HFO-1234yf Low GWP Refrigerant – Information for Manufacturing and Service Facilities

10 November, 2010

Mary E. Koban

Sr. Automotive Engineer

DuPont Fluoroproducts

Automotive Summit

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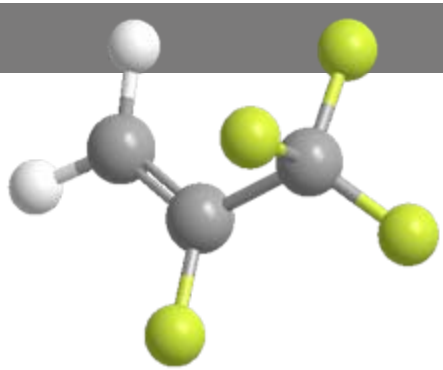
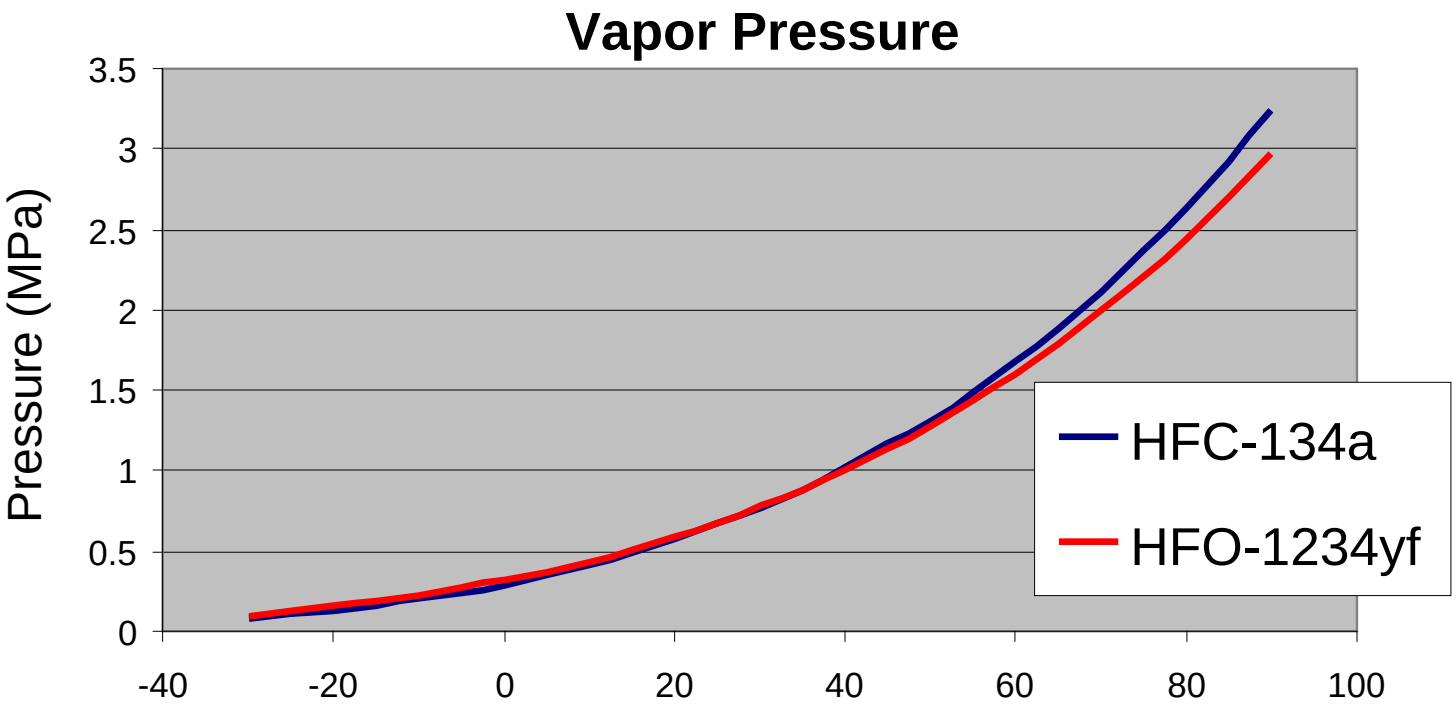
Agenda

- HFO-1234yf Properties
- Flammability of HFO-1234yf
- Automotive OEM Plant Implementation
- Automotive Service Implementation
- Summary

HFO-1234yf Properties



Properties	HFO-1234yf	HFC-134a
Pvap, MPa (25°C)	0.677	0.665
Pvap, MPa (80°C)	2.44	2.63
GWP (100 ITH)	4	1430 (AR4)
Toxicity	A-Low	A-Low
Flammability	Mild	None

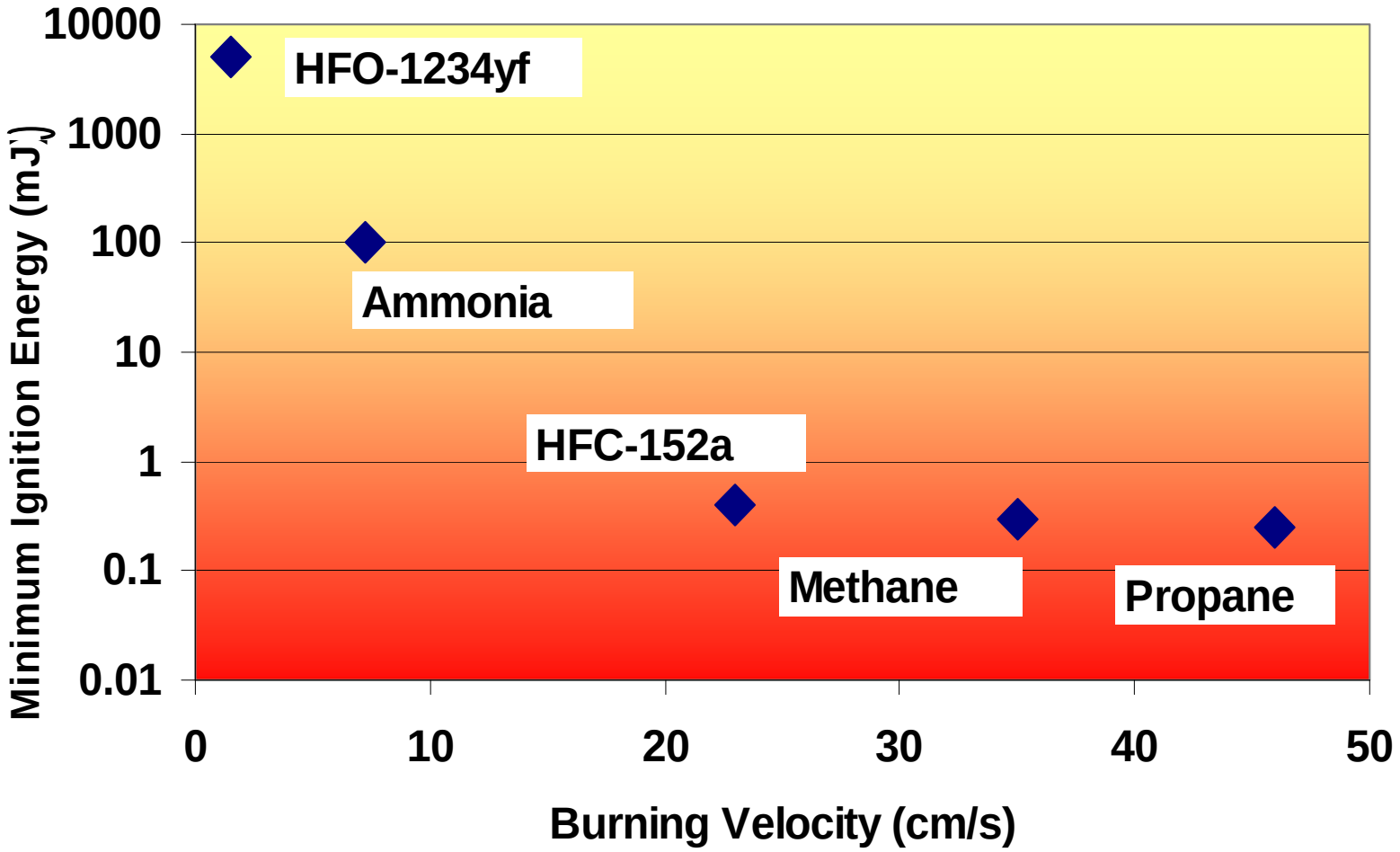


- Same operating conditions as 134a (similar P/T curve)
- Thermally stable under extreme use conditions in a MAC system
- Cooling capacity equivalent to 134a
- Energy efficiency better or equivalent to 134a
- Only modest design changes required in MAC

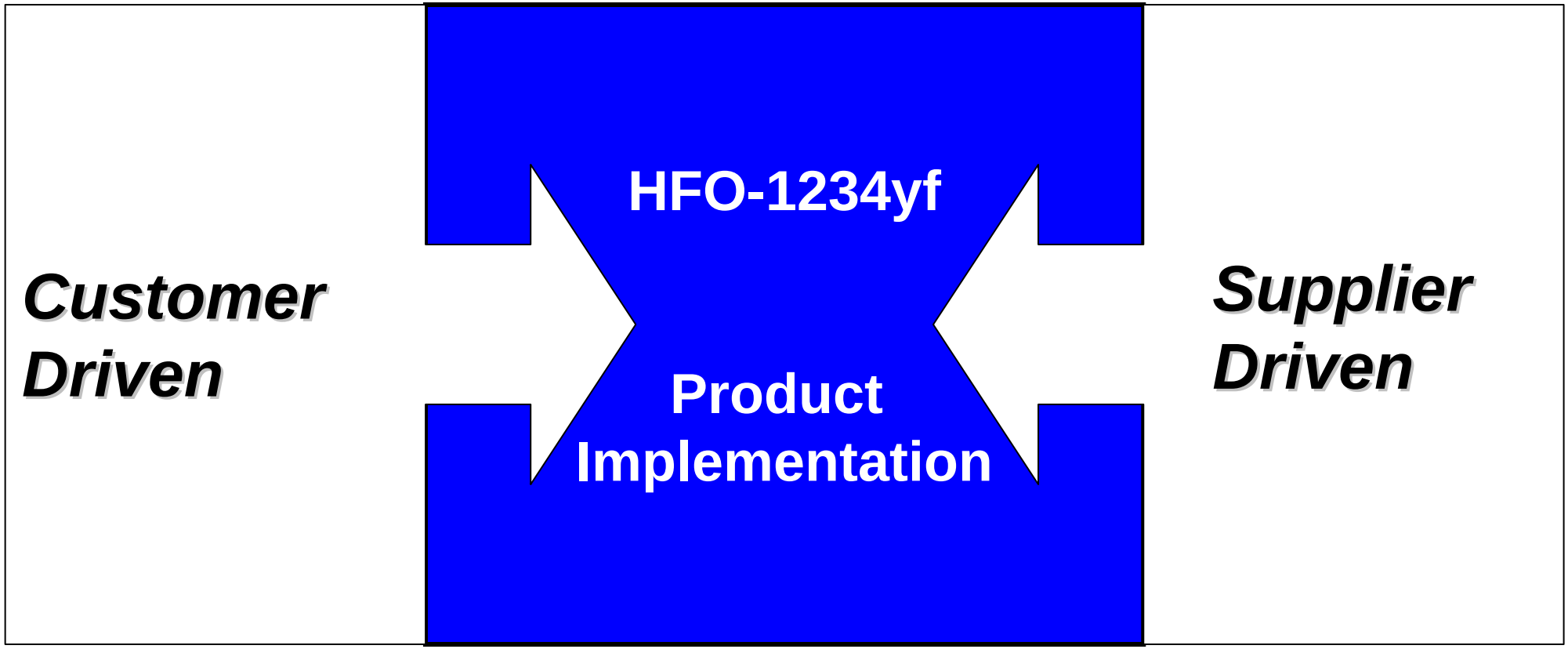
HFO-1234yf has vapor pressure, toxicity class A, similar to R-134a, but has mild flammability

HFO-1234yf Flammability Properties

- High MIE indicates HFO-1234yf is very difficult to ignite
- Burning velocity of HFO-1234yf is only 1.5 cm/sec – weak flame not easily propagated



HFO-1234yf Automotive OEM Plant Implementation



Dual input process for successful product implementation. Customer/Supplier giving input into process is needed to make this a success!

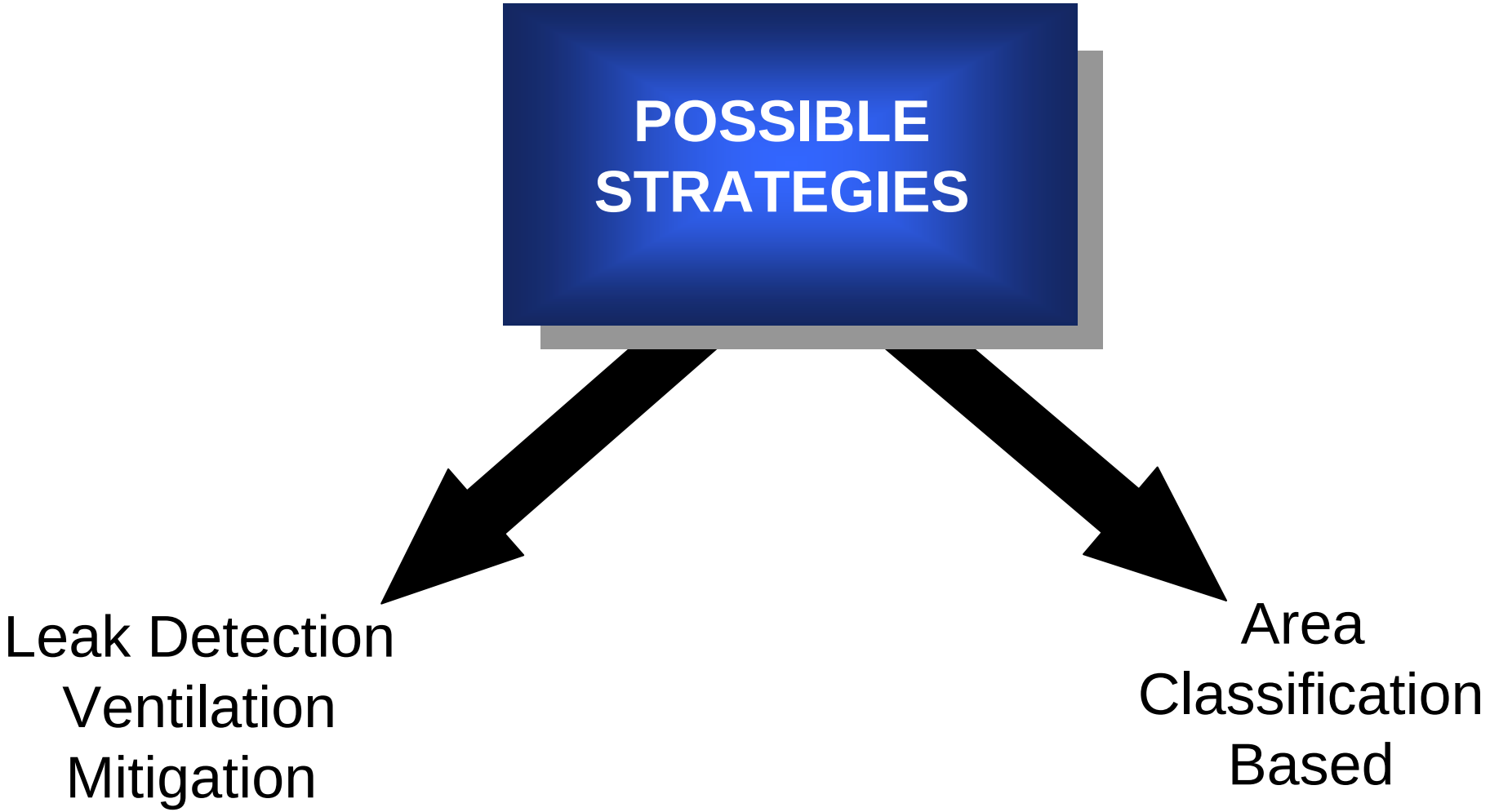
HFO-1234yf Automotive OEM Plant Implementation

Product Plant Site Implementation

- **Customer Driven Process**
  - Specific to each customer plant site (country, local regulations, etc.)
  - Key Aspects
    - Regulations (ATEX, Serveso, ADR, etc.)
    - Site constraints (available land, etc.)
    - Volumes (types of storage)

- **Supplier Driven Process-Product Stewardship**
  - Can customer safely handle the product?
  - Does customer have the correct information to make implementation a success?

HFO-1234yf Automotive OEM Plant Implementation



Strategy employed will depend on location, volume, potential amount of refrigerant in area, potential leak scenarios, etc.

HFO-1234yf Automotive OEM Plant Implementation

Potential Implementation Strategies

Potential OEM Plant Zones	Amt of Refrigerant	Potential Zone Strategies	Potential Process Duration	Potential Applicable Regulations
Inside Auto Plant - Refrigerant Filling Stations	Intermediate amt of refrigerant, but multiple stations	No Zone	30 seconds	Directive 98/24/EC (Chem Agents @ Work)
		Zone 2	30 seconds	ATEX 137 / ATEX 95
Inside Auto Plant - Refrigerant Lines	Intermediate, limited by line size	No Zone		Directive 98/24/EC (Chem Agents @ Work)
Inside Auto Plant - Refrigerant Filled Vehicles on Assembly Line	Minimal < 1 kg per vehicle	No Zone		Directive 98/24/EC (Chem Agents @ Work)
Outside Auto Plant- Refrigerant Lines leading into Plant	Intermediate, limited by line size, high ventilation	No Zone		Directive 98/24/EC (Chem Agents @ Work)
		Zone 2		ATEX 137 / ATEX 95
Outside Auto Plant- Bulk Storage	Large, 20 metric tonnes per storage tank	No Zone	No release of refrigerant, only during leak situation	Directive 98/24/EC (Chem Agents @ Work)
		Zone 2		ATEX 137 / ATEX 95
Outside Auto Plant - Bulk Unloading of Refrigerant	Large, considered part of bulk, but limited in duration	Zone 1 or 0	Several hours to off-load refrigerant	ATEX 137 / ATEX 95

- ***Various HFO-1234yf plant implementation strategies can be employed.***
- ***It is important to consult with appropriate regulatory agencies regarding strategies and limitations***

HFO-1234yf Automotive OEM Plant Implementation

Comparison of Some Appropriate Regulations for Germany HFO-1234yf vs HFC-134a

HFO-1234yf	HFC-134a
■ Ordinance on Industrial Safety and Health / Technical Rules for Industrial safety (BetrSichV / TRBS)	■ Ordinance on Industrial Safety and Health / Technical Rules for Industrial safety (BetrSichV / TRBS)
■ Technical Regulations for Pressure Vessels (TRB)	■ Technical Regulations for Pressure Vessels (TRB)
■ Technical Regulations for Pressurized Gases (TRG)	■ Technical Regulations for Pressurized Gases (TRG)
■ Rules for Safety and Health at work issued by the Professional Associations (BGR)	■ Rules for Safety and Health at work issued by the Professional Associations (BGR)
■ National German regulation on water hazard classification (VwVwS)	■ National German regulation on water hazard classification (VwVwS)
■ Ordinance on Hazardous Substances (GefStoffV)	■ Ordinance on Hazardous Substances (GefStoffV)
■ International Transport of Dangerous Goods by Road and by Rail (ADR / RID)	■ International Transport of Dangerous Goods by Road and by Rail (GGVS/ADR)
■ Pressure Equipment Directive (PED)	■ Pressure Equipment Directive (PED)
■ REACH regulation 1907/2006	■ REACH regulation 1907/2006
■ Explosion Protection Directions (Ex-RI)	
■ Equipment or Protective System Intended for use in Potentially explosive atmospheres (Directive 94/9/EC (ATEX))	

Regulations are similar for both products.
HFO-1234yf has some additional regulations that need to be considered due to mild flammability

HFO-1234yf Automotive Service Implementation-
Potential Leakage Scenarios

- **CFD-Computational Fluid Dynamics**
- **DuPont conducted CFD modeling to understand potential flammable region of a leak from a severed AC line under various leakage scenarios**
- **Three Scenarios evaluated**
  1. Leak from a point in open space (simulating vehicle with potential leak sitting outdoors)
  2. Leak from a point in bounded space (simulating potential leak in garage or mfr plant)
  3. Leak from a point under an open car hood and impinging on a surface (in a service garage)
- **CFD Model Output**
  - Refrigerant concentration at several distances (x,y and z directions) from the leak point during leak event.
  - Size of refrigerant plume above lower flammability limit (LFL)

Results useful as input for risk assessments

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CFD MODEL DEVELOPMENT

Approach Used

- **Several CFD Models Designed**
- **1st CFD Model - Release was initially modeled with no bounding**
- **2nd & 3rd CFD Model -Release modeled as bounded vapor release using methodology in Venetsanos paper**
- **Information presented at the *American Institute of Chemical Engineers 2010 Spring National Meeting 6th Global Congress on Process Safety 44th Annual Loss Prevention Symposium, San Antonio, Texas***

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An inter-comparison exercise on the capabilities of CFD models to predict the short and long term distribution and mixing of hydrogen in a garage

A.G. Venetsanos[a,*], E. Papanikolaou[a], M. Delichatsios[a,b], J. Garcia[c], O.R. Hansen[d], M. Heitsch[e], A. Huser[f], W. Jahn[g], T. Jordan[h], J.-M. Lacome[i], H.S. Ledin[j], D. Makarov[k], P. Middha[d], E. Studer[l], A.V. Tchouvelev[m], A. Teodorczyk[n], F. Verbecke[k], M.M. Van der Voort[o]

[a]Environmental Research Laboratory, National Centre for Scientific Research Demokritos (NCSRD), Aghia Paraskevi, Attiki, 15310 Athens, Greece
[b]FireSERT Institute, University of Ulster (UU), Newtownabbey BT37 0QB, Northern Ireland, UK
[c]Escuela Técnica Superior de Ingenieros Industriales, Universidad Politécnica de Madrid (UPM), José Gutiérrez Abascal, 2, E-28006 Madrid, Spain
[d]GEXCON AS (GXC), Fantoftvegen 38, Box 6015 Postterminalen, N-5892 Bergen, Norway
[e]Gesellschaft für Anlagen-und Reaktorsicherheit (GRS) mbH, Research Management Division, Schwertnergasse 1, 50667 Köln, Germany
[f]Det Norske Veritas (DNV) AS Energy Solutions, Oslo, Norway
[g]Forschungszentrum Juelich (FZJ), 52425 Juelich, Germany
[h]KIT, Forschungszentrum Karlsruhe (FZK), Postfach 3640, 76021 Karlsruhe, Germany
[i]Explosion-Dispersion Unit, Institut National de l'Environnement industriel et des Risques (INERIS), Parc Technologique Alata, BP2, F-60550 Verneuil-en-Halatte, France
[j]Health and Safety Laboratory (HSL), Harpur Hill, Buxton, Derbyshire SK17 9JN, UK
[k]HySAFER Centre, University of Ulster (UU), Newtownabbey BT37 0QB, Northern Ireland, UK
[l]Heat Transfer and Fluid Mechanics Laboratory, Commissariat à l'Energie Atomique (CEA), F-91191 Gif-sur-Yvette Cedex, France
[m]A.V.Tchouvelev & Associates Inc. (AVT), 6591 Spimaker Circle, Mississauga, ON L5W 1R2, Canada
[n]Warsaw University of Technology (WUT), Poland
[o]TNO Defense, Security and Safety, Process Safety and Dangerous Goods, 2280 AA Rijswijk, The Netherlands

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ABSTRACT

The paper presents the results of the CFD inter-comparison exercise SBEP-V3, performed within the activity Inshyde, internal project of the Hyfade network of excellence, in the framework of evaluating the capability of various CFD tools and modelling approaches in predicting the short and long term mixing and distribution of hydrogen releases in confined spaces. The experiment simulated was INERIS-TEST-6C, performed within the Inshyde project by INERIS, consisting of a 1 g/s vertical hydrogen release for 240 s from an orifice of 20 mm diameter into a rectangular room (garage) of dimensions 3.78 × 7.2 × 2.88 m in width, length and height respectively. Two small openings at the bottom of the front side of the room assured constant pressure conditions. During the test hydrogen concentration time histories were measured at 12 positions in the room, for a period up to 5160 s after the end of release, covering both the release and the subsequent diffusion phases. The benchmark was organized in two phases. The first phase consisted of

* Corresponding author.
E-mail address: vensts@ipta.demokritos.gr (A.G. Venetsanos).
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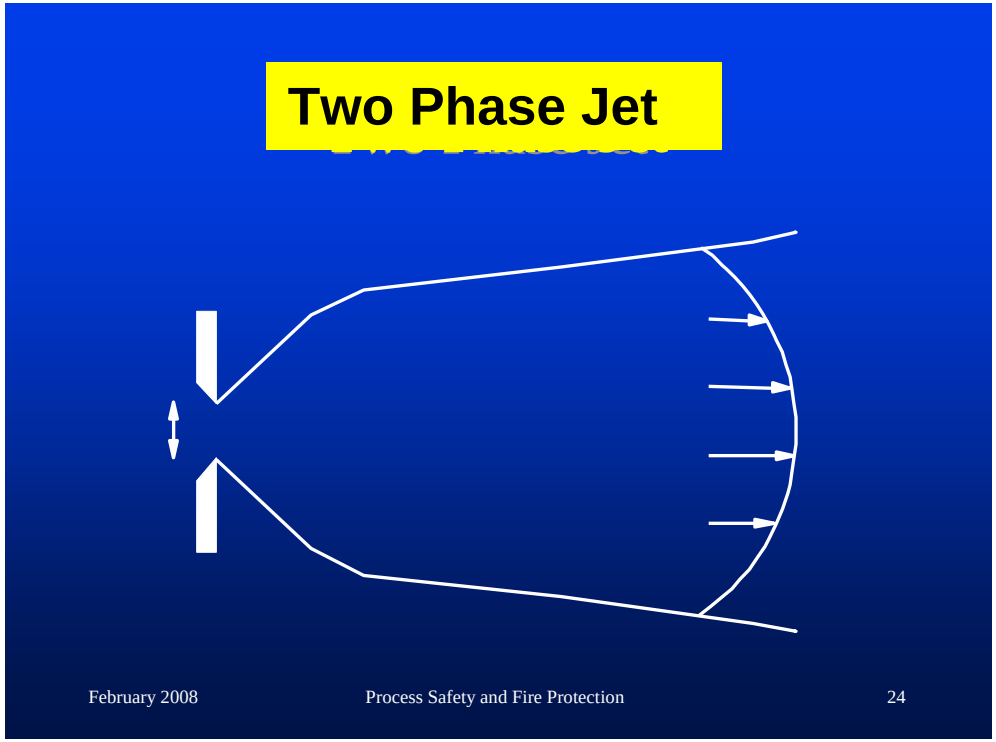
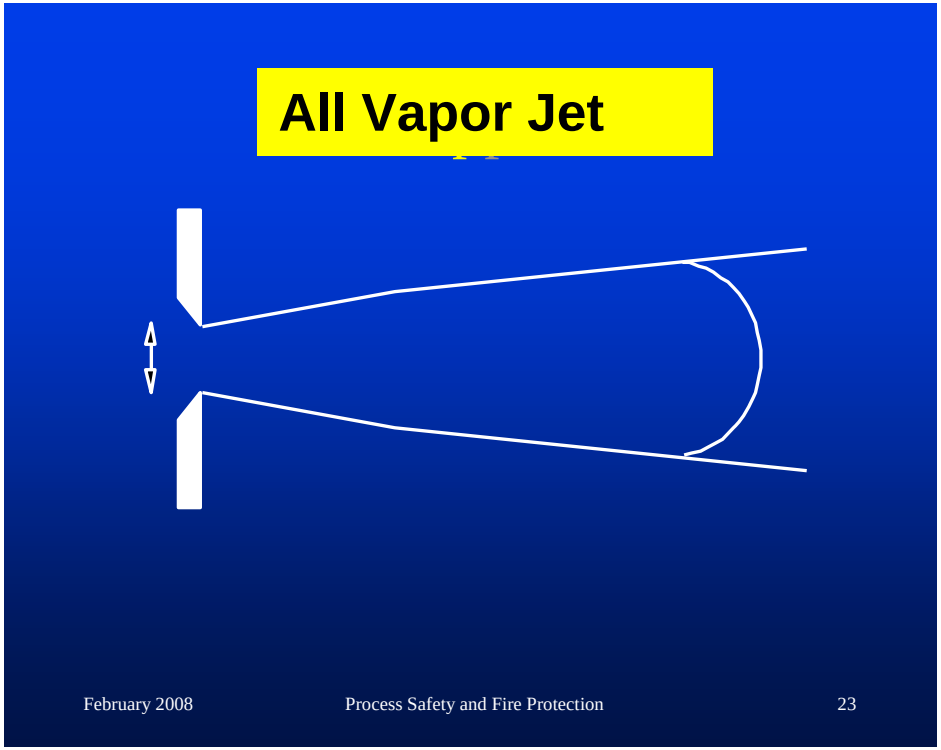
CFD MODEL DEVELOPMENT

- **Assumptions for all three scenarios**
  - **600 g total refrigerant leaked**
  - **12.4 g/s of HFO-1234yf**
  - **total time of leak 48.4 secs**
  - **Air exchange rate was zero, or low wind field (<0.5 m/sec) for unbounded leak**
- **Release Details**
  - **HFO-1234yf will create a two phase leak when released under a severed line situation.**
  - **The release plume was modeled as vapor phase, since initial modeling did not show large differences in shape of jet plume**

HFO-1234yf Plume Release Diagrams



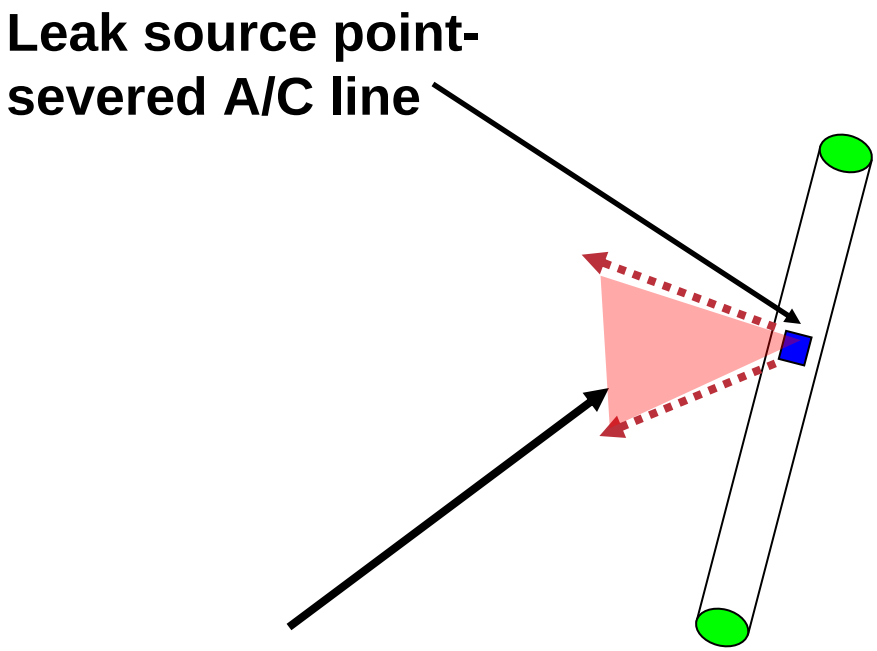


- Liquid and vapor combined release will have the shape above.
- HFO-1234yf will create a two phase release under a severed line situation.

- An all vapor release will have the shape above
- Plume is fully formed within 1/2 second of the start of the release.
- Modeled in both horizontal and parallel directions of the air flow

Outcome -similarities in plume shape/length

Diagram of Scenario - Unbounded leak



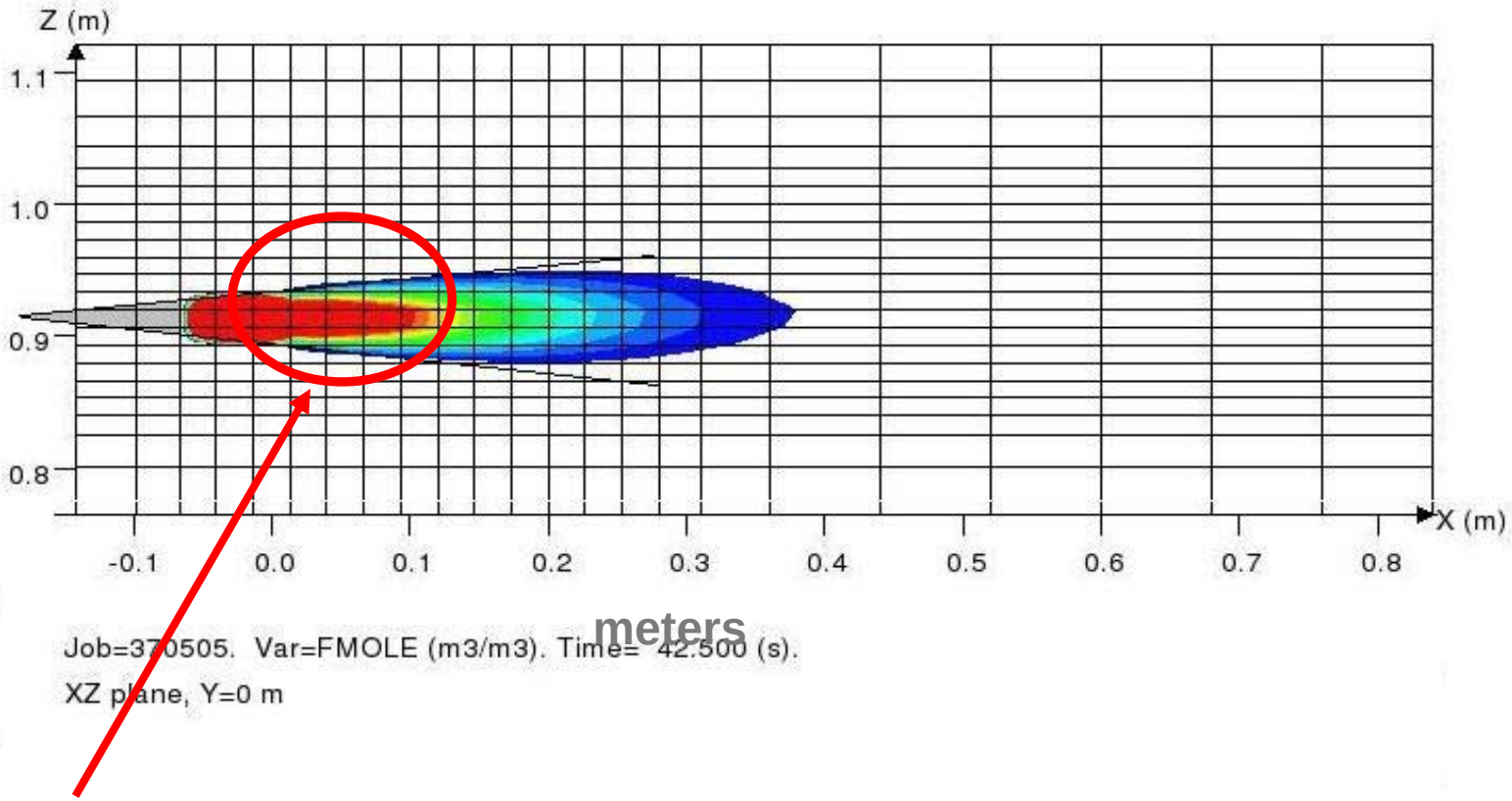
Refrigerant plume formed when refrigerant escapes from leakpoint

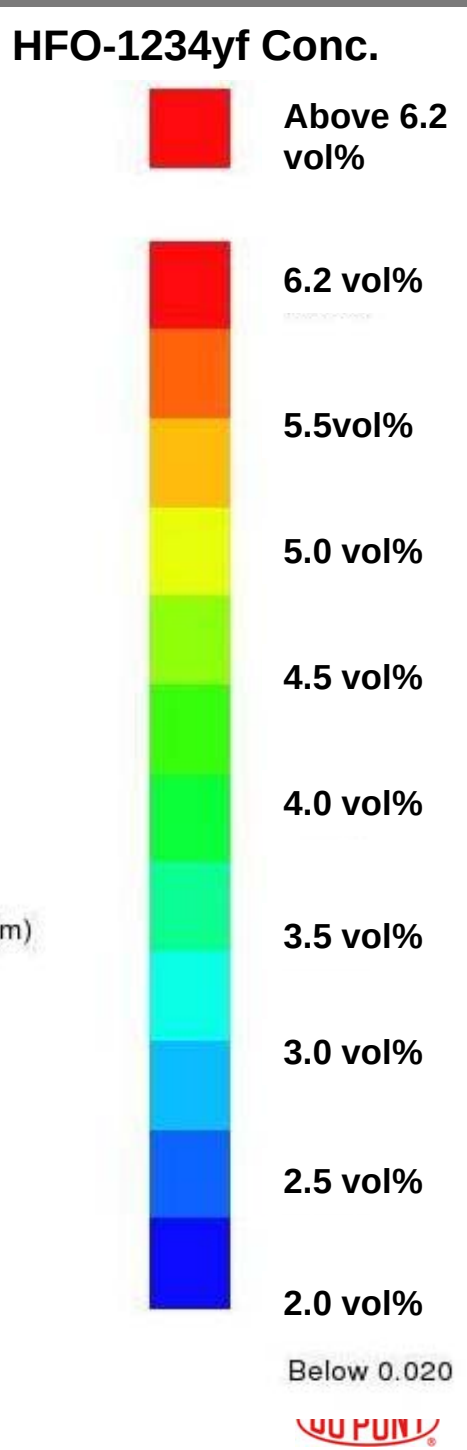
Assumptions:

- ***Leak is not bounded by room/structure. (imagine severed line AC line outside, not bound/hitting any object)***
- ***Leak assumed to be in low wind field, so no dissipation of refrigerant by wind.***

Plume Concentration Profile – Unbounded Leak

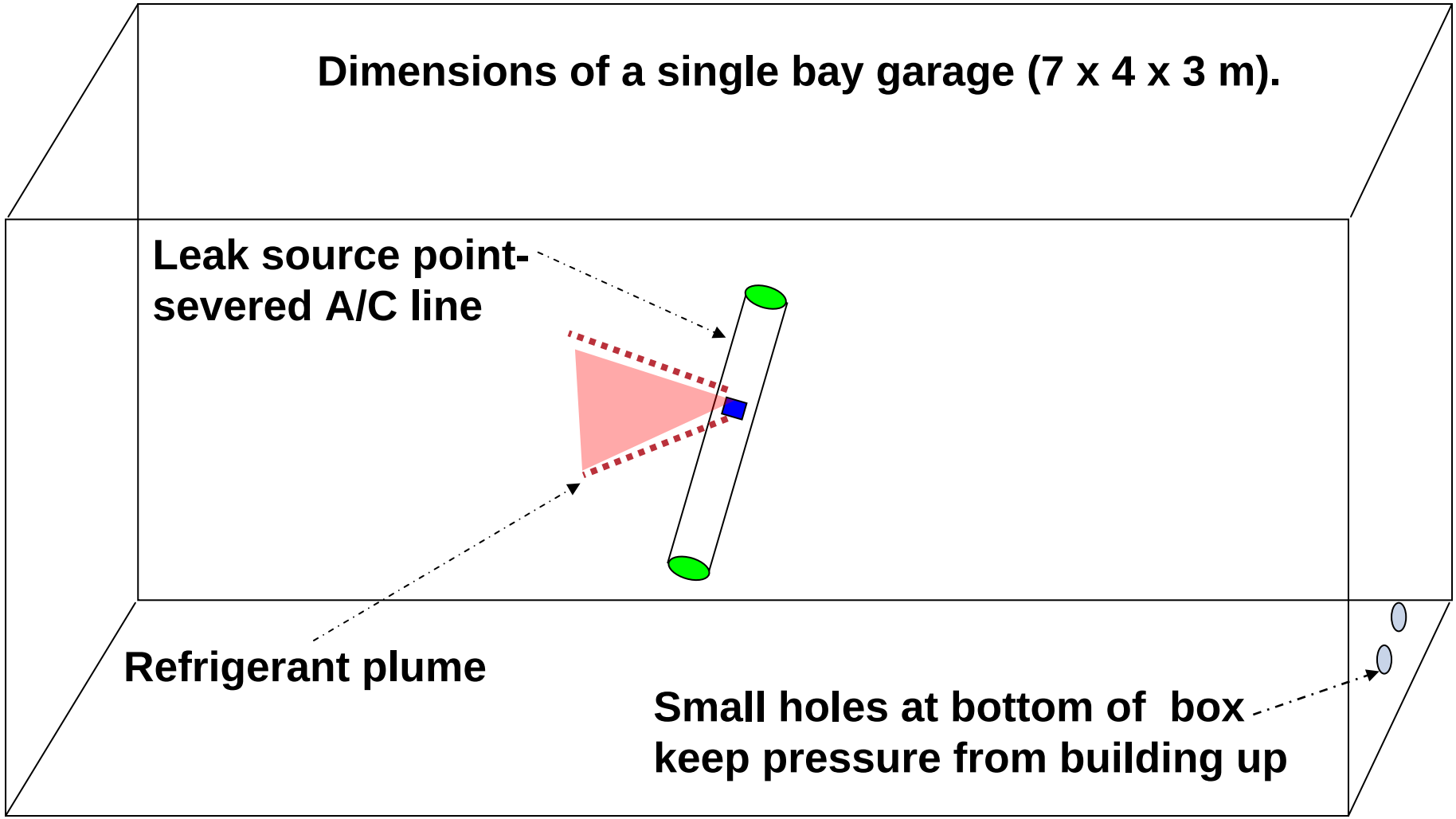
Results can vary based on hole size/shape and release direction versus air currents.





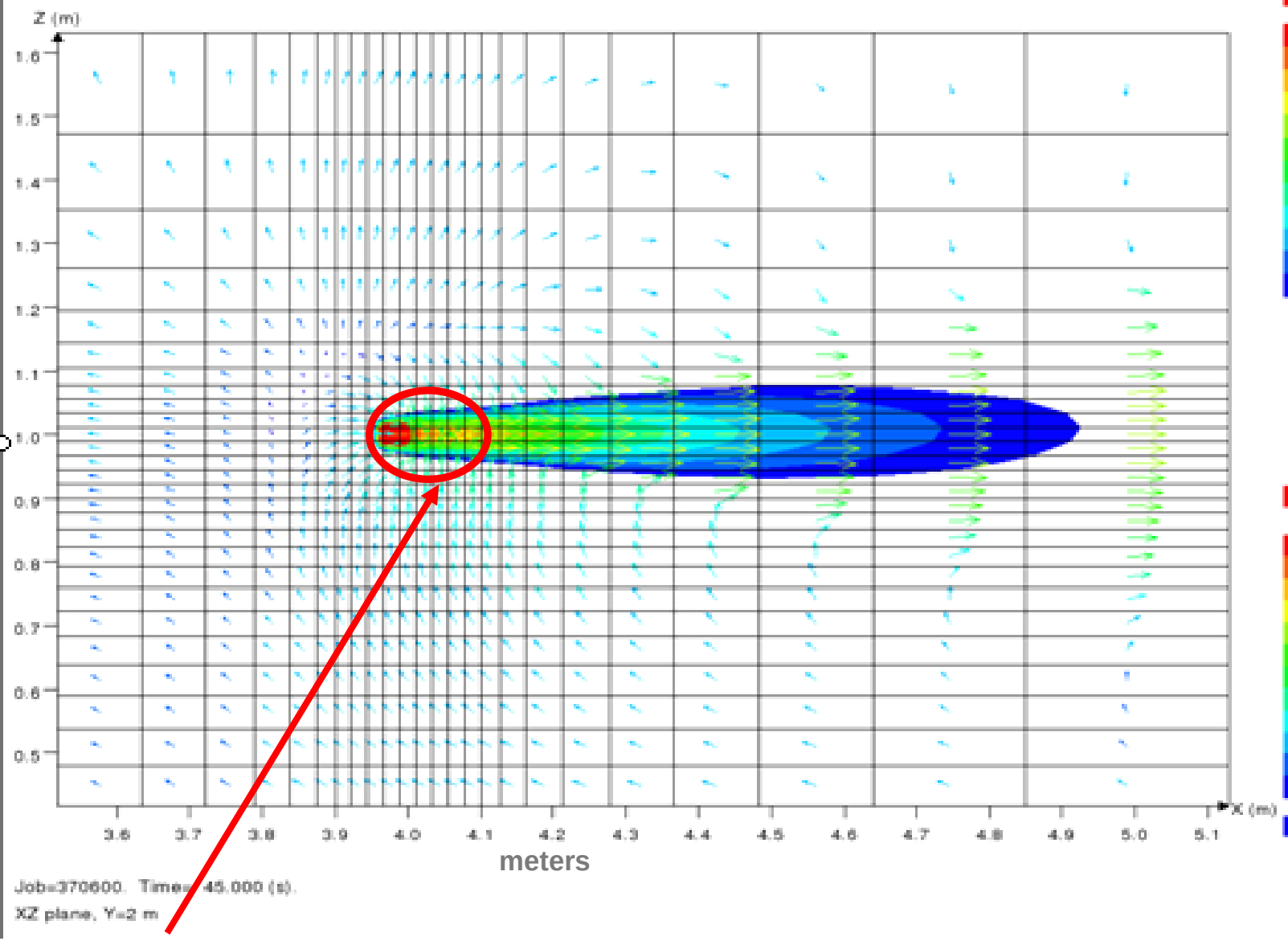
Length of plume above LFL is very small (about 15 cm)

Diagram of Scenario - Bounded leak



- Assumed 600 g charge released in 48 seconds and zero air flow

Plume Profile – Bounded Leak



HFO-1234yf Conc.

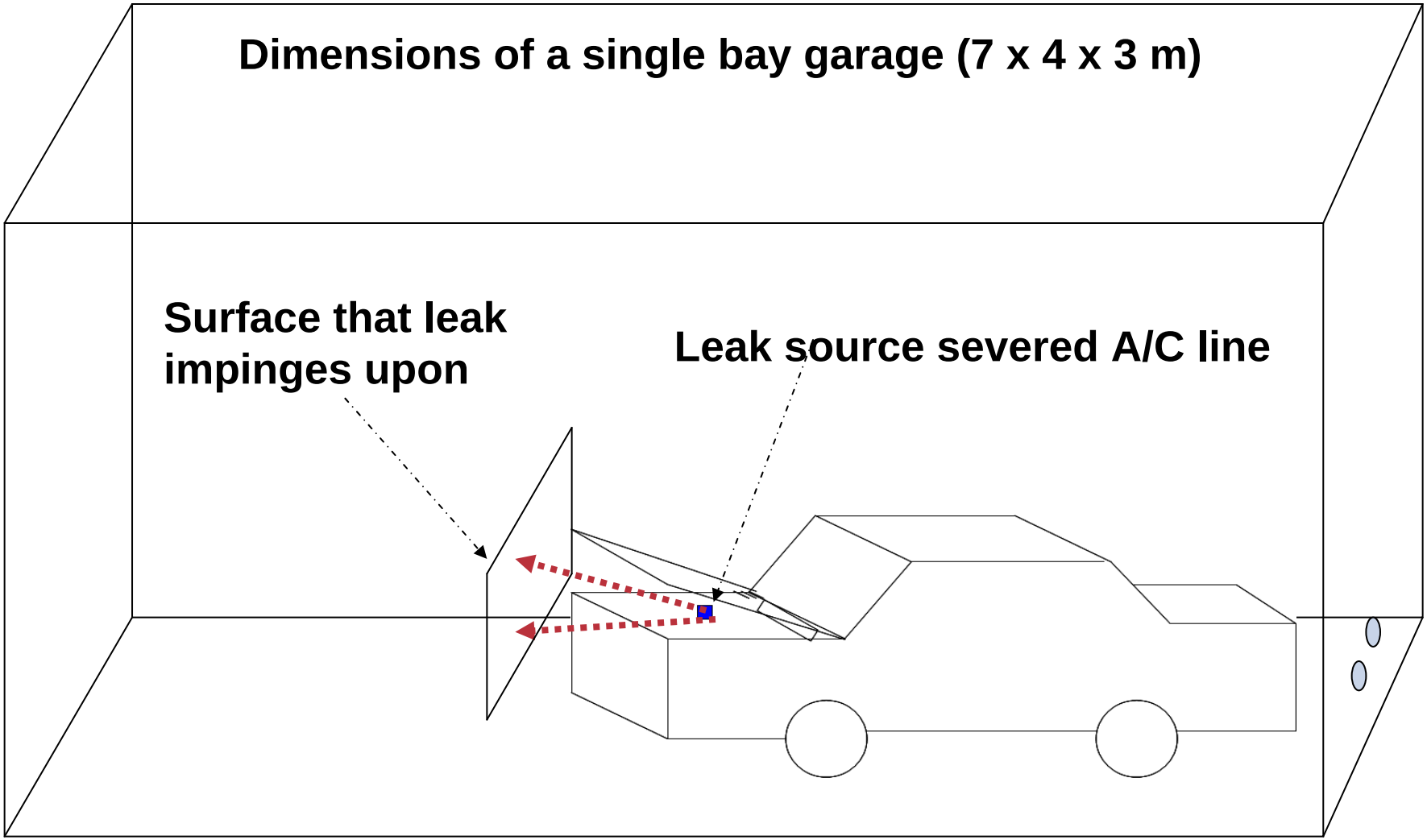
- >10 vol%
- 10 vol%
- 6.3 vol%
- 4.0 vol%
- 2.5 vol%
- 1.6 vol%

Air Velocity

- >100 m/sec
- 100 m/sec
- 10 m/sec
- 1.0 m/sec
- 0.1 m/sec
- Below 0.1 m/s

Plume above LFL is very small (10 cm in x direction, 2 cm in z)

Diagram of Surface Impinging Scenario



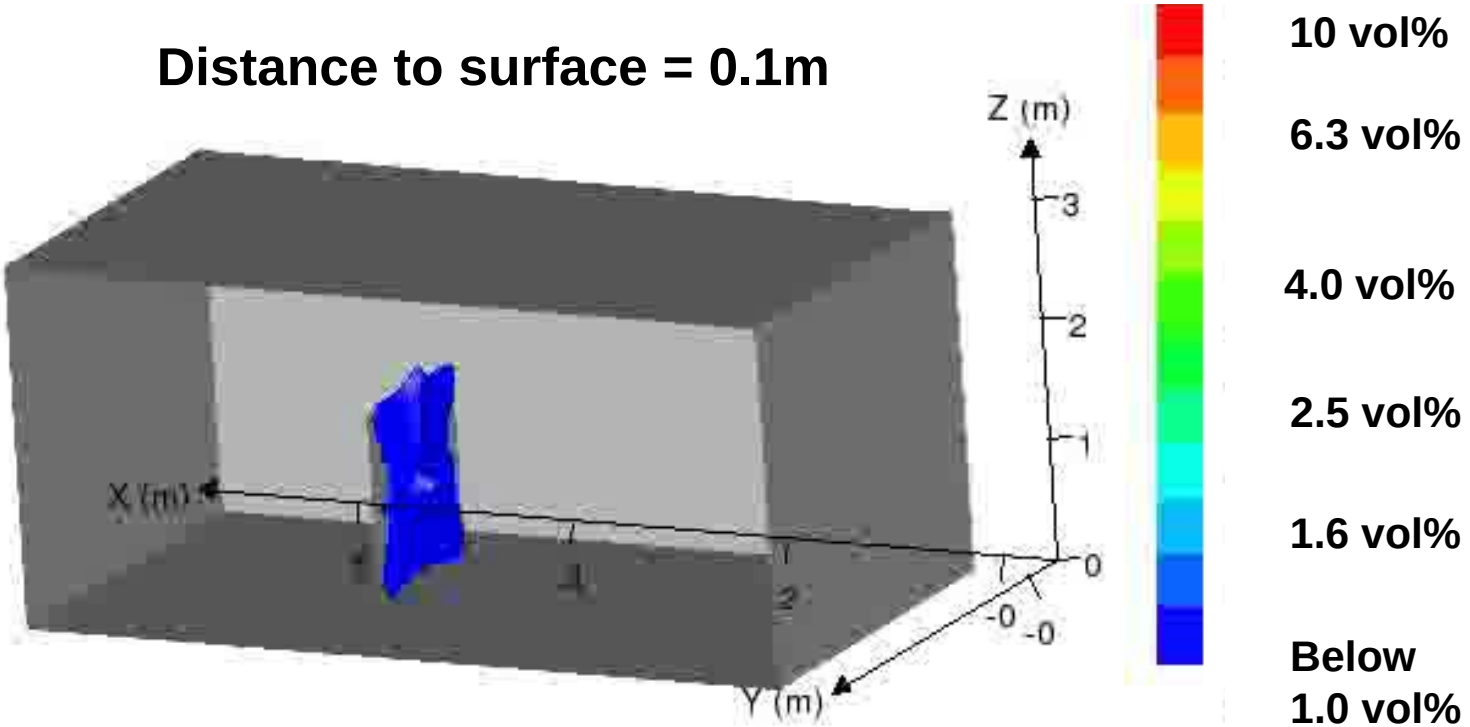
Small holes at bottom of box keep pressure from building up

Modeled three different distances of leak to impinging surface (0.1 m, 0.22 m and 0.85 m)

Plume Profile – Bounded Leak Impinged on a Surface (0.1m)

HFO-1234yf Concentration

Distance to surface = 0.1m



10 vol%

6.3 vol%

4.0 vol%

2.5 vol%

1.6 vol%

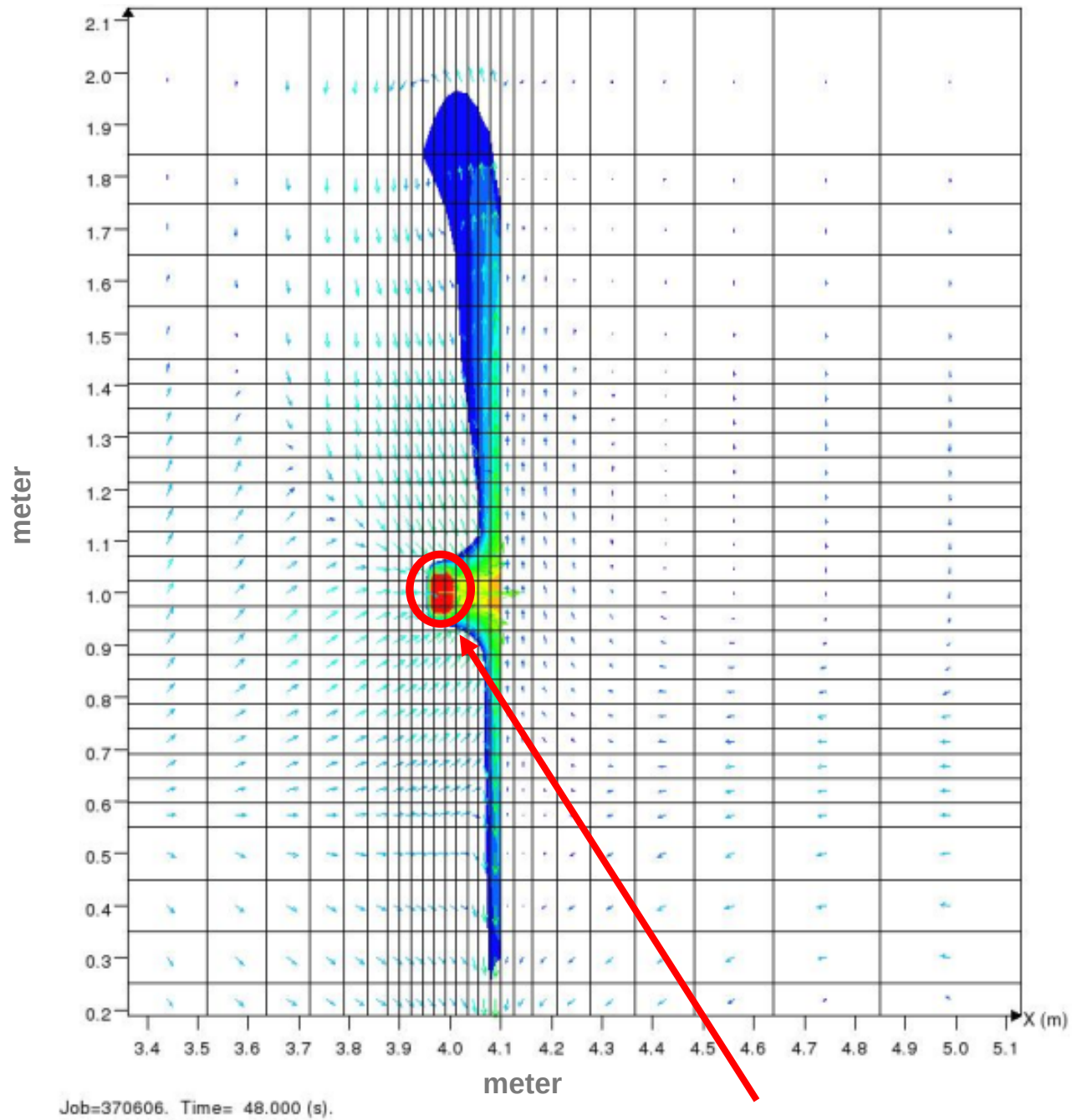
Below 1.0 vol%

Job=370606. Var=FMOLE (m3/m3) /log10/. Time= 48.000 (s).

X=-0.3 : 7.3, Y=-0.3 : 3.3, Z=0.05 : 3.3 m

Plume is continually dispersed by surface, almost no flammable zone available

Plume Profile – Bounded Leak Impinged on a Surface – Side View



HFO-1234yf Conc.

- >10 vol%
- 10 vol%
- 6.3 vol%
- 4.0 vol%
- 2.5 vol%
- 1.6 vol%
- Below 1.0 vol%

Air Velocity

- >100 m/s
- 100 m/s
- 10 m/s
- 1.0 m/s
- 0.1 m/s
- Below 0.1 m/s

Plume is continually dispersed by surface with almost no flammable zone formed (~ 2-4 cm around impact point)

Summary

- **HFO-1234yf is very similar to HFC-134a, except for mild flammability.**
- **HFO-1234yf has low burning velocity, high minimum ignition energy and is difficult to ignite. HFO-1234yf is less flammable than other commonly used substances.**
- **Potential automotive OEM plant implementation strategies have been investigated.**
- **Potential automotive service leak scenarios have been investigated for use in service implementation (risk assessments.)**
- **As with any substance, customers will need to follow appropriate regulations and best practices for product implementation.**

More Information

www.Refrigerants.DuPont.com

www.SmartAutoAC.com

Please feel free to contact the author at Mary.e.Koban@usa.dupont.com for any additional information.

Thank You!