Refrigerant Distribution Van Front & Aux		
Component Description	System Off (10°C)	System On High Load (30°C/80%RH)	System On Low Load (10°C/60%RH)
Discharge Line	7%	2%	1%
Condenser/Receiver	22%	45%	44%
Liquid Line (Main)	2%	8%	9%
Liquid Line (Aux)	8%	29%	32%
Evaporator (Main)	2%	5%	6%
Evaporator (Aux)	2%	6%	6%
Suction Line (Main)	16%	1%	1%
Suction Line (Aux)	33%	3%	2%
Compressor	6%	1%	<1%
Total	100%	100%	100%

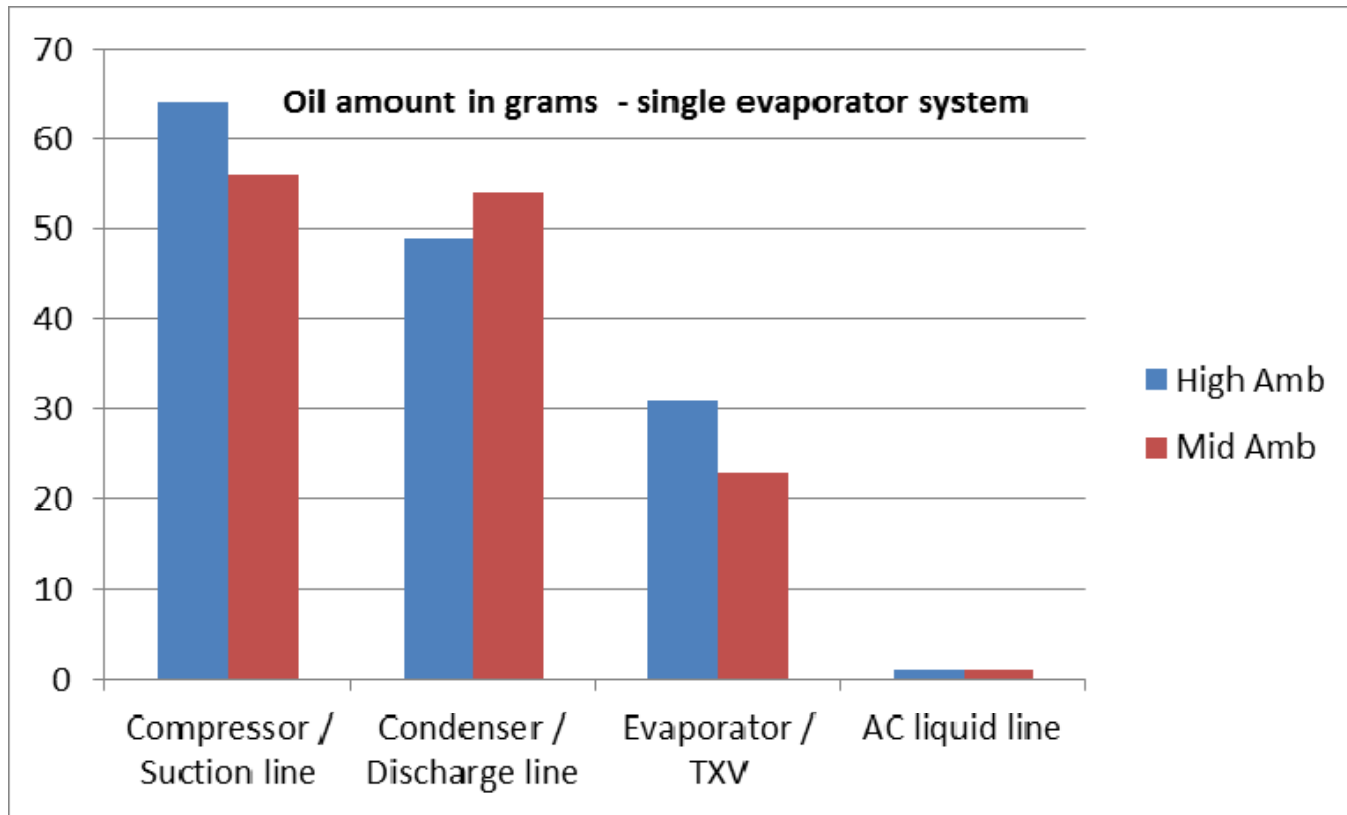
Attachment B

OEM Data on Refrigerant Distribution in AC System Components (Example 2)

Refrigerant distribution per component:



Oil Distribution per component:



Refrigerant Distribution and Oil Distribution in percentage per Component: High and medium ambient condition summary

Refrigerant and Compressor Oil Distribution Single evaporator system	Oil Distribution (%)	Refrigerant Distribution (%)
Compressor / Suction line	44.1	2.2
Condenser / Discharge line	33.8	77.5
Evaporator / TXV	21.4	9.0
AC liquid line	0.7	11.4
TOTAL:	100.0	100.0
Compressor / Suction line	41.8	3.1
Condenser / Discharge line	40.3	69.4
Evaporator / TXV	17.2	14.5
AC liquid line	0.7	13.0
TOTAL:	100.0	100.0

Attachment C

**OEM Data on the Impact of Steam Release During Collision on
Refrigerant Ignition and Fire Propagation (Example 1)**

Coolant Behavior Consideration

Problem Definition

Question:

What impact does the release of coolant have on the mitigation of refrigerant ignitions?

Hypothesis:

Releasing coolant will generate vapor aerosolized water particles (steam) that will **displace oxygen, replacing it with a non-combustible material. The presence of steam would therefore tend to quench ignition** and any propagation that may occur.

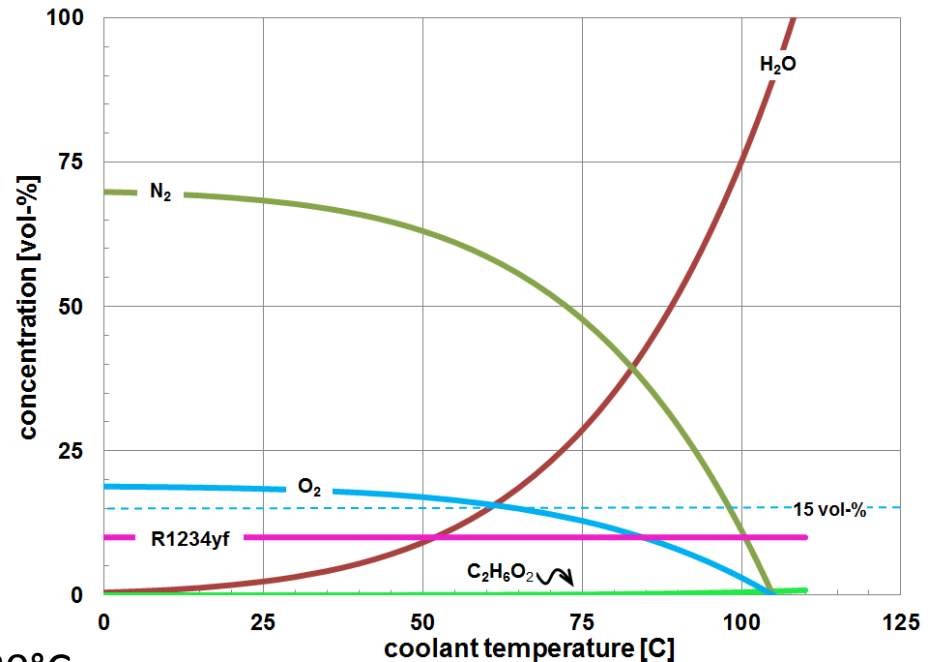
Methodology:

- 1) Summarize theory of coolant release relating to oxygen
- 2) Rate of occurrence of radiator breach through CAE & crashed vehicles
- 3) Impact of steam during actual vehicle testing
- 4) Relevance of timing: steam generation vs presence of refrigerant
- 5) Conclusions

Theory of Coolant Release

Coolant Release Impact

- When a radiator breaches, coolant is released under hood. This calculation is performed at equilibrium vapor conditions and ideal gas assumptions. Does not consider aerosol effect.
- Plot shows
 - R-1234yf @ 7.75 vol-% (stoich.)
 - Dry air (79 vol-% N_2 & 21 vol-% O_2)
With a radiator breach containing
 - 50:50 mix $C_2H_6O_2$ and H_2O
- Key Facts/Observations
 - 15 vol-% O_2 needed for ignition
 - US Bureau of Mines Bulletin 627
 - $O_2 < 15\%$ occurs when coolant $70^\circ\text{C} - 80^\circ\text{C}$
 - Coolant temperature always $> 80^\circ\text{C}$ when exhaust surface $> 700^\circ\text{C}$
 - This analysis very conservative
 - Not consider heat capacity of water vapor and aerosol
 - Does not consider displacement of refrigerant by steam
 - Heat sink to pull heat from ignition kernel of weak flame



Calculations suggest ignitions mitigated whenever coolant breach occurs

Rate of Occurrence of Coolant Breach

- CAE and Crashed Vehicles -

Radiator Breach Behavior

Question:

Coolant expected to have significant mitigating impact, but how often radiator breach occur during collision?

CAE Analysis – front-end collision

No Breach

Uncertain

Breach

Vehicle	Component	Speed (kph)							
		20	25	30	35	40	45	50	55
Vehicle #1	Condenser	n/a	n/a						
	Radiator	n/a	n/a						
Vehicle #2	Condenser								
	Radiator								
Vehicle #3	Condenser								
	Radiator								

CAE analysis indicates that radiator will always breach
- at lower speeds than that required to breach the A/C system or
- during a collision severe enough to breach A/C system

Radiator Breach Behavior (2)

Question:

Coolant expected to have significant mitigating impact, but how often radiator breach occur during collision?

Vehicle Data– front-end collision

Vehicle	Speed (kph)	Radiator	Condenser
Vehicle #1	56		
Vehicle #2	42.5		
Vehicle #3	45		
	45		
	45		
	50		
	50		

No Breach
 Breach

Vehicle data from actual crash tests validate CAE analysis → radiator always breached
- at lower speeds than that required to breach the A/C system or
- during a collision severe enough to breach A/C system

Impact of steam during actual vehicle testing

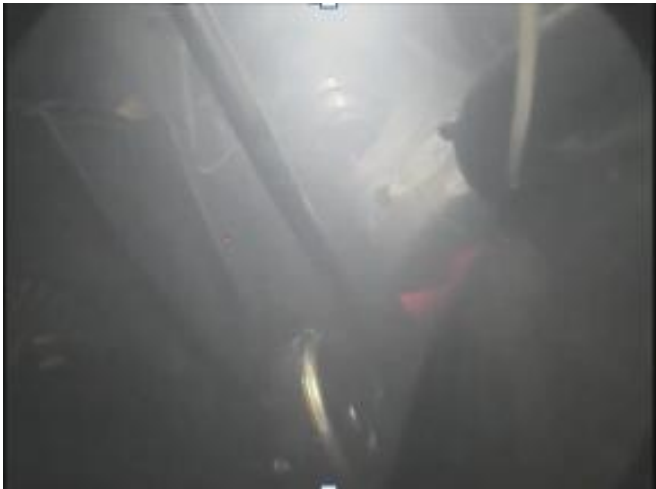
Steam Impact – Release Testing

Test Setup:

- Daimler nozzle, fully tuned system for ignition, > 790°C surface temps, fan off

Configuration	# tests	Result
No coolant release	5	Ignition (5/5)
Coolant Release	5	No Ignitions (0/5)

Sample of release test showing steam impact:



Coolant release always mitigated ignition of refrigerant

Steam Impact – full hot/wet crash tests

Test Setup:

- Production level vehicle, all fluids, 750 - 790°C surface temps, 45kph - 50kph

Sample of release test showing steam impact:



Under hood picture showing steam



Coolant release always occurred. Refrigerant ignition never occurred

Relevance of Timing

- steam generation vs presence of refrigerant -

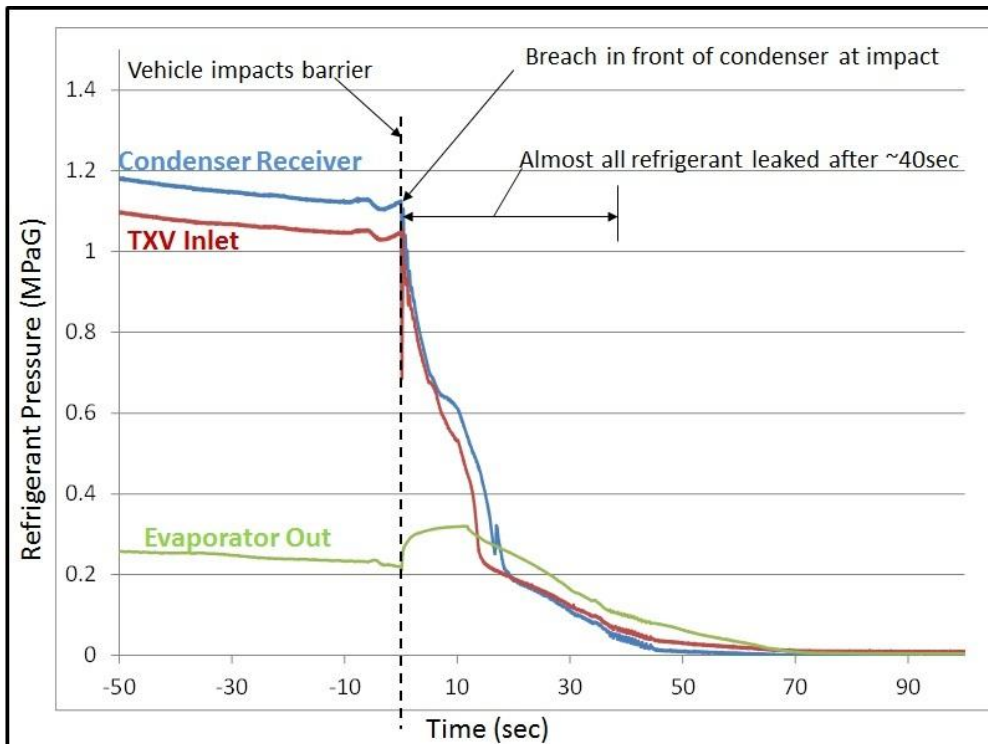
Timing of Steam Generation vs Refrigerant Release

Question:

Calculations may show that coolant has a mitigating effect, but do the 2 occur at the same time and in the same location?

Evidence:

Refrigerant often leaks out < 60sec



Steam generated for minutes



This picture is 125 sec after collision (continues for many more minutes)

Steam generated in same location and for longer time than refrigerant concentration

Conclusions

- **Coolant release significantly mitigate refrigerant ignitions**
 - Calculations show O₂ levels not high enough to support ignition
 - CAE simulations indicate radiator will always breach
 - At lower speeds than A/C system breach occur or
 - During collision severe enough to damage A/C system
 - Real crash data validate CAE simulations
 - Release tests demonstrated coolant always mitigate refrigerant ignition
 - Crash testing showed
 - Coolant always released during testing
 - No ignitions observed

Attachment D

**OEM Data on the Impact of Steam Release During Collision on
Refrigerant Ignition and Fire Propagation (Example 2)**

Executive Summary

Purpose	1) Conduct Crash tests with production fluids in order to better understand input parameters and probabilities for the CRP1234-4 Risk Assessment
Scope	1) Conduct Crash Tests on a C & D Segment Size Vehicle <ol style="list-style-type: none">Crash Test Type is a 64kph Right Hand 40% Offset Rigid BarrierEngine RPM set to Maximum in order to achieve high exhaust temps with Air Conditioning OnAll vehicle fluids filled to standard production levels, which includes R-1234yf & PAG Oil for the Air Conditioning System
Analysis	1) Both C & D Segment vehicle crash tests resulted in no Refrigerant Ignition <ol style="list-style-type: none">The maximum exhaust manifold surface temperature at impact was approximately 542 CAll A/C components (Compressor, Condenser and A/C Lines) were all brokenConsiderable amount of steam was observed for more than 60 seconds after impact<ol style="list-style-type: none">Even if the exhaust surface temps were above 800C this would allow enough time for surface temps to drop below the refrigerant ignition temperature of 700 C, which is the conservative value that is used for the CRP1234-4 Risk Assessment<ol style="list-style-type: none">Exhaust Surface temps typically cool at a rate of 3 to 5 C per second at these extreme temperatures
Conclusion	1) These tests indicate that Coolant should be considered as a mitigating factor in the Fault Tree Analysis Risk assessment due to the considerable amount of steam observed after impact.

1 Crash Test Information

- 1) Pre-condition
 - a) Ambient temperature: 15 ~ 20°C
 - b) Engine RPM set to Maximum in order to achieve high exhaust temps with Air Conditioning On
 - c) All vehicle fluids filled to standard production levels, which includes R-1234yf & PAG Oil for the Air Conditioning System

Items	C SEG Passenger	D SEG SUV
Engine	Gasoline I4 1.6L	Gasoline V6 3.3L
Exhaust manifold position	Rear side of eng. room	Front/rear side of eng. room
Exhaust gas temperature(°C)	-	760
Exhaust manifold surface temperature(°C)	495~542	520
Engine room air temperature (°C)	80~100	105
Coolant temperature(°C)	102	117
Engine oil temperature(°C)	136	144
High pressure(psi)	207	218
Low pressure(psi)	-	23
High pressure side temp.(°C)	97	114~130
Low pressure side temp.(°C)	15	29

- 2) Crash Test Type
 - a) 64kph Right Hand 40% Offset Rigid Barrier

3) Test Results

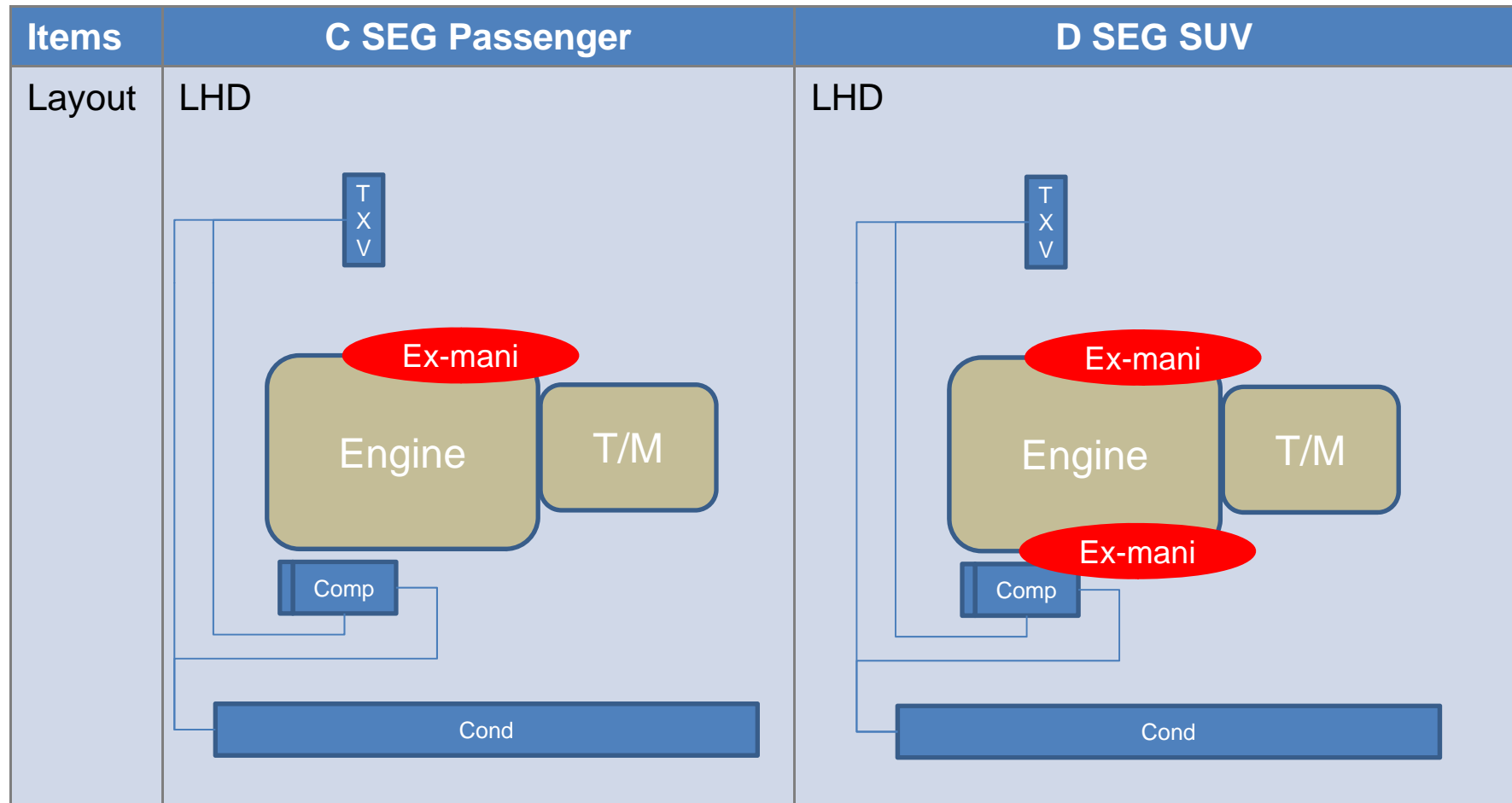
Items		C SEG Passenger	D SEG SUV
Result		NO ignite	NO ignite
A/C components	Compressor	Broken	Broken
	Condenser	Broken	Broken
	A/C plumbing	Broken	Broken

Details

2

Vehicle Layout

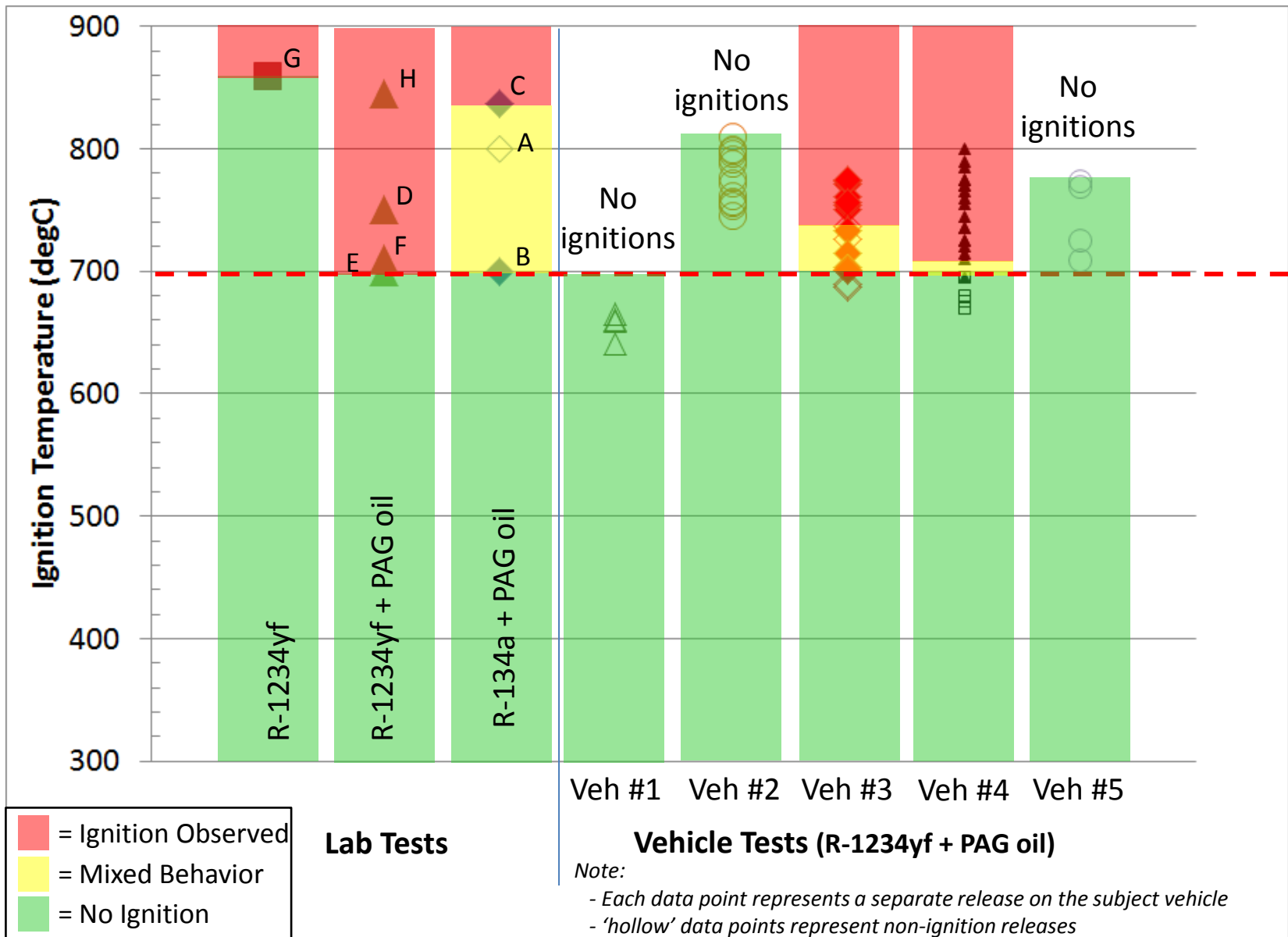
3



Attachment E

**OEM Test Data on Effect of Surface Temperature on Refrigerant
Ignition (Example 1)**

Graphical Summary of Flammability Testing of Refrigerant-Oil Mixtures



All data supports use of 700°C as minimum relevant temperature.
No data supports use of auto-ignition temperature (405°C) as being relevant

Detailed Test Data (Lab Testing)

R-134a

Figure Legend	Configuration	Ignition Temperature	Source
A	R-134a + PAG oil	> 800°C (no ignition observed)	<i>Ignition of refrigerant oil mixtures on hot Surfaces – Ineris</i> (Jan 15, 2009) – CRP1234
B	R-134a + PAG oil	≥ 700°C (ignition observed after discharge completed. Fire continued until extinguished and spread to cabin inlet)	<i>Refrigerant Decomposition Tests Part II: Passenger Car Engine Compartment Tests – Hughes</i> (Aug 24, 2009)
C	R-134a + PAG oil	≥ 837°C (ignition observed due to combustion of PAG oil)	<i>Hot Surface Ignition and Fire Propagation Characteristics of R134a and R1234yf Refrigerants – Ford</i> SAE2012-01-0984

R-1234yf

Figure Legend	Configuration	Ignition Temperature	Source
D	R-1234yf + PAG oil	≥ 750°C (ignition observed)	<i>Ignition of refrigerant oil mixtures on hot Surfaces – Ineris</i> (Jan 15, 2009) – CRP1234
E	R-1234yf + PAG oil	≥ 700°C (ignition observed but was a short flash lasting 1-2 seconds)	<i>Refrigerant Decomposition Tests Part II: Passenger Car Engine Compartment Tests – Hughes</i> (Aug 24, 2009)
F	R-1234yf + PAG oil	≥ 710°C (ignition observed)	<i>Ignition sensitivity and toxics generation by a refrigerant when submitted to a high temperature – Ineris</i> (Nov 26, 2011) – MRB CRP
G	Pure R-1234yf	≥ 860°C (ignition observed)	
H	R-1234yf + PAG oil	≥ 845°C (ignition observed due to combustion of PAG and refrigerant)	<i>Hot Surface Ignition and Fire Propagation Characteristics of R134a and R1234yf Refrigerants – Ford</i> SAE2012-01-0984

Detailed Test Data (Vehicle Testing)

R-1234yf (each row represents the results of multiple tests using a given vehicle)

Configuration	Ignition Temperature	Source
Vehicle #1	No ignition observed (vehicle not capable of exceeding 700°C)	OEM Testing (front takedown, gasoline non-turbo)
Vehicle #2	No ignition observed (includes max exhaust surface temperature 810°C)	OEM Testing (front takedown, gasoline turbo)
Vehicle #3	≥ 700°C	OEM Testing (longitudinal, gasoline turbo)
Vehicle #4	≥ 695°C	OEM Testing (front takedown, gasoline turbo)
Vehicle #5	No ignition observed (includes max surface temperature 775°C)	OEM Testing (rear takedown, gasoline non-turbo)

Attachment F

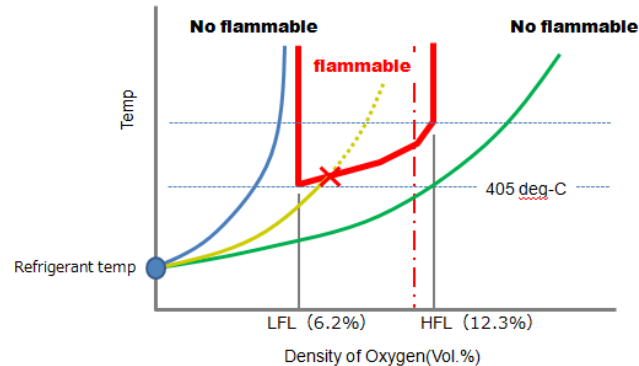
**OEM Test Data on Effect of Surface Temperature on Refrigerant
Ignition (Example 2)**

Background

Validation plan

Parameter of flammable

- a. Density of Oxygen. (Space / distance)
- b. Blow speed of Ref & Oil. (XXX g/sec)
- c. Condition of Ref & Oil Mix.
- d. Temperature.



Clarify flammable condition in ENG compartment

[Refrigerant Ignition Test Flow]

① Collision situation confirmation by full-scale crash test

- Clarify refrigerant blow out area
- Clarify of remaining space

② Clarification highest ENG ROOM temperature

- Confirm the portion that reaches ignition temperature
- Clarify the pre-setting condition of worst case

③ Confirmation of refrigerant blowing out condition

- Confirmation of blowing out location

④ Confirmation of refrigerant blowing out velocity

- Setting of amount of blowing out refrigerant

⑤ Conduct Vehicle test



Daimler

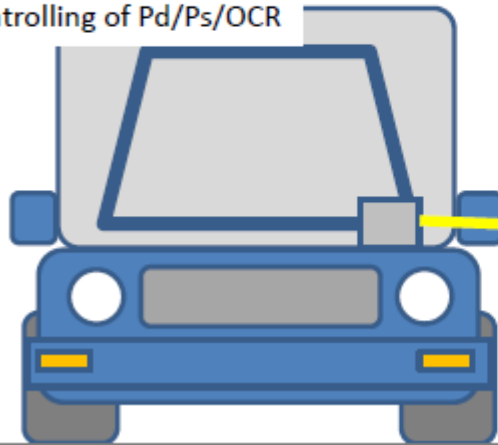


Our purpose is to clarify the conditions of refrigerant ignition.

Validation Method

Refrigerant supply vehicles

Controlling of Pd/Ps/OCR



Ignition test vehicle

Controlling of Temp/Space/Release position



A/C line

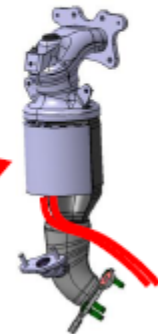
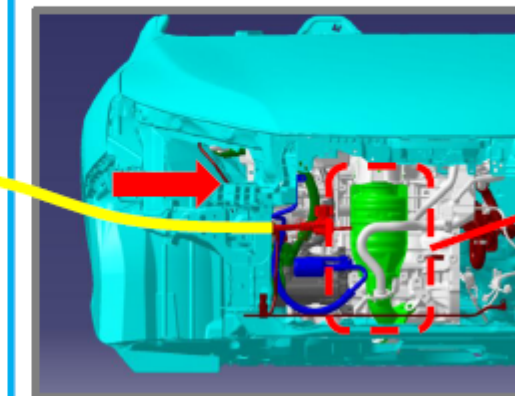
※Pd/Ps/OCR detail is shown in list

Releasing Ref & Oil mix gas from exact A/C line of CBU.



Electric heater

A/C line



Flammability Test Results

CAT Temperature	CAT cover	Bonnet	Under cover	Cooling Fan	Injecting position	Injecting Height	Injection pressure	OCR	Result	Result
650	No	Close	Yes	OFF	High side (60mm)	Low	1.5MPaG	3.5%	No ignition	No Propagation
700	↑	↑	↑	↑	↑	↑	↑	↑	No ignition	No Propagation
760	↑	↑	↑	↑	↑	↑	↑	↑	No ignition	No Propagation
↑	↑	↑	↑	↑	↑	↑	1.0MPaG	↑	No ignition	No Propagation
↑	↑	↑	↑	↑	↑	↑	0.5MPaG	↑	No ignition	No Propagation
↑	↑	↑	↑	↑	↑	High	1.0MPaG	↑	Oil ignition	No Propagation
↑	↑	↑	↑	↑	↑	↑	0.5MPaG	↑	Oil ignition?	No Propagation
↑	↑	OPEN	↑	↑	↑	↑	1.0MPaG	↑	No ignition	No Propagation
↑	↑	OPEN	No	↑	↑	↑	↑	↑	No ignition	No Propagation
↑	↑	Close	↑	↑	↑	↑	↑	↑	Oil ignition	No Propagation
↑	↑	↑	↑	↑	↑	↑	0.5MPaG	↑	Oil ignition	No Propagation

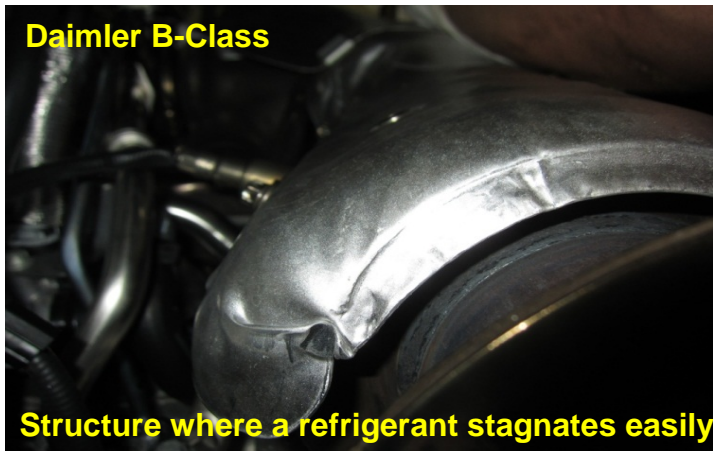
We found some oil ignition phenomenon, but could not find refrigerant ignition condition.

Comparison of Daimler and Realistic Case

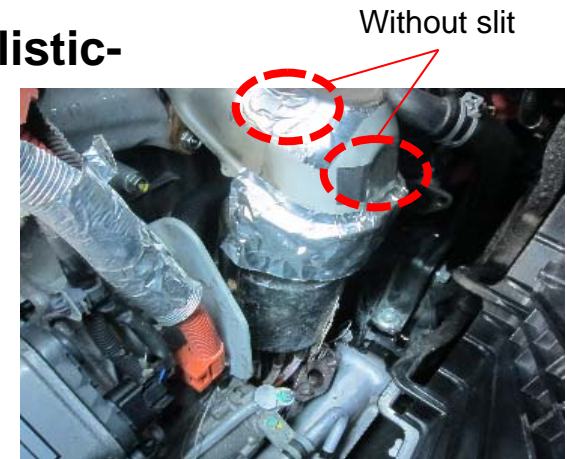
<Oil change>

We verified PAG and POE both oil.

<The difference in heat shield structure>



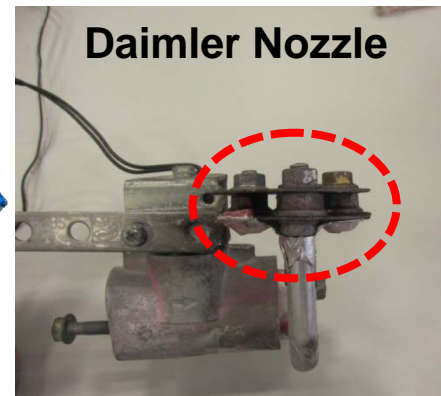
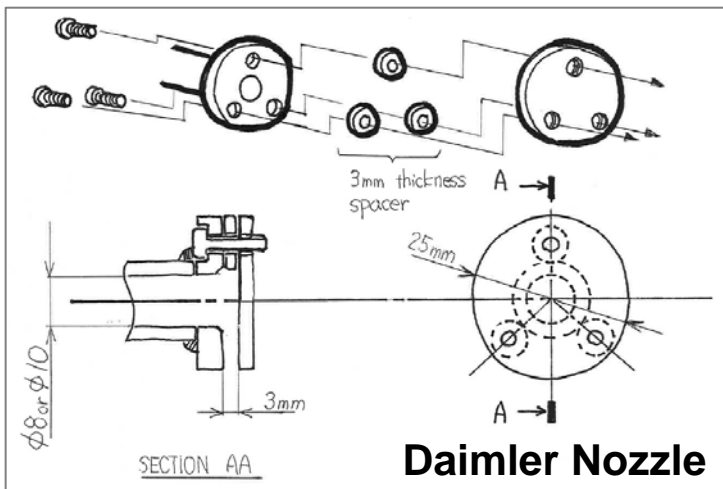
- Realistic-



Extension

A heat shield is modified to make a condition close to Daimler.

<Nozzle Structure>



OR

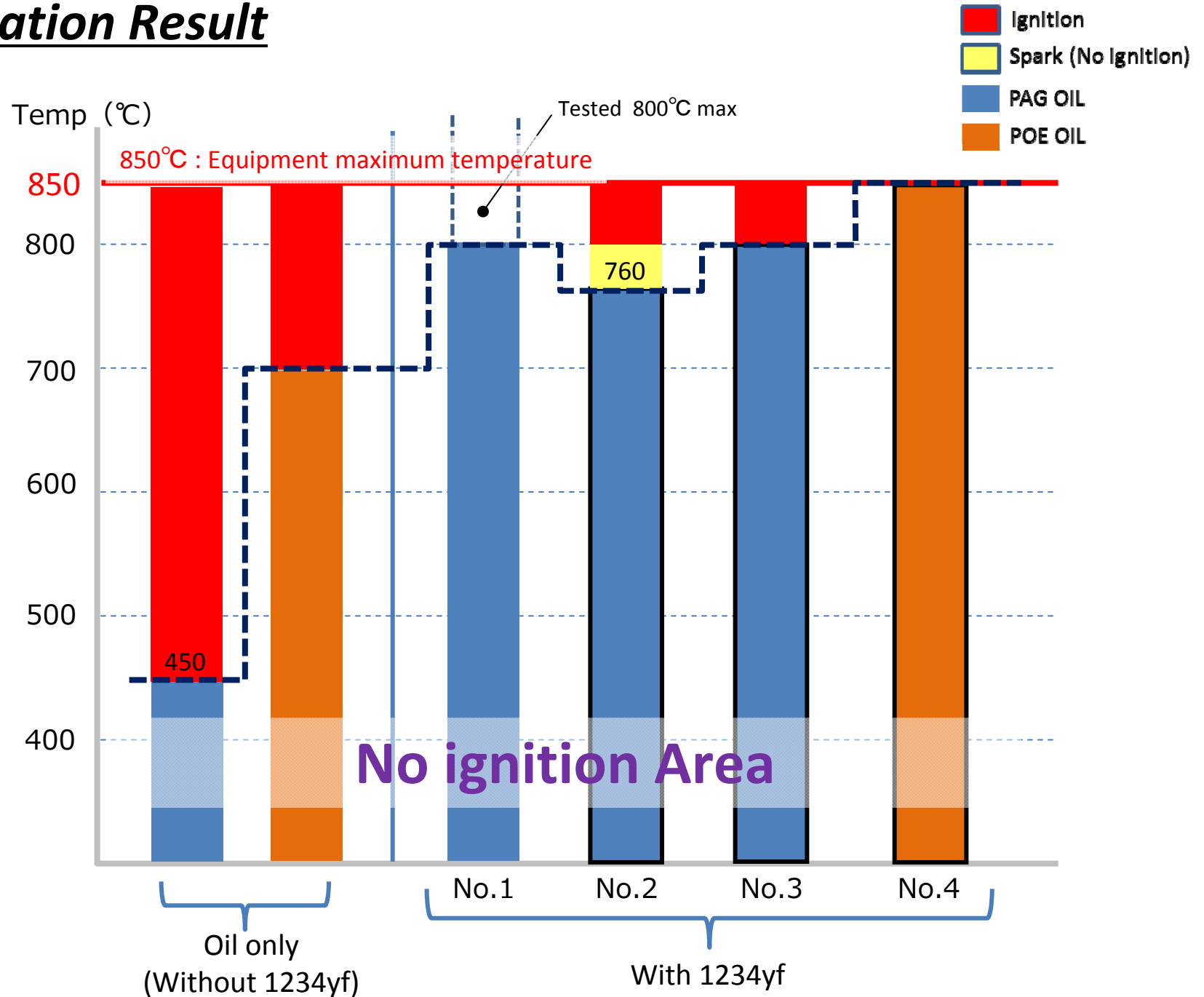


We validated Daimler and realistic both nozzle.

Test Condition

Test No.	Temp	Oil OCR=3.5%	Nozzle	Heat shield	Pd	Fan	Hood
1	$\geq 800^{\circ}\text{C}$	PAG	Straight	Mass production *with slit	2.0MPa(gage)	OFF	Close
2	↑	↑	Daimler	Mass production +without slit +Extension	↑	↑	↑
3	↑	↑	↑	Without Heat shield	↑	↑	↑
4	↑	POE	↑	Mass production +without slit +Extension	↑	↑	↑

Validation Result



Attachment G

OEM Data from Vehicle Thermal Testing (Example 1)

Thermal Analysis of Exhaust Surfaces

- Methods and Results -

Introduction

Background:

- The CRP team has had numerous discussions to establish conservative inputs into the fault trees
- One of the significant inputs to the trees is the % of time that an average customer will spend above a relevant exhaust surface temperature (i.e. 700°C)
- To date, numerous estimates have been put forward by members of the team but questions remain regarding the right method.

Purpose:

- Provide clarification on a method for determining % of time at temperature > 700°C.
- Substantiate the values currently included in the fault tree

Method

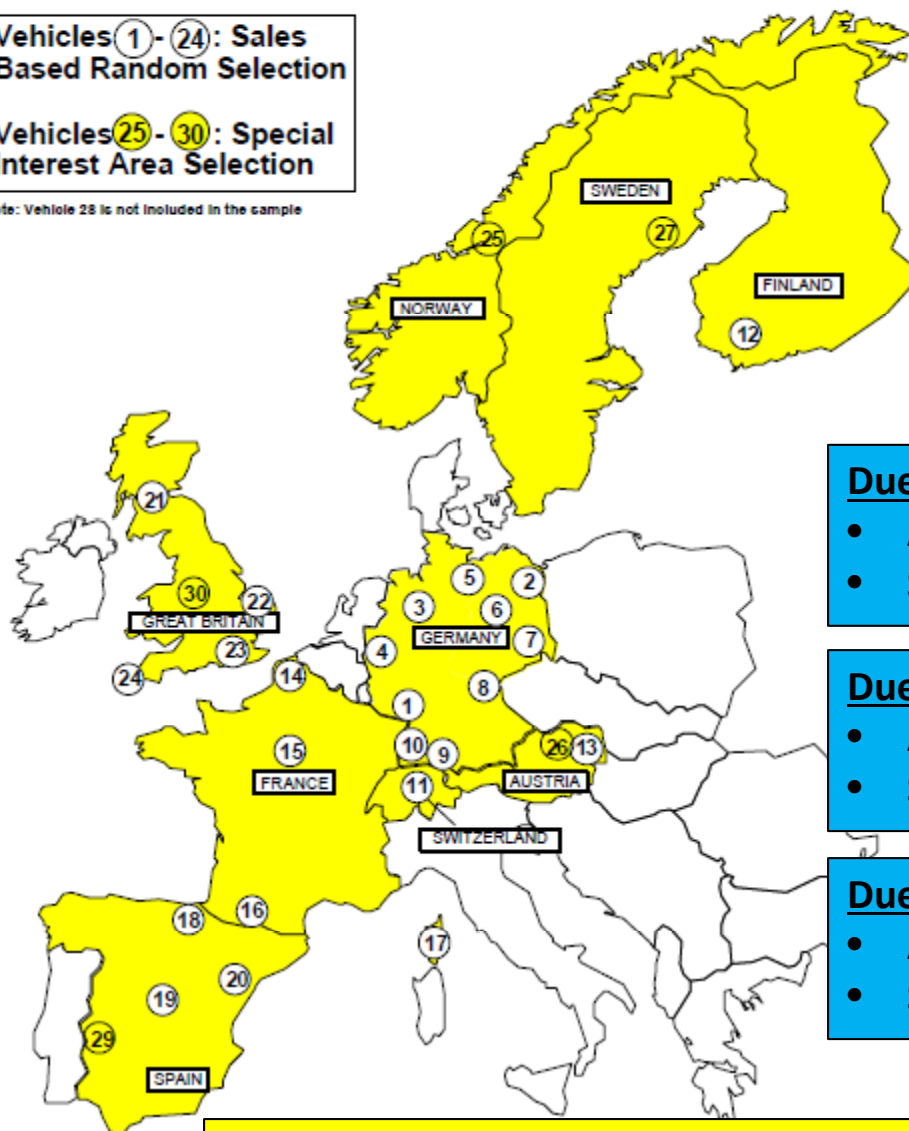
- Identify relevant conditions where temperatures can exceed 700°C using thermal validation procedure
- Relevant Conditions identified as grades, WOT, Vmax
- Analyze real customer data for 4 cyl, V6, V8 to understand drive behavior
 - Data collected from total of 57 vehicles and > 1,270,650miles
 - 2 regions used: United States and Germany/Europe
- Weibull results and determine % time average customer spend at grade, WOT, Vmax
- Sum % for each to obtain overall % > 700°C

Example of European Study

Vehicles ① - ②④: Sales Based Random Selection

Vehicles ②⑤ - ③①: Special Interest Area Selection

Note: Vehicle 28 is not included in the sample



Due to grade operation

- Average Customer (50%) = 0.06% of time > 700°C
- Severe Customer (90%) = 0.35% of time > 700°C

Due to WOT operation

- Average Customer (50%) = 0.03% of time > 700°C
- Severe Customer (90%) = 0.40% of time > 700°C

Due to Vmax operation

- Average Customer (50%) = 0.03% of time > 700°C
- Severe Customer (90%) = 0.78% of time > 700°C

Aggregate Time > 700°C: US + Europe

- Average Customer (50%) = 0.06% + 0.03% + 0.03% = 0.12% > 700°C
- Severe Customer (90%) = 0.35% + 0.40% + 0.78% = 1.53% > 700°C

Comments on Assessment Method:

This assessment was deemed to be conservative for the following reasons:

- Assumed every vehicle can achieve exhaust surface $> 700^{\circ}\text{C}$
 - Not reduce occurrence % for diesel or NA vehicles
- Assumed a WOT of any duration resulted in temp $> 700^{\circ}\text{C}$
 - Profile data suggests multiple back-to-back WOTs necessary
- Assumed top 3 speed bands same as Vmax resulting in temp $> 700^{\circ}\text{C}$
- Assumed Vmax is relevant for all regions of globe – no reduction in occurrence %
 - Data suggests not a relevant consideration for US
- Assumed that continuous driving at grade $> 4\%$ for 90s results in temp $> 700^{\circ}\text{C}$
- Adding across 90% bands for grade, WOT, Vmax overinflates 90% result
 - Likely reporting 99% result

Backup

Grade Consideration:

Grades:

- Analyzed grade profile data from thermal testing and found that the user needs to operate continuously at a grade to exceed 700°C
 - The relevant continuous time was determined to be 90 seconds
- Sorting condition used was
 - Measured grade > X% (used 4%, 7%, 12%)
 - Vehicle speed > 0kph
 - Continuous time > 90 seconds
- Number of occurrences determined, Weibull results
- Select average (50%) customer and a severe (90%) customer to determine time at grade

Conservative Assumptions:

- Any time that grade > X% for continuous 90s (speed > 0kph) → assume exhaust surface > 700°C
- All vehicles can achieve 700°C → no consideration for diesels or NA vehicles that cannot reach 700°C

WOT Consideration:

Wide Open Throttle (WOT):

- Analyzed thermal profile data from thermal testing and found that the user needs to operate back-to-back WOTs to exceed 700°C
 - Determined that need to be > 10s long within 20s of each other
- Initial Result
 - Analyzed 24 vehicles (309,601 miles) and did not find 1 occurrence of this
- Modified Criteria
 - Considered that whenever WOT occurs, temperature > 700°C

Conservative Assumptions:

- Any time that WOT occurs, even momentary, assumed that temp > 700°C
 - Data suggests that continuous preconditioning is required
 - Necessary preconditioning never occurred in all vehicles analyzed
- All vehicles can achieve 700°C → no consideration for diesels or NA vehicles that cannot reach 700°C

Vmax Consideration:

Vmax:

- Analyzed thermal profile data from thermal testing and found that the user needs to operate continuously at Vmax to exceed 700°C
 - Determined that need to be > 30s long
- Initial Result
 - Analyzed 33 vehicles (>550,000 miles) in US and did not find Vmax occurrence
 - 24 analyzed (706,000 miles) 4 cyl in Germany
- Modified Criteria
 - Considered that whenever Vmax occurs, for any period, temperature > 700°C
 - Considered speeds in 2 bands below Vmax as > 700°C

Conservative Assumptions:

- Any time that Vmax occurs, even momentary, assumed that temp > 700°C
 - Data suggests that continuous preconditioning is required
- All vehicles can achieve 700°C → no consideration for diesels or NA vehicles that cannot reach 700°C
- Expanded to lower speed bands and included as “Vmax”

Attachment H

OEM Data from Vehicle Thermal Testing (Example 2)

Thermal Testing Summary

June 20, 2013

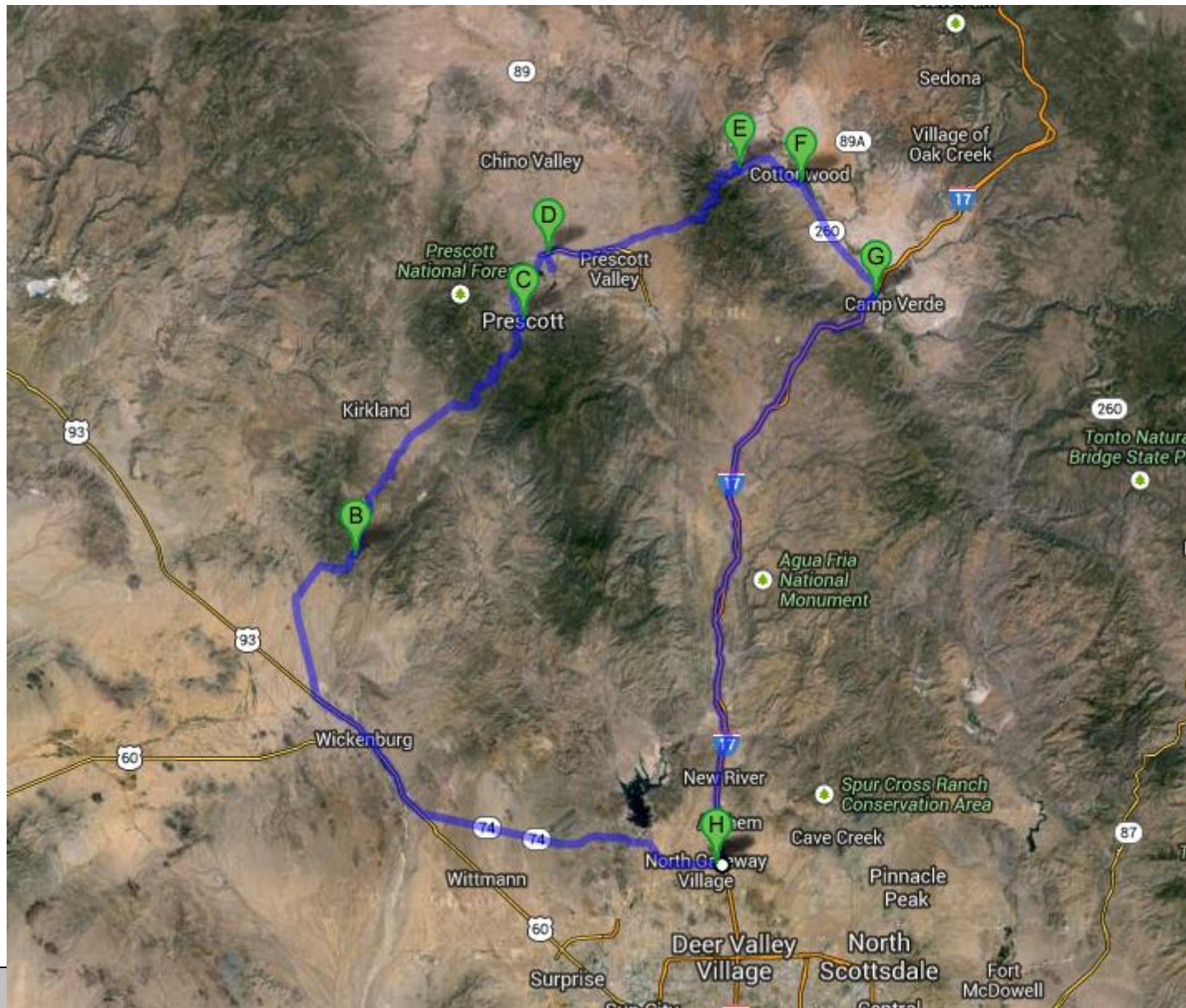
Thermal Testing Summary

- Vehicle: Small CUV
 - 2.0L Turbocharged Direct Injection Gas Engine
 - Automatic Transmission
- Testing Location:
 - Location was Southwestern USA (north of Phoenix, AZ)
 - Two circular routes West and East of I-17
 - Conducted in both clockwise & counterclockwise directions
 - Location was selected based on worst case routes in Arizona for grades and loads on vehicle
 - Location was not selected for highest possible ambient

Thermal Testing Summary

- Testing Methodology:
 - Testing objective was to produce highest possible underhood exhaust temperatures
 - Highest temperatures are not seen under more modest loads or more normal driving profiles
 - Vehicle had to be driven at or near load limits to produce highest temperatures
 - “Base” testing w/o a trailer was at near max vehicle load (98% GVWR)
 - “Trailer” testing was at max rating for vehicle plus trailer; combined weight rating (100% GCWR),

West Route



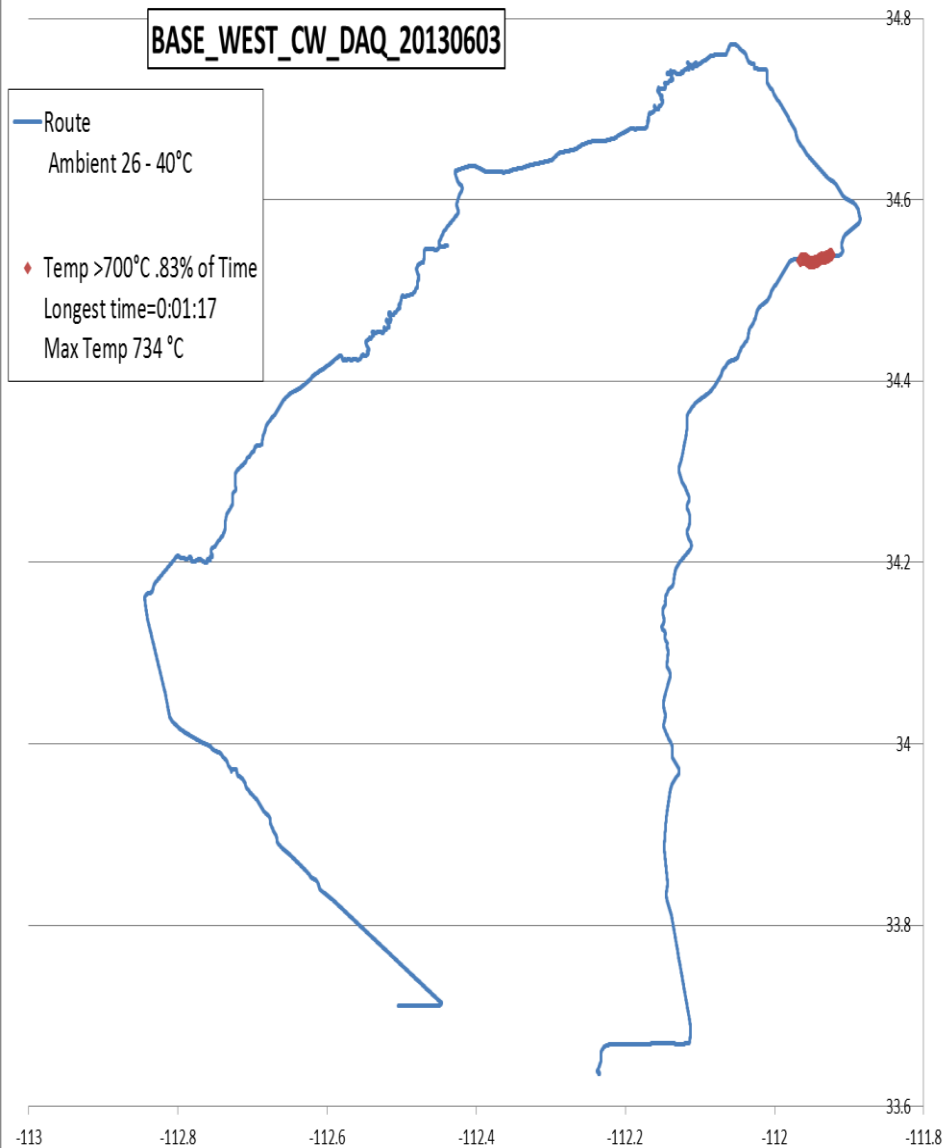
East Route



BASE_WEST_CW_DAQ_20130603

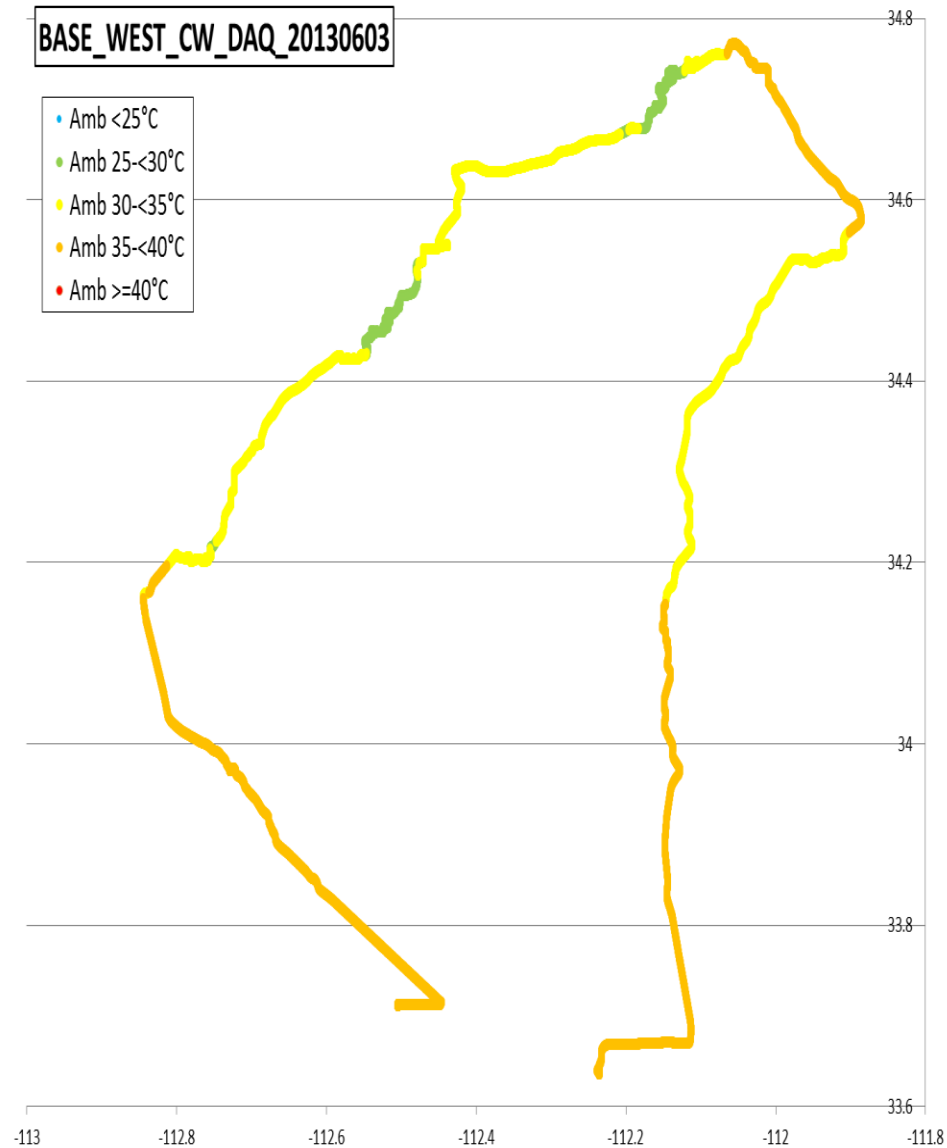
Route
Ambient 26 - 40°C

Temp >700°C .83% of Time
Longest time=0:01:17
Max Temp 734 °C



BASE_WEST_CW_DAQ_20130603

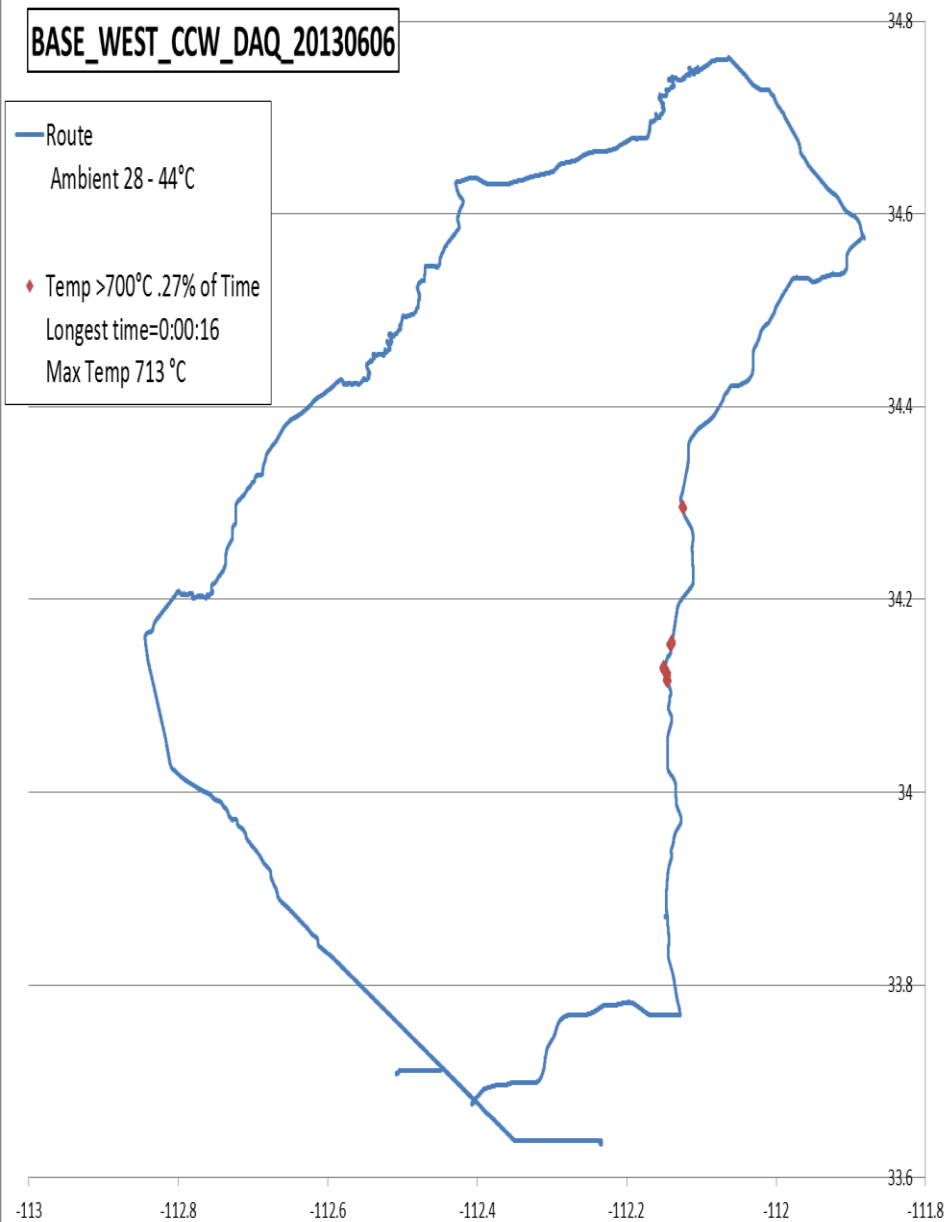
Amb <25°C
Amb 25-<30°C
Amb 30-<35°C
Amb 35-<40°C
Amb >=40°C



BASE_WEST_CCW_DAQ_20130606

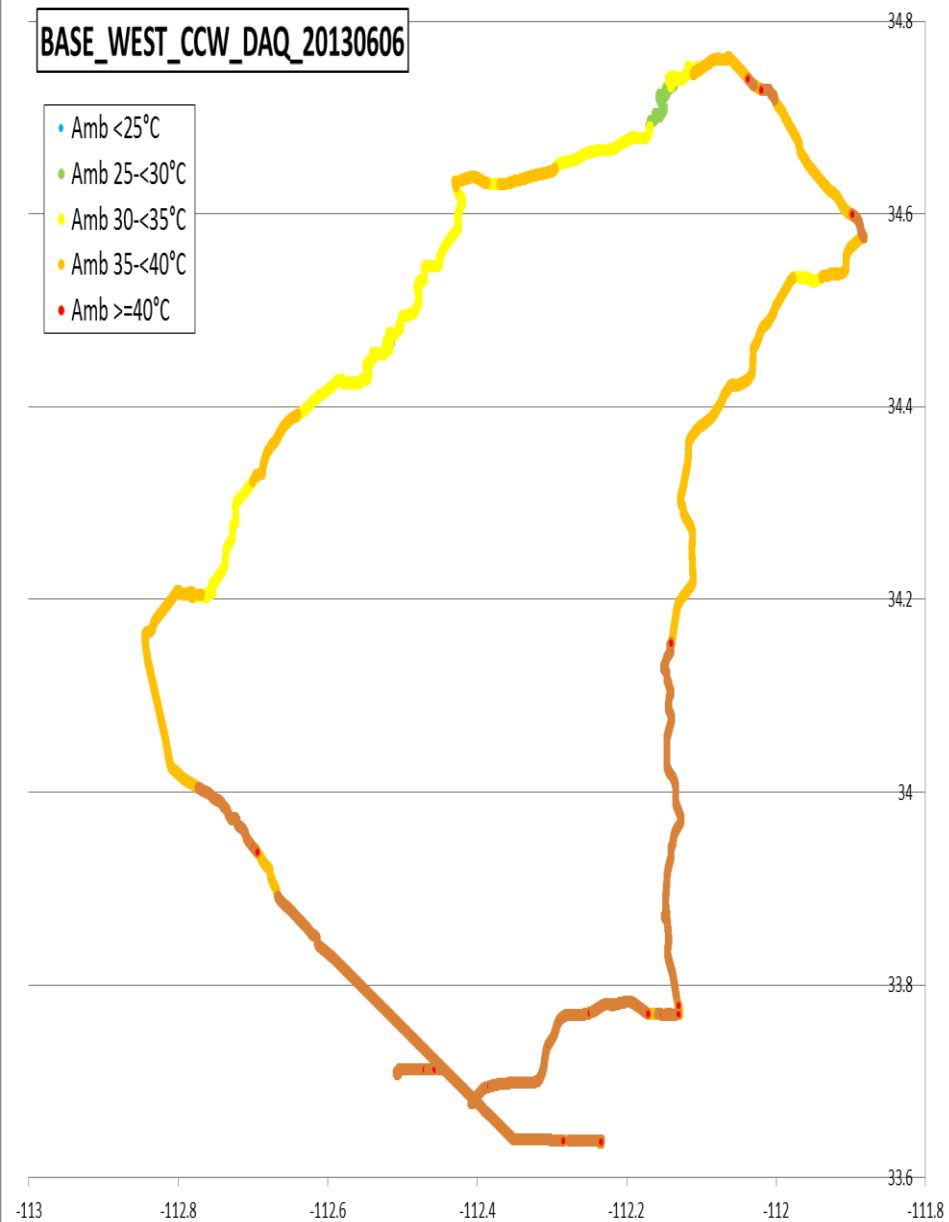
Route
Ambient 28 - 44°C

Temp >700°C .27% of Time
Longest time=0:00:16
Max Temp 713 °C



BASE_WEST_CCW_DAQ_20130606

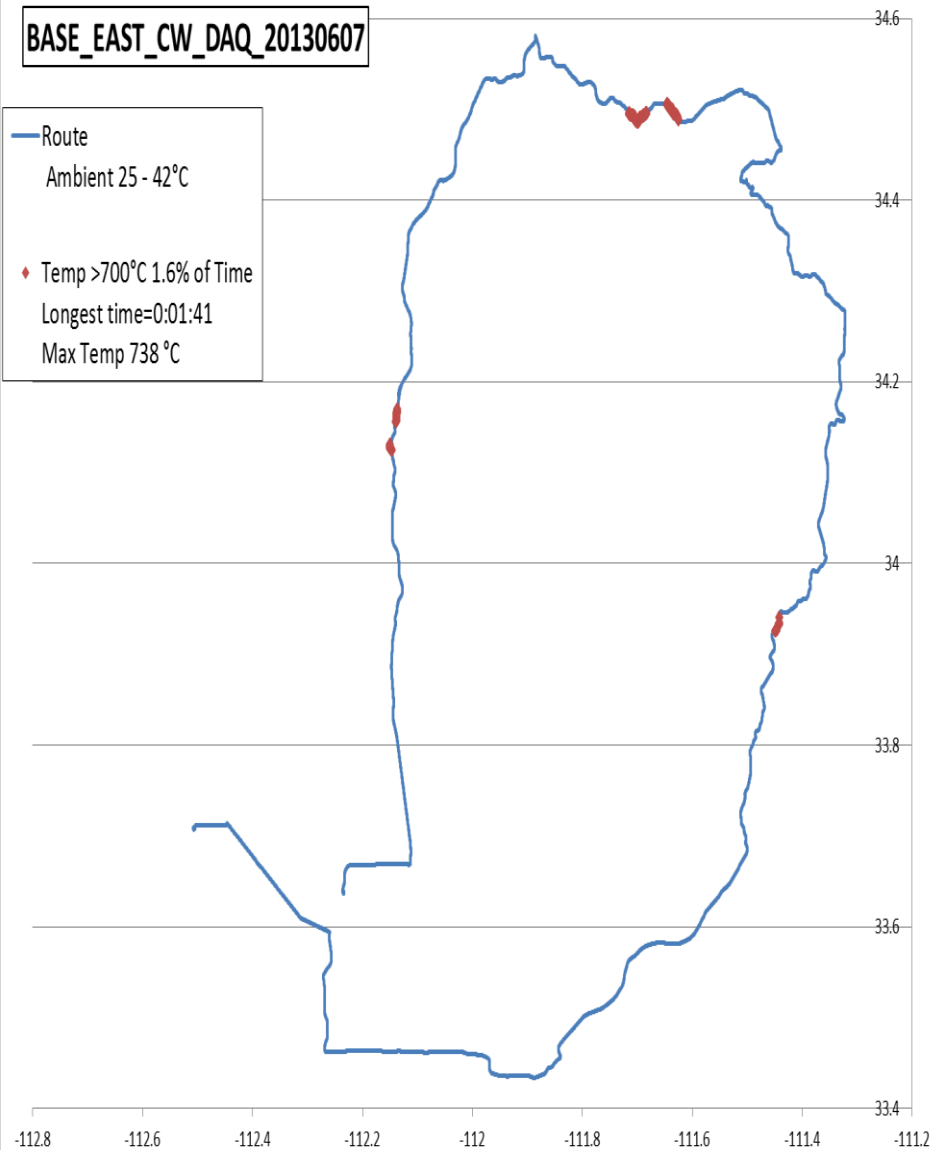
Amb <25°C
Amb 25-<30°C
Amb 30-<35°C
Amb 35-<40°C
Amb >=40°C



BASE_EAST_CW_DAO_20130607

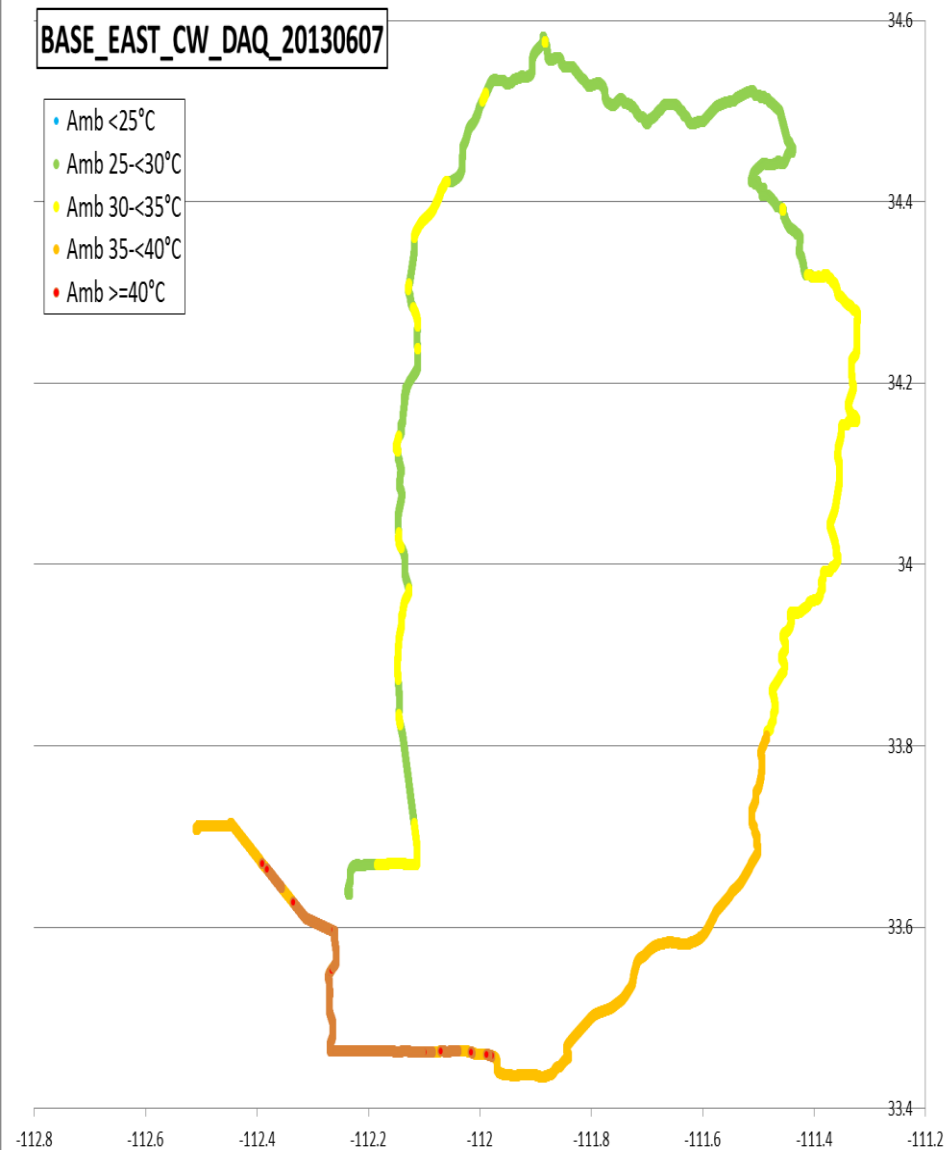
Route
Ambient 25 - 42°C

♦ Temp >700°C 1.6% of Time
Longest time=0:01:41
Max Temp 738 °C

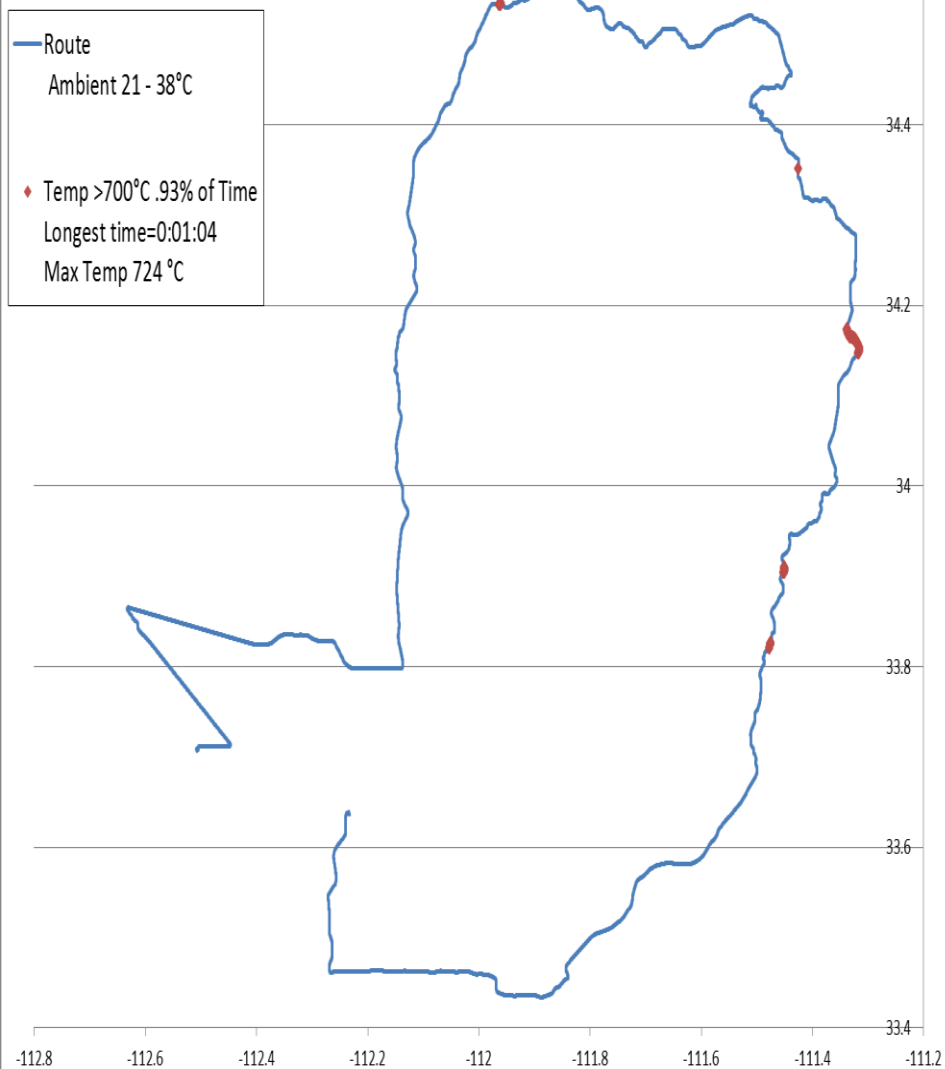


BASE_EAST_CW_DAO_20130607

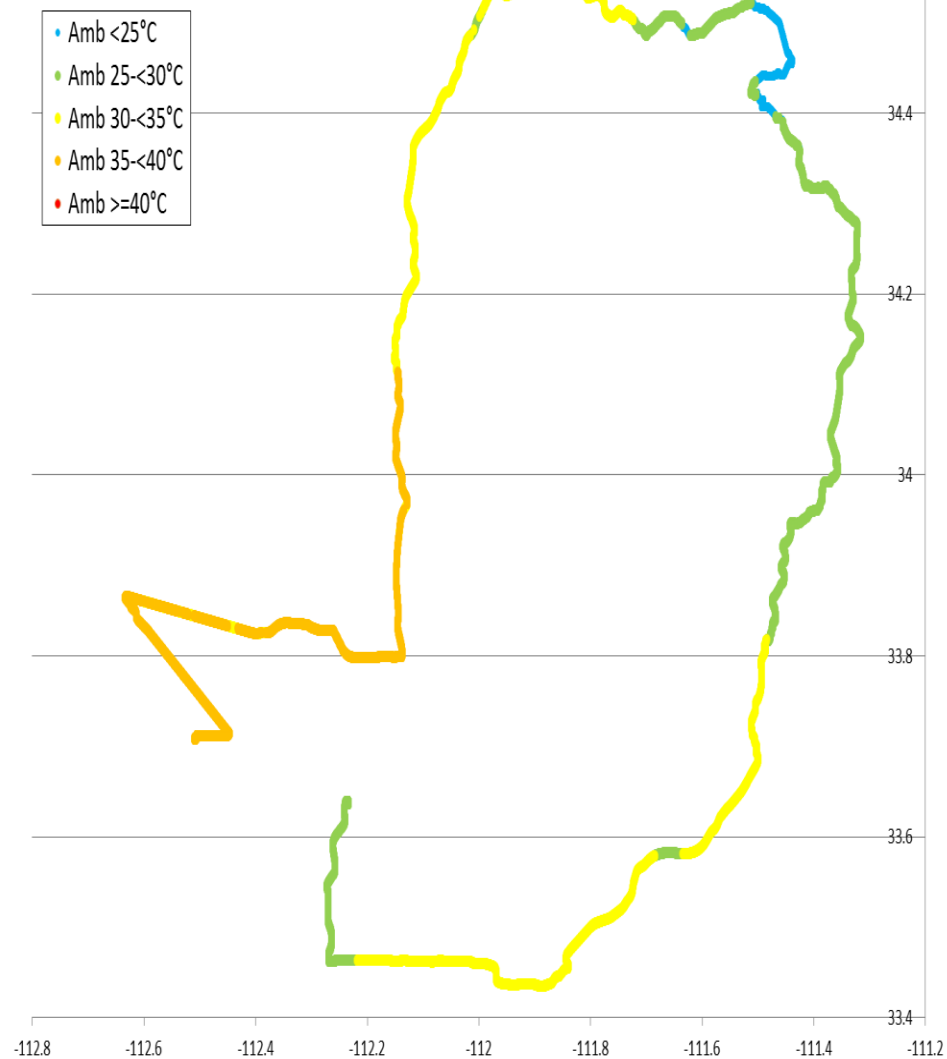
• Amb <25°C
• Amb 25-<30°C
• Amb 30-<35°C
• Amb 35-<40°C
• Amb >=40°C



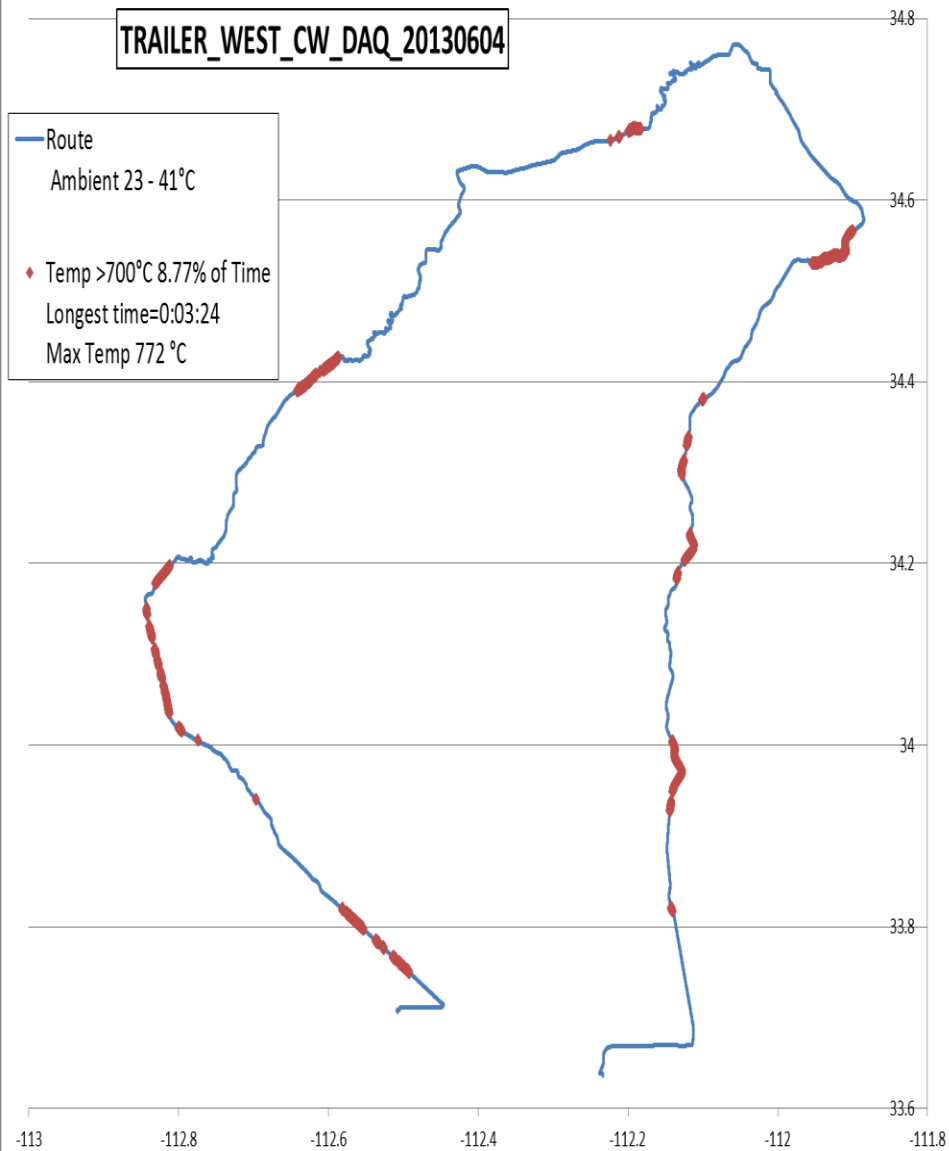
BASE_EAST_CCW_DAO_20130604



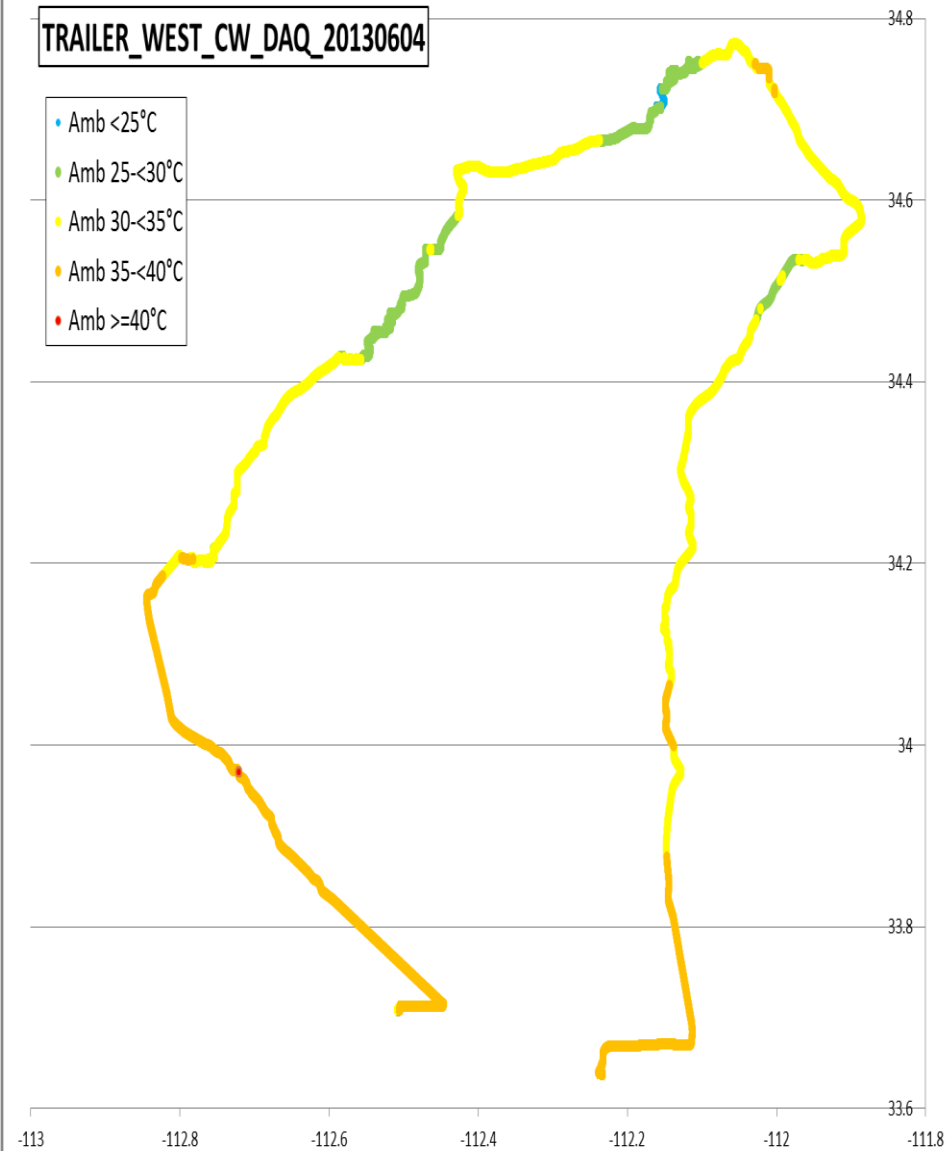
BASE_EAST_CCW_DAO_20130604



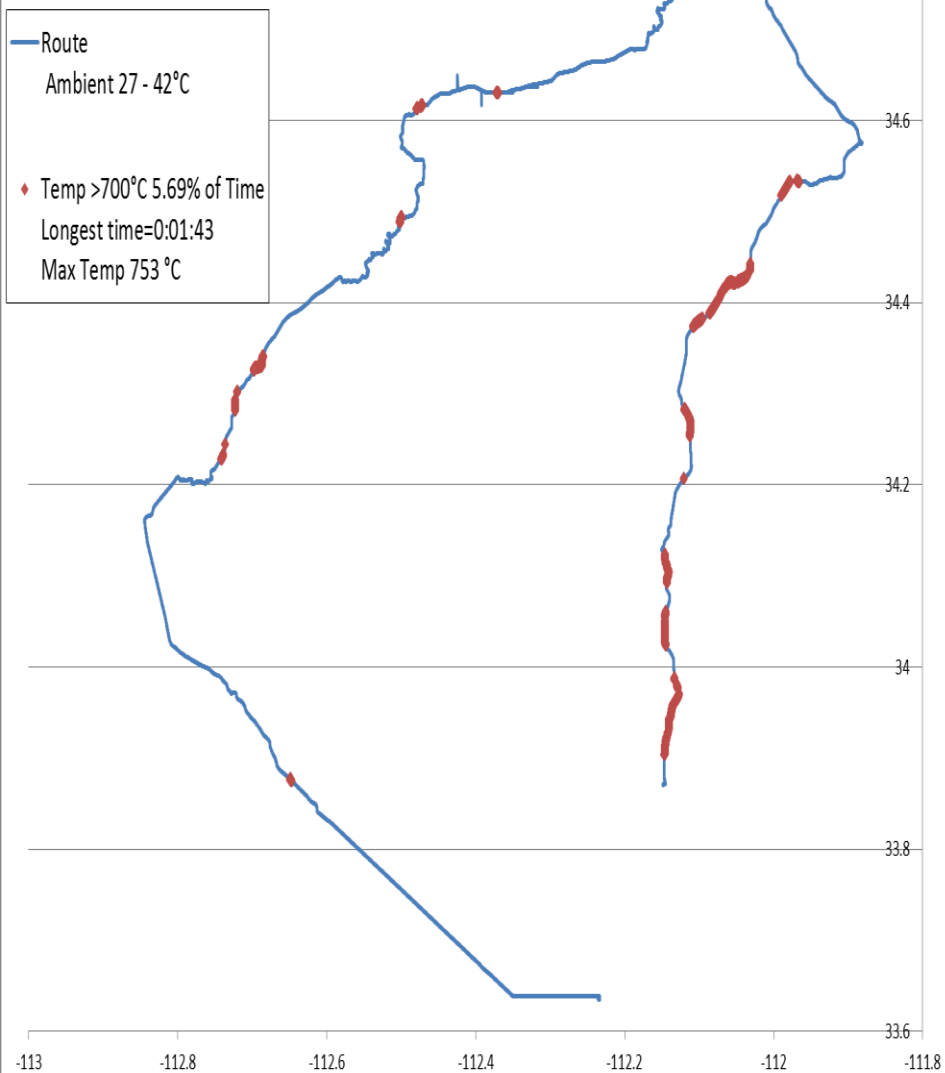
TRAILER_WEST_CW_DAQ_20130604



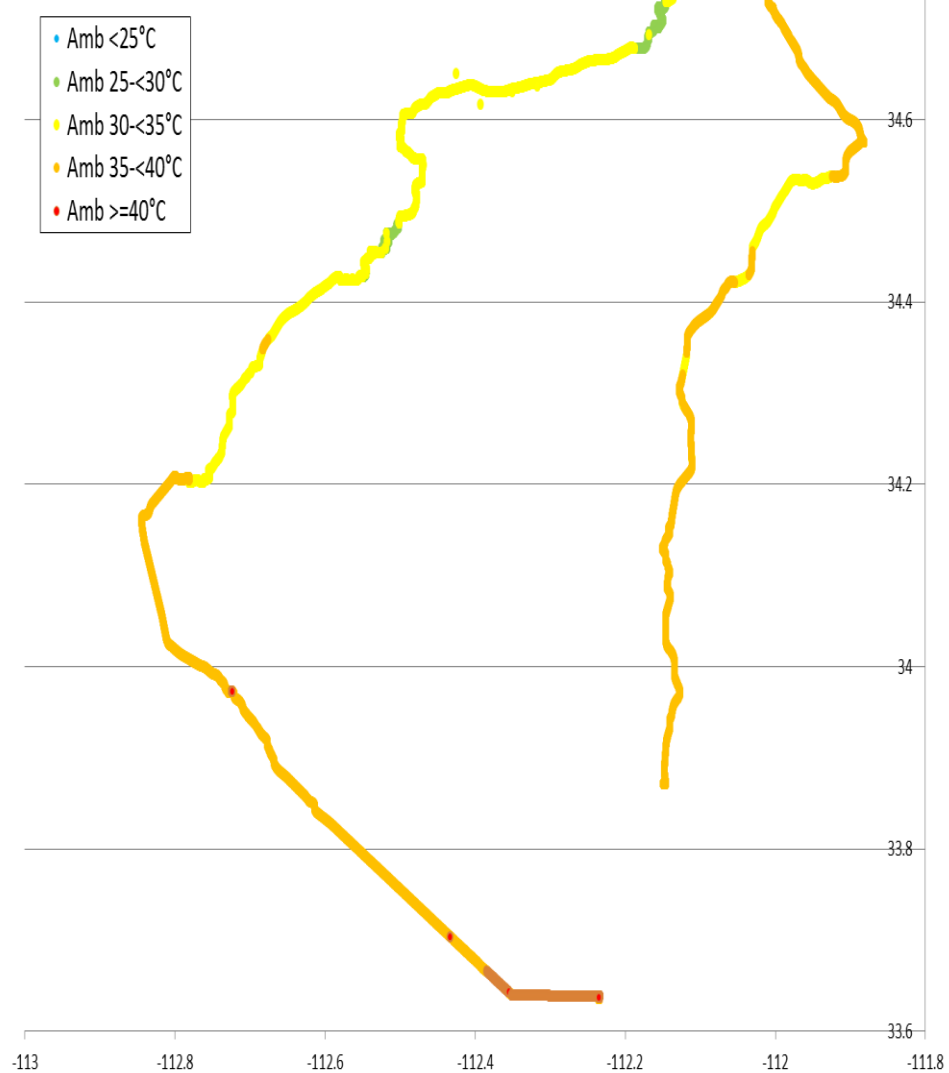
TRAILER_WEST_CW_DAQ_20130604



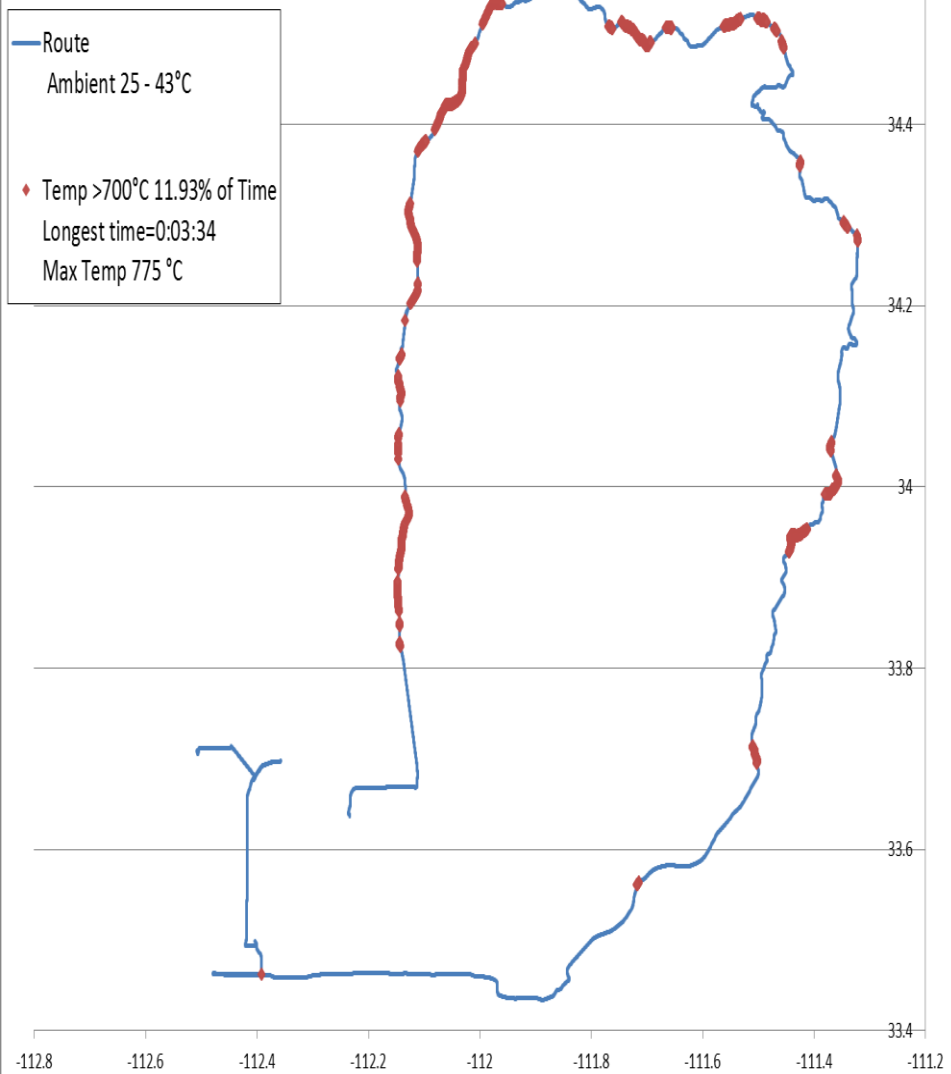
TRAILER_WEST_CCW_DAQ_20130605



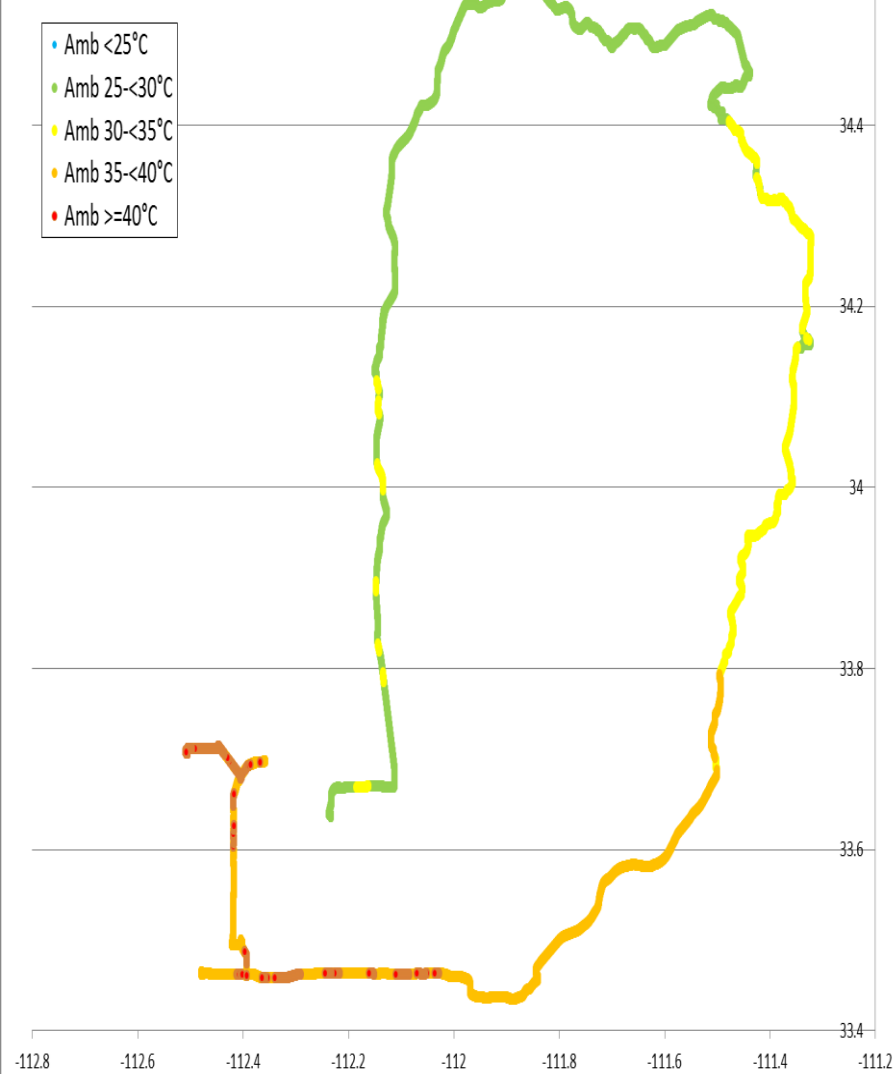
TRAILER_WEST_CCW_DAQ_20130605



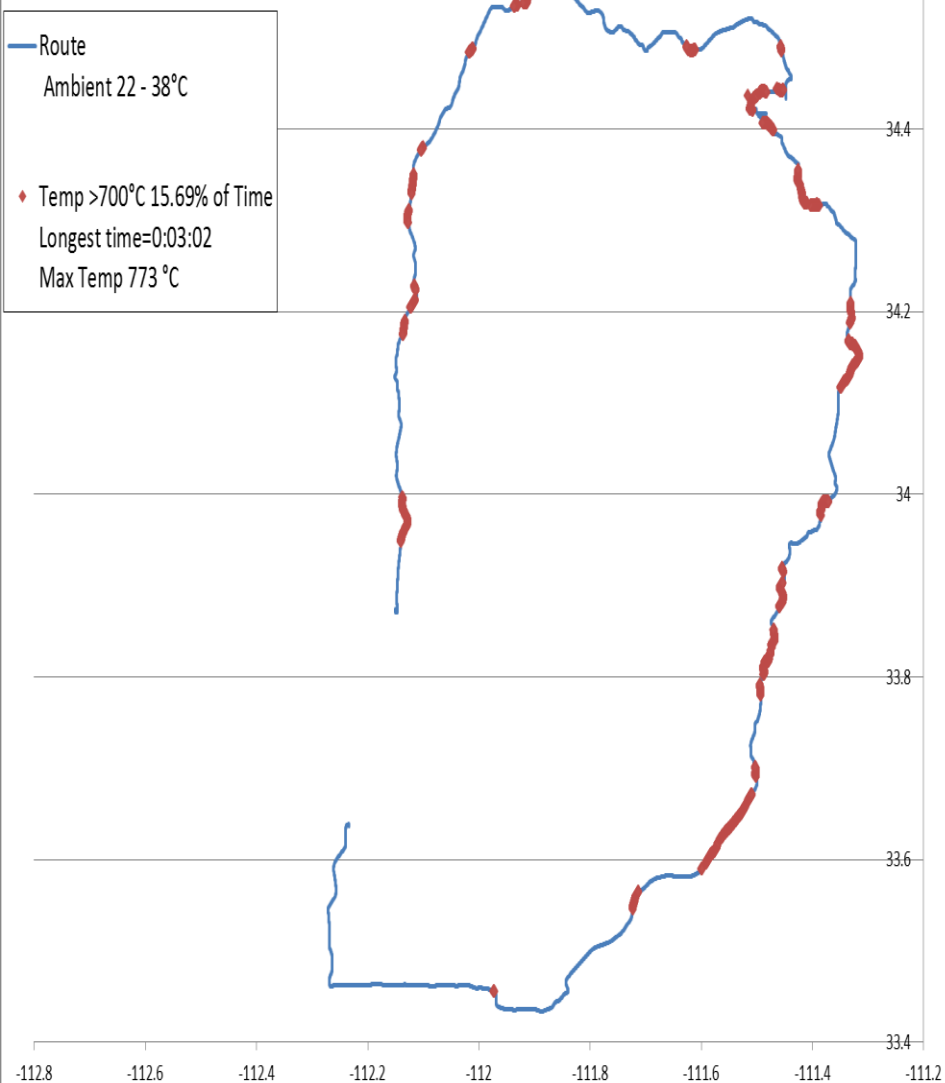
TRAILER_EAST_CW_DAO_20130606



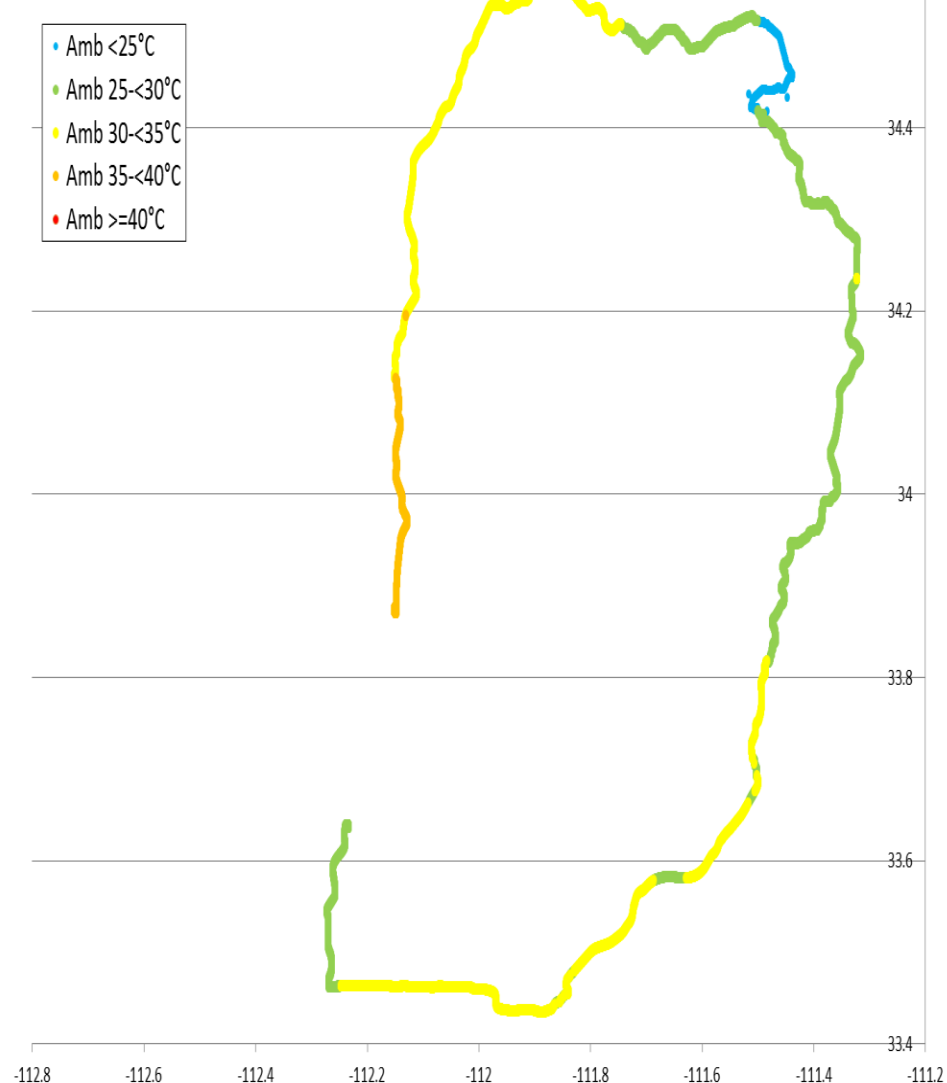
TRAILER_EAST_CW_DAO_20130606



TRAILER_EAST_CCW_DAQ_20130605



TRAILER_EAST_CCW_DAQ_20130605



Summary Table

Thermal Testing Summary of Results

Route	Direction	Test Condition (Base or Trailer)	Highest Exhaust Surface Temperature		
			Percent Time >700°C	Longest Time >700°C (h:mm:ss)	Maximum (°C)
West	CW	Base	0.8%	0:01:17	734
West	CCW	Base	0.3%	0:00:16	713
East	CW	Base	1.6%	0:01:41	738
East	CCW	Base	0.9%	0:01:04	724
Average		Base	0.9%	0:01:04	727
West	CW	Trailer	8.8%	0:03:24	772
West	CCW	Trailer	5.7%	0:01:43	753
East	CW	Trailer	11.9%	0:03:34	775
East	CCW	Trailer	15.7%	0:03:02	773
Average		Trailer	10.5%	0:02:56	768
Average Adjusted for Customer Usage *		Trailer	<0.1%	0:02:56	768

* Customer Trailer Usage is less the 1% of total operating hours

Considering the severity of the routes and the amount of time customers tow trailers, use of 1% for time greater than 700°C in the SAE CRP FTA is reasonable

Attachment I

Analysis of GIDAS Database Regarding Fires and Fuel Releases

FUEL LEAKAGE & CARS CAUGHT FIRE AFTER FRONTAL/SIDE IMPACT IN GIDAS*

April 2013

* GIDAS: German In-Depth Accidents Study

➔ current status July 2012 (22.347 Accidents)

Fuel leakage of cars after frontal impact in GIDAS

Year of 1 st registration	All		Fuel Leakage (FL)	
	n	% *	n	% **
<2000	7245	60,6%	400	5,5%
2000+	3655	30,6%	102	2,8%
Unknown	1063	8,9%	61	5,7%
Total	11963	100%	563	4,7%

* % per column

** % per row of All

Case Selection:

- 1st collision
- only cars
- frontal impacts (PDOF=11,12,1)
- EES<>"unknown"

Year of 1 st Registration & EES		Fuel Leakage					
		No / Unknown		Yes		All	
Year of 1 st Reg.	EES	n	%	n	%	n	%
<2000	< 16 Km/h	3696	98,1%	73	1,9%	3769	100%
	16-50 Km/h	3047	92,0%	266	8,0%	3313	100%
	> 50 Km/h	102	62,6%	61	37,4%	163	100%
Sub Total of <2000		6845	94,5%	400	5,5%	7245	100%
2000+	< 16 Km/h	2123	98,9%	23	1,1%	2146	100%
	16-50 Km/h	1381	95,5%	65	4,5%	1446	100%
	> 50 Km/h	49	77,8%	14	22,2%	63	100%
Sub Total of 2000+		3553	97,2%	102	2,8%	3655	100%
Unknown	< 16 Km/h	551	97,0%	17	3,0%	568	100%
	16-50 Km/h	423	93,6%	29	6,4%	452	100%
	> 50 Km/h	28	65,1%	15	34,9%	43	100%
Sub Total of "Unknown"		1002	94,3%	61	5,7%	1063	100%
Total		11400	95,3%	563	4,7%	11963	100%

Fuel leakage of cars after side impact in GIDAS

Year of 1 st registration	All		Fuel Leakage (FL)	
	n	% *	n	% **
<2000	2870	59,1%	108	3,8%
2000+	1590	32,7%	35	2,2%
Unknown	400	8,2%	0	0,0%
Total	4860	100%	143	2,9%

* % per column

** % per row of All

Case Selection:

- 1st collision
- only cars
- side impacts (PDOF=2,3,4&8,9,10)
- EES<>"unknown"

Year of 1 st Registration & EES		Fuel Leakage					
		No / Unknown		Yes		All	
Year of 1 st Reg.	EES	n	%	n	%	n	%
<2000	< 16 Km/h	1692	98,0%	35	2,0%	1727	100%
	16-50 Km/h	1051	94,9%	56	5,1%	1107	100%
	> 50 Km/h	19	52,8%	17	47,2%	36	100%
Sub Total of <2000		2762	96,2%	108	3,8%	2870	100%
2000+	< 16 Km/h	1092	99,1%	10	0,9%	1102	100%
	16-50 Km/h	457	95,6%	21	4,4%	478	100%
	> 50 Km/h	6	60,0%	4	40,0%	10	100%
Sub Total of 2000+		1555	97,8%	35	2,2%	1590	100%
Unknown	< 16 Km/h	229	100,0%	0	0,0%	229	100%
	16-50 Km/h	161	100,0%	0	0,0%	161	100%
	> 50 Km/h	10	100,0%	0	0,0%	10	100%
Sub Total of "Unknown"		400	100,0%	0	0,0%	400	100%
Total		4717	97,1%	143	2,9%	4860	100%

Cars caught fire after frontal impact in GIDAS

Year of 1 st registration	All		Cars caught Fire	
	n	% *	n	% **
<2000	7245	60,6%	60	0,8%
2000+	3655	30,6%	16	0,4%
Unknown	1063	8,9%	0	0,0%
Total	11963	100%	76	0,6%

* % per column

** % per row of All

Case Selection:

- 1st collision
- only cars
- frontal impacts (PDOF=11,12,1)
- EES<>"unknown"

Year of 1 st Registration & EES		Cars caught fire					
		No / Unknown		Yes		All	
Year of 1 st Reg.	EES	n	%	n	%	n	%
<2000	< 16 Km/h	3753	99,6%	16	0,4%	3769	100%
	16-50 Km/h	3281	99,0%	32	1,0%	3313	100%
	> 50 Km/h	151	92,6%	12	7,4%	163	100%
Sub Total of <2000		7185	99,2%	60	0,8%	7245	100%
2000+	< 16 Km/h	2142	99,8%	4	0,2%	2146	100%
	16-50 Km/h	1437	99,4%	9	0,6%	1446	100%
	> 50 Km/h	60	95,2%	3	4,8%	63	100%
Sub Total of 2000+		3639	99,6%	16	0,4%	3655	100%
Unknown	< 16 Km/h	568	100,0%	0	0,0%	568	100%
	16-50 Km/h	452	100,0%	0	0,0%	452	100%
	> 50 Km/h	43	100,0%	0	0,0%	43	100%
Sub Total of "Unknown"		1063	100,0%	0	0,0%	1063	100%
Total		11887	99,4%	76	0,6%	11963	100%

Cars caught fire after side impact in GIDAS

Year of 1 st registration	All		Cars caught Fire	
	n	% *	n	% **
<2000	2870	59,1%	11	0,4%
2000+	1590	32,7%	1	0,1%
Unknown	400	8,2%	0	0,0%
Total	4860	100%	12	0,2%

* % per column

** % per row of All

Case Selection:

- 1st collision
- only cars
- side impacts (PDOF=2,3,4&8,9,10)
- EES<>"unknown"

Year of 1 st Registration & EES		Cars caught fire					
		No / Unknown		Yes		All	
Year of 1 st Reg.	EES	n	%	n	%	n	%
<2000	< 16 Km/h	1724	99,8%	3	0,2%	1727	100%
	16-50 Km/h	1099	99,3%	8	0,7%	1107	100%
	> 50 Km/h	36	100,0%	0	0,0%	36	100%
Sub Total of <2000		2859	99,6%	11	0,4%	2870	100%
2000+	< 16 Km/h	1102	100,0%	0	0,0%	1102	100%
	16-50 Km/h	477	99,8%	1	0,2%	478	100%
	> 50 Km/h	10	100,0%	0	0,0%	10	100%
Sub Total of 2000+		1589	99,9%	1	0,1%	1590	100%
Unknown	< 16 Km/h	229	100,0%	0	0,0%	229	100%
	16-50 Km/h	161	100,0%	0	0,0%	161	100%
	> 50 Km/h	10	100,0%	0	0,0%	10	100%
Sub Total of "Unknown"		400	100,0%	0	0,0%	400	100%
Total		4848	99,8%	12	0,2%	4860	100%

Fuel leakage & cars caught fire after frontal impact in GIDAS

Year of 1 st registration	All		FL + Caught Fire	
	n	% *	n	% **
<2000	7245	60,6%	38	0,5%
2000+	3655	30,6%	10	0,3%
Unknown	1063	8,9%	0	0,0%
Total	11963	100%	48	0,4%

* % per column

** % per row of All

Case Selection:

- 1st collision
- only cars
- frontal impacts (PDOF=11,12,1)
- EES<>"unknown"

Year of 1 st Registration & EES		Cars with fuel leakage + Cars caught fire					
		No / Unknown		Yes		All	
Year of 1 st Reg.	EES	n	%	n	%	n	%
<2000	< 16 Km/h	3760	99,8%	9	0,2%	3769	100%
	16-50 Km/h	3294	99,4%	19	0,6%	3313	100%
	> 50 Km/h	153	93,9%	10	6,1%	163	100%
Sub Total of <2000		7207	99,5%	38	0,5%	7245	100%
2000+	< 16 Km/h	2143	99,9%	3	0,1%	2146	100%
	16-50 Km/h	1441	99,7%	5	0,3%	1446	100%
	> 50 Km/h	61	96,8%	2	3,2%	63	100%
Sub Total of 2000+		3645	99,7%	10	0,3%	3655	100%
Unknown	< 16 Km/h	568	100,0%	0	0,0%	568	100%
	16-50 Km/h	452	100,0%	0	0,0%	452	100%
	> 50 Km/h	43	100,0%	0	0,0%	43	100%
Sub Total of "Unknown"		1063	100,0%	0	0,0%	1063	100%
Total		11915	99,6%	48	0,4%	11963	100%

Fuel leakage & cars caught fire after side impact in GIDAS

Year of 1 st registration	All		FL + Caught Fire	
	n	% *	n	% **
<2000	2870	59,1%	2	0,07%
2000+	1590	32,7%	0	0,0%
Unknown	400	8,2%	0	0,0%
Total	4860	100%	2	0,04%

* % per column

** % per row of All

Case Selection:

- 1st collision
- only cars
- side impacts (PDOF=2,3,4&8,9,10)
- EES<>"unknown"

Year of 1 st Registration & EES		Cars with fuel leakage + Cars caught fire					
		No / Unknown		Yes		All	
Year of 1 st Reg.	EES	n	%	n	%	n	%
<2000	< 16 Km/h	1724	100,0%	0	0,0%	1724	100%
	16-50 Km/h	1100	99,8%	2	0,2%	1102	100%
	> 50 Km/h	33	100,0%	0	0,0%	33	100%
Sub Total of <2000		2857	99,9%	2	0,1%	2859	100%
2000+	< 16 Km/h	1102	100,0%	0	0,0%	1102	100%
	16-50 Km/h	475	100,0%	0	0,0%	475	100%
	> 50 Km/h	9	100,0%	0	0,0%	9	100%
Sub Total of 2000+		1586	100,0%	0	0,0%	1586	100%
Unknown	< 16 Km/h	232	100,0%	0	0,0%	232	100%
	16-50 Km/h	169	100,0%	0	0,0%	169	100%
	> 50 Km/h	14	100,0%	0	0,0%	14	100%
Sub Total of "Unknown"		415	100,0%	0	0,0%	415	100%
Total		4858	100,0%	2	0,0%	4860	100%

Back-Up

Details of fuel leakage & fire magnitude after frontal impact in GIDAS

Year of 1 st registration	All		Fuel Leakage (FL)		FL + Caught Fire	
	n	% *	n	% **	n	% **
<2000	7245	60,6%	400	5,5%	38	0,5%
2000+	3655	30,6%	102	2,8%	10	0,3%
Unknown	1063	8,9%	61	5,7%	0	0,0%
Total	11963	100%	563	4,7%	48	0,4%

* % per column

** % per row of All

Case Selection:

- 1st collision
- only cars
- frontal impacts (PDOF=11,12,1)
- EES<>"unknown"

1 Fuel Leakage (FL) after frontal impact	Year of first registration							
	<2000		2000+		Unknown		All	
	n	%	n	%	n	%	n	%
Yes, nfs	171	2,4%	42	1,1%	31	2,9%	244	2,0%
Fuel Tank	13	0,2%	2	0,1%	3	0,3%	18	0,2%
Fuel Lines (Engine Comp.)	204	2,8%	55	1,5%	26	2,4%	285	2,4%
Fuel Lines (not EngComp.)	9	0,1%	3	0,1%	1	0,1%	13	0,1%
Other	3	0,0%	0	0,0%	0	0,0%	3	0,0%
Sub Total	400	5,5%	102	2,8%	61	5,7%	563	4,7%
Total	7245	61%	3655	30%	1063	9%	11963	100%

2 Fuel Leakage & cars caught fire after frontal impact	Year of first registration							
	<2000		2000+		Unknown		All	
	n	%	n	%	n	%	n	%
Engine Compartment	16	0,2%	4	0,1%	0	0,0%	20	0,2%
Engine & Passenger Comp.	3	0,0%	2	0,1%	0	0,0%	5	0,0%
Total Vehicle	19	0,3%	4	0,1%	0	0,0%	23	0,2%
Sub Total	38	0,5%	10	0,3%	0	0,0%	48	0,4%
Total	7245	61%	3655	30%	1063	9%	11963	100%

Cars with Front Impacts in GIDAS Split by Speed Range

EES by Frontal Impact (VDI1=11,12,1)	Total		Fuel Leakage (FL)		FL+Fire	
	n	%	n	%	n	%
< 16 Km/h	6483	54,2%	113	1,7%	12	0,2%
16-50 Km/h	5211	43,6%	360	6,9%	24	0,5%
> 50 Km/h	269	2,2%	90	33,5%	12	4,5%
Total	11963	100%	563	4,7%	48	0,4%

Fuel Leakage (FL) after frontal impact	< 16 Km/h		16-50 Km/h		> 50 Km/h		All Speeds	
	n	%	n	%	n	%	n	%
Yes, nfs	47	0,6%	151	4,1%	46	4,3%	244	2,0%
Tank	6	0,1%	12	0,3%	0	0%	18	0,2%
Fuel Lines (Engine Comp.)	56	0,8%	187	5,1%	42	4,0%	285	2,4%
Fuel Lines (not EComp.)	3	0,0%	8	0,2%	2	0,2%	13	0,1%
Other	1	0,0%	2	0,1%	0	0%	3	0,0%
Sub Total	113	1,6%	360	9,8%	90	8,5%	563	4,7%
Total	7245	61%	3655	30%	1063	9%	11963	100%

Fuel Leakage & cars caught fire after frontal impact	< 16 Km/h		16-50 Km/h		> 50 Km/h		All Speeds	
	n	%	n	%	n	%	n	%
Engine Compartment	4	0,1%	12	0,3%	4	0,4%	20	0,2%
Engine & Occupant Comp.	1	0,0%	4	0,1%	0	0%	5	0,0%
Entire Vehicle	7	0,1%	8	0,2%	8	0,8%	23	0,2%
Sub Total	12	0,2%	24	0,7%	12	1,1%	48	0,4%
Total	7245	61%	3655	30%	1063	9%	11963	100%

Documented traffic accidents

GIDAS – Effective 01.07.2012

22.347 completely documented & reconstructed accidents

**40.038
vehicles**

**55.750
persons**

**29.697
injured persons**

**40.038
reconstructions**

**26.449
passenger cars**

**37.830
car occupants**

**76.736
single injuries**

**89.838 recon-
struction events**

**2.618
trucks**

**4.589 truck/bus
tram occupants**

**21.665 slightly
injured persons**

**34.747 vehicle-to-
vehicle collisions**

**862
busses & trams**

**3.001
pedestrians**

**7.414 seriously
injured persons**

**11.444 vehicle-to-
object collisions**

**9.989
two-wheeler**

**10.330
cyclists**

**618 fatally
injured persons**

Attachment J

**Supporting Data for the Probability Vehicle Occupants are Unable to Leave the
Vehicle Post-Collision**

Question: What is the probability that occupants are unable to leave the vehicle in the event of a crash

Funk *et al.* 2002. "Necessity of fire department response to the scene of motor vehicle crashes" *American Journal of Emergency Medicine* -20(7)

The authors conducted a review of accident records for a township located in New York state. They reported that 38 of 14,450 motor vehicle collisions (the total number reported during the time period of study) required some extrication (0.3%, 0.0026). This number would apply to the overall frequency of entrapment in collisions of any severity. The authors also reported that 38 of 2,095 collisions which involved personal injury required extrication (2%, 0.018). Because this subset of collisions (14% of the total) involved injury, they would be more characteristic of mid-to high severity collisions. Note that the 38 extrications required when there was injury is the same number of extrications required among all collisions, meaning that the number of extrications required when there is no personal injury was 0. Finally, the authors reported that 38 of 198 motor vehicle crashes to which a fire department responded, suggesting the most serious type of crash, required some extrication (20% or 0.19). It is probably reasonable to suggest that this number would be most characteristic of high severity collisions.

US State of Tennessee, Department of Safety, data for 2007

www.tn.gov/safety/stats/CrashData/default.shtml

2007 total collisions– 172,130

2007 – total number of individuals trapped in motor vehicle accidents – 3,448 (whether successfully extricated or not)

This is the total number of individuals, not the number of collisions, involving extrication. If we divide this by the typical number of passengers per vehicle in the US (approximately 1.5), we get ~2300 collisions which involved/required extrication. The ratio, 2,300/172,130 yields an extrication frequency of 1.3% or 0.013. Note that this number pertains to all crashes, regardless of severity.

US State of Nebraska, State Fire Marshall, data for 2000

<http://www.sfm.ne.gov/statistics/pdf/2000/detailedstats-2000.pdf>

Number of vehicle accidents with injuries which involved a response = 2,662

Cases requiring extrication of victim(s) from vehicle = 26

This is equivalent to 0.01 or 1% of vehicle collisions which involved injuries severe enough to require emergency services involvement.

City of Minneapolis, MN

<http://uclue.com/?xq=1812>

Motor vehicle accidents with injuries = 679

Cases requiring extrication of victim(s) from vehicle = 22

Overall frequency: 3% (0.032)

City of Midland, MI

<http://www.midland-mi.org/government/departments/fire/Fire2003-2004.pdf>

Accidents with injuries where EMS/fire department is called in = 135

Cases requiring occupant extrication = 5

Overall frequency: 4% (0.037)

Data for Orange County FL

(www.orangecountyfl.net/.../Orange%20Spiel%20Feb-Mar%202011.pdf)

It was reported that for 1 day (Sept 24, 2010) fire and rescue services responded to 27 vehicle accidents of which 1 involved extrication 4% (0.037). However, the same size is quite small.

However, it was also reported for Orange County (<http://uclue.com/?xq=1812>):

"for one year, 13,313 traffic accidents, and 531 entrapments". Level of severity was not specified but will be assumed to mean all accident types. This equates to a frequency of 4% (0.04) per accident.

Taken together these data suggest that for all collisions combined (dominated by low speed collisions, many of which will not involve emergency responders), the risk the occupants are unable to leave the vehicle post-collision is probably less than 1% (based on Funk *et al.* and data from Tennessee). The smaller datasets (Midland MI, Orange County FL, Minneapolis MN) suggest slightly higher percentages (3-4%) but these do not reflect very low speed collisions where EMS or the fire department are not called. It is more likely that such collisions only involve police services, *e.g.*, for filling out a report for insurance purposes. For collisions involving injuries (consistent with a medium or high severity collision) the risk of needing extrication is probably more on the order of 1-4% (data for Nebraska, Midland MI, Minneapolis MN, and Orange County FL all of which reflect fire department/EMS statistics). For even more serious crashes (*i.e.*, high severity crashes) the risk may be as high as 20% (based primarily on Funk *et al.*).

Based on an average probability of occupants being unable to leave the vehicle post-collision of 1% (for all crashes), the CRP chose to use a value of 5% for high severity front collisions, 20% for high severity side collisions (which have greater potential for damaging vehicle doors), 0.1% for mid severity front, 5% for mid severity side, and 0.01 % for low severity front and side collisions.

Attachment K

OEM Test Data on Vehicle Operating Temperatures

Percent of Time Exhaust Surface Temperatures are above 600°C and 700°C*

Vehicle/ Powertrain Description	50th Percentile Customer			90th Percentile Customer		
	Percent of Customer Hours			Percent of Customer Hours		
	> 600°C	> 700°C	>600 <=700°C	> 600°C	> 700°C	>600 <700°C
Medium Size Van FWD Turbo Diesel	2.6%	0.0335%	2.5%	4.4%	0.0197%	4.4%
Small Van FWD Gas Non-Turbo	3.9%	1.8%	2.1%	5.3%	2.4%	2.9%
Small Cross Utility FWD Gas Turbo Direct Injection	6.2%	3.1%	3.2%	10.9%	5.7%	5.2%

*Based on Standard Thermal Test Results and Customer Use profile

The results of this analysis incorporated into the SAE CRP FTA Sensitivity Analysis