MRB CRP Updated Risk Assessment for Low GWP Blend Refrigerants

Tom Lewandowski, Ph.D., DABT
Gradient
Seattle, WA USA

SAE International™

Prior Risk Assessments for Auto AC Systems

- Jetter et al., 2001
  - Generic "proof of concept" paper
- Blackwell et al. (2005,2006)
  - R-152a and CO_2
- Delphi and Delphi/TUV
  - R-152a
- SAE CRP150
  - 3 new R-134a alternatives (all later withdrawn)
- SAE CRP1234
  - HFO-1234yf and CO_2
- MRB CRP
  - new refrigerant blends

SAE International™

Risk Assessment Approach

- Goals
  - To determine whether use of new refrigerants increases risks for passengers, service personnel or others relative to existing risks of R-134a
  - To assist US EPA in making a SNAP determination
- Key Questions
  - Effects on health (refrigerant toxicity)
    - Question: How likely is it that there will be an exposure above a health-based limit (HBL)?
  - Flammability
    - Question: How likely is it that the refrigerant will be ignited with someone present by foreseeable energy sources or under feasible conditions?
  - Decomposition Products
    - Question: How likely is exposure to decomposition products (e.g., HF) in the event of refrigerant ignition or thermal decomposition?

SAE International™

Risk Assessment Approach (cont)

- Scenarios Considered
  - Vehicle Occupants
    - Release from a fault during operation (corrosion, hose leaks)
      - In cabin and in engine compartment (aspiration)
    - Release due to a vehicle collision
      - In cabin and in engine compartment (aspiration)
  - “Good Samaritans”
  - “Bystanders” outside vehicle
  - First responders
  - Repair workers (Professional and DIY)
  - Assembly plant workers
- Some were addressed qualitatively

SAE International™

Data Collection

- OEM data on vehicle operation
- Literature data on events and behaviors
- Toxicity
  - All components already well tested, evaluated
  - Low acute toxicity for blends, comparable/better than R-134a
- Flammability
  - Basic properties (LFL, UFL, Ign. Temp, burning velocity)
  - Concentration measurement in simulated releases
  - Potential ignition sources
- Decomposition products
  - Bench scale testing
  - Field testing

Focus since summer 2011

SAE International™

Fault Tree Analysis (FTA)

- Similar to EPA sponsored risk assessment of R-152a and R-744 and similar to prior SAE CRP1234
- Results are compared to other non-AC related automotive risks
- Relative to prior SAE effort, added hybrid vehicles and dual evaporator vehicles to evaluation
- Fault trees presented previously were updated to reflect newer information

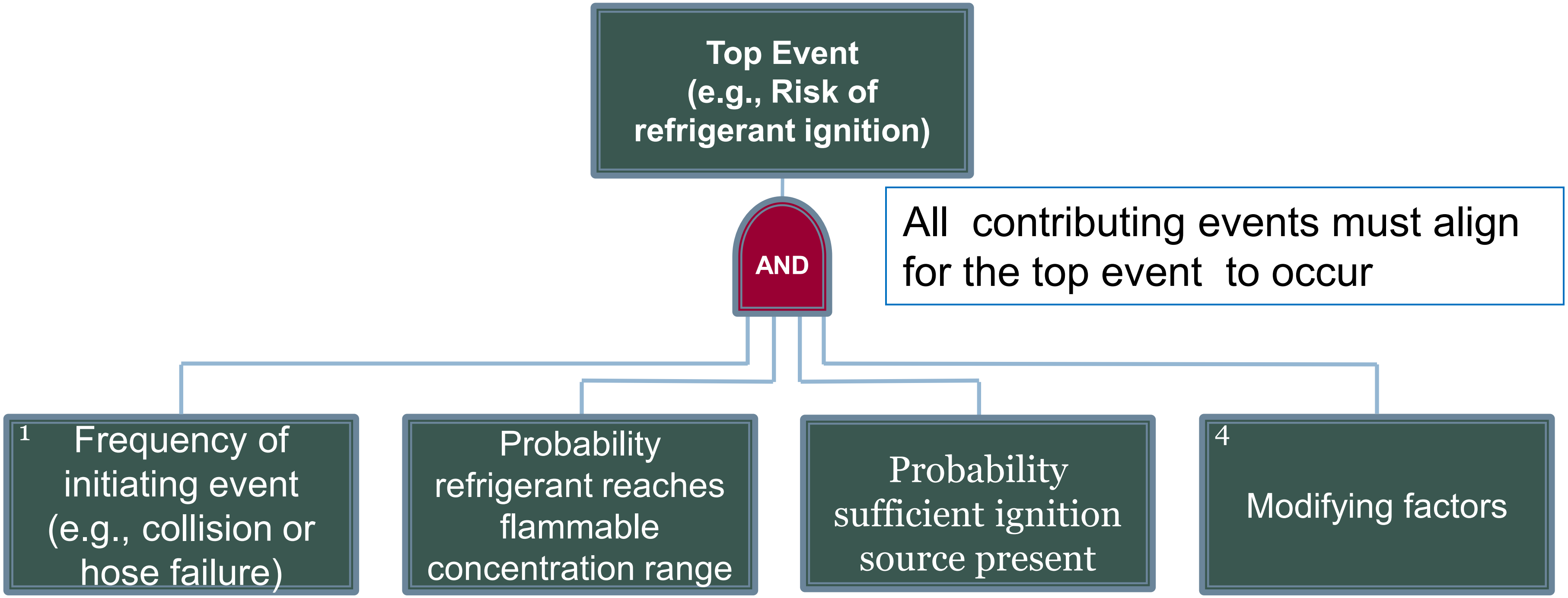
SAE International™

Hazard Scenarios Studied in FTA

Event Type	Location and Source of Refrigerant Release	Location of Exposed Individual
Vehicle collisions	Cabin, Evaporator leak	Occupant in passenger cabin
	Engine comp., Broken tube/hose	Former occupant in engine comp.
	Engine comp., Broken tube/hose	Good Samaritan in engine comp.
	Engine comp, Broken tube/hose	Occupant trapped in passenger cabin
Vehicle fires (vehicle in operation)	Engine comp., Fire damage to AC lines	Former occupant in engine comp.
	Engine comp., Fire damage to AC lines	Occupant trapped in passenger cabin
Vehicle fires (vehicle parked)	Engine comp., Fire damage to AC lines	Vehicle owner/other person in engine comp.
AC system leaks	Engine comp., Broken tube/hose	Occupant trapped in passenger cabin
	Engine comp., Broken tube/hose	Former occupant in engine comp.

SAE International™

Risks Require a Combination of Factors



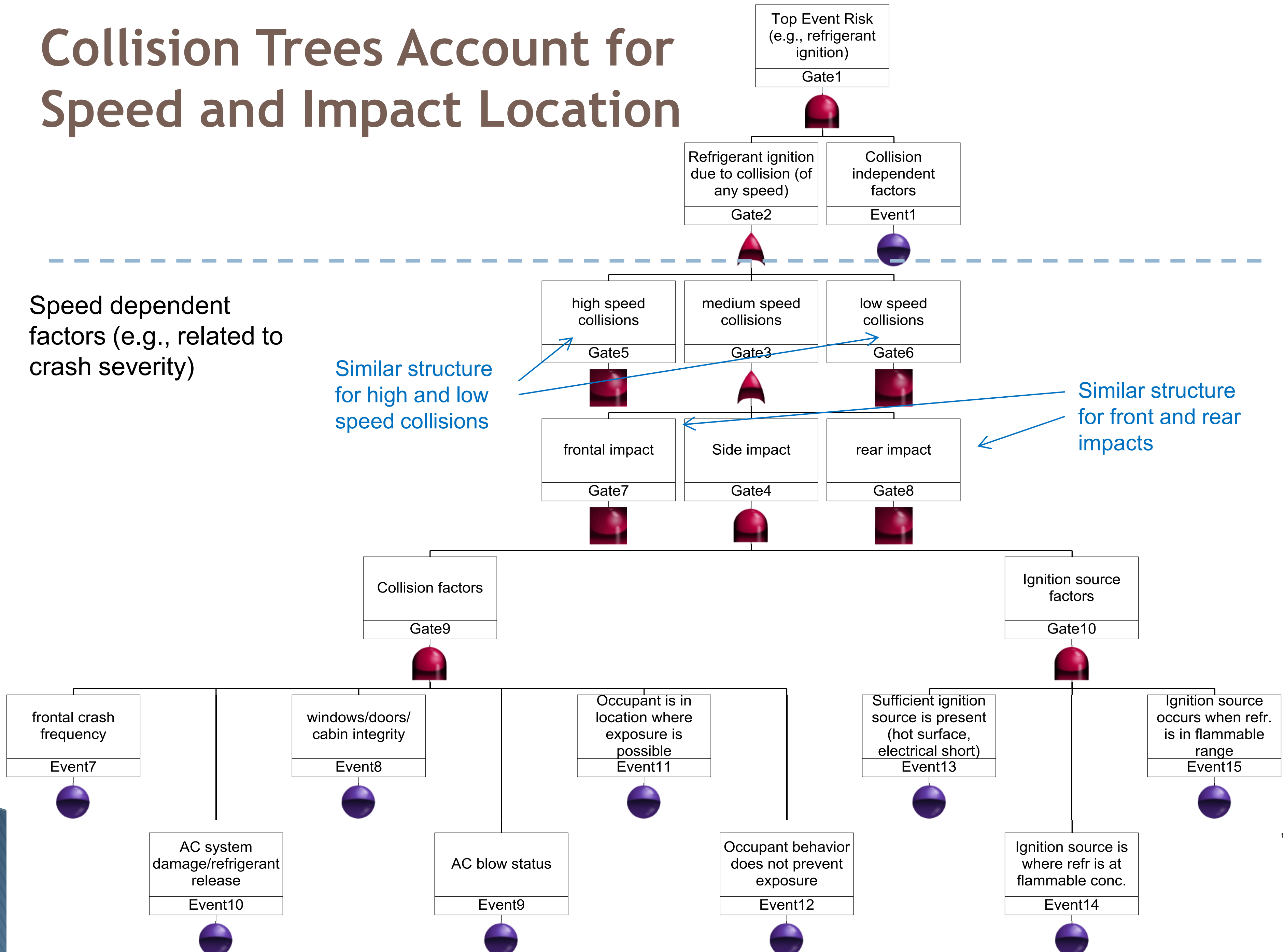
Data from on modeling and measurement studies, engine compartment geometries

Is a hot enough or energetic source likely to present when a release occurs?

Vehicle integrity, blower status, timing and location of release relative to ignition source(s), behavioral factors

Collision Trees Account for Speed and Impact Location

Speed dependent factors (e.g., related to crash severity)



Sources of Input Data for FTA

- Inputs related to vehicle collisions based on averages of national statistics from several countries
- Inputs related to collision consequences (e.g., AC system damage) estimated based on OEM crash data
- Inputs related to refrigerant concentrations and timing derived from results of modeling & measurement studies
- Assumptions concerning refrigerant ignition and decomposition based on field studies
  - **Aware of recent Daimler test results; currently exploring how this new information may affect the FTA**
- Inputs where data are lacking were derived as expert OEM consensus
- Inputs considered to be highly uncertain were assessed through sensitivity analysis

SAE International™

Service Scenarios Studied in FTA

Event Type	Location and Source of Refrigerant Release	Location of Exposed Individual
Certified Technician exposure	Engine comp., Broken tube/hose	Technician in engine compartment
Certified Technician Ignition Event	Leak at Equipment	Technician in engine compartment

- Evaluated risks of a leak during service in a professional shop
  - Based on CFD conducted for prior CRP (now published), refrigerant leaks are only in the flammable range a few cm out from the leak source
  - Service pits are assumed to be covered by existing confined space regulations and were not included in the risk assessment
- DIYers
  - Modeling indicates that flammable concentrations are not obtained in the heel release and are extremely unlikely in the charge kit leak scenario

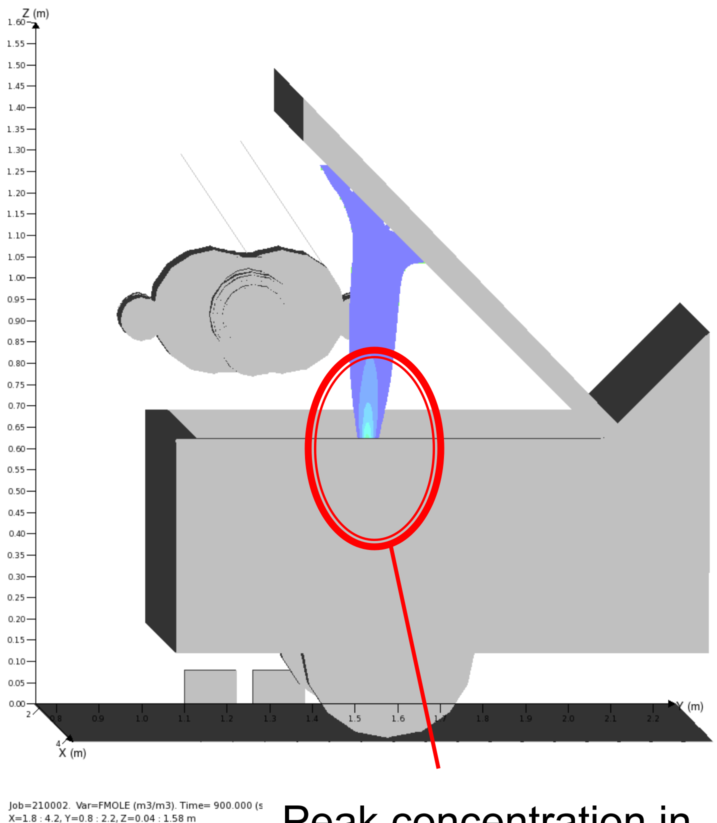
SAE International™

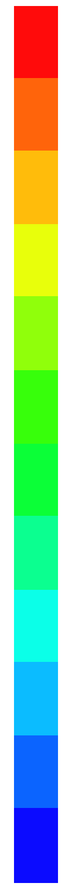
DIY Concentration Modeling

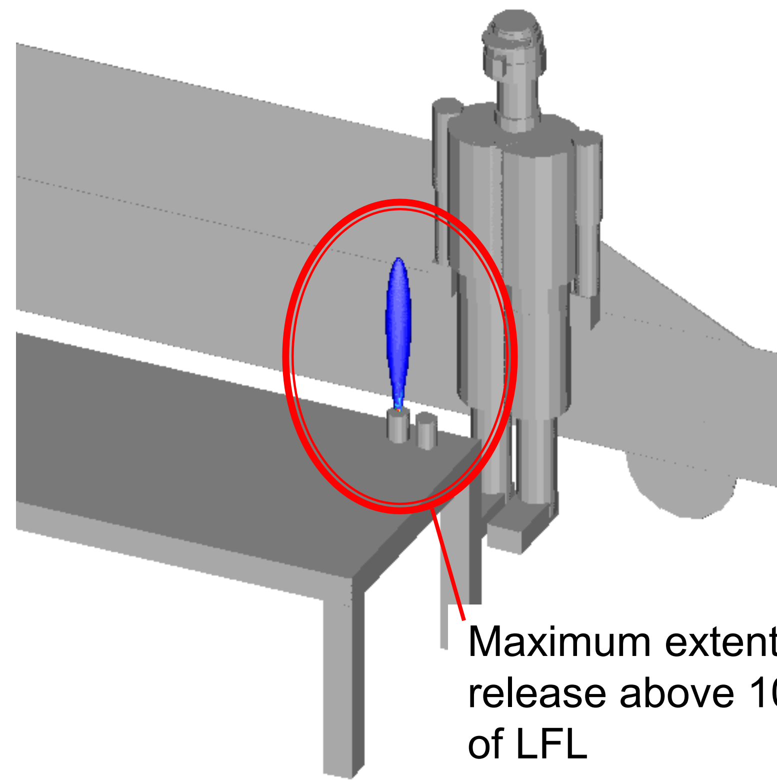
- Prior CRP work indicated flammable concentration would only be near the leak location in *professional* repair cases
  - Flammable zone was only a few cm in length near the leak
- New modeling done to assess risks for DIYers in the event of a charge kit leak or from release of can heel
- Worst-case release rate assumptions in both cases (i.e., no ventilation, high leak rate)
- Neither scenario indicated that flammable concentrations would be reached at any time during the release

Charge kit leak

Can heel release







Peak concentration in plume remains well below LFL (and also the ATEL)

Maximum extent of release above 10% of LFL

SAE International™

FTA Results

Risk Comparison to Other Vehicle Events

Event	Probability per vehicle per operating hour
Probability of being in a police reported vehicle collision	5×10^{-5}
Probability of vehicle collision due to vehicle brake failure	3×10^{-7}
Probability of highway vehicle fire (any cause)	1×10^{-7}
Probability of an airbag-related fatality associated with a vehicle collision	2×10^{-10}
Probability of vehicle occupant/former occupant experiencing HF exposure above health based limits associated with R-1234yf ignition/decomposition.	2×10^{-14}
Probability of vehicle occupant/former occupant experiencing HF exposure above health based limits associated with AC6 ignition/decomposition.	1×10^{-14}
Probability of vehicle occupant being exposed to an open flame due to R-1234yf ignition	4×10^{-15}
Probability of vehicle occupant being exposed to an open flame due to AC6 ignition	5×10^{-17}

SAE International™

Risk Comparison to Other Workplace Events

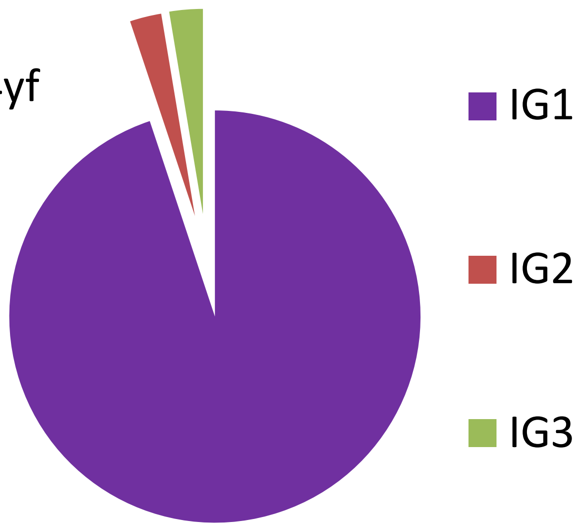
Event	Probability
Non-fatal recordable Injury at work (all occupations, per working hour)	2×10^{-5}
Probability an AC service technician is struck by object resulting in lost work days (per working hour)	2×10^{-6}
Probability of a fatal fall at the workplace (all occupations, per working hour)	2×10^{-9}
Probability of AC service technician exposure to an open flame due to R-1234yf ignition (per hour of vehicle service)	8×10^{-21}
Probability of AC service technician exposure to an open flame due to AC6 ignition (per hour of vehicle service)	5×10^{-22}
DIYer exposures to AC6 or R-1234yf (per working hour)	Essentially zero

SAE International™

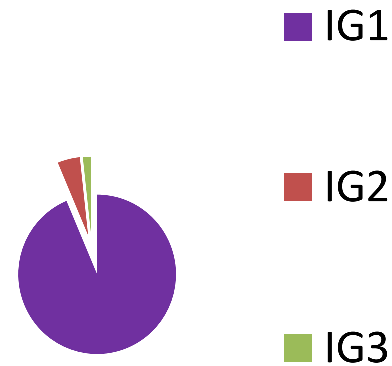
Relative Risk Contribution in FTA

Probability of vehicle occupant being exposed to an open flame due to refrigerant ignition

R-1234yf



AC6



Combined risk = 4×10^{-15}

Combined risk = 5×10^{-17}

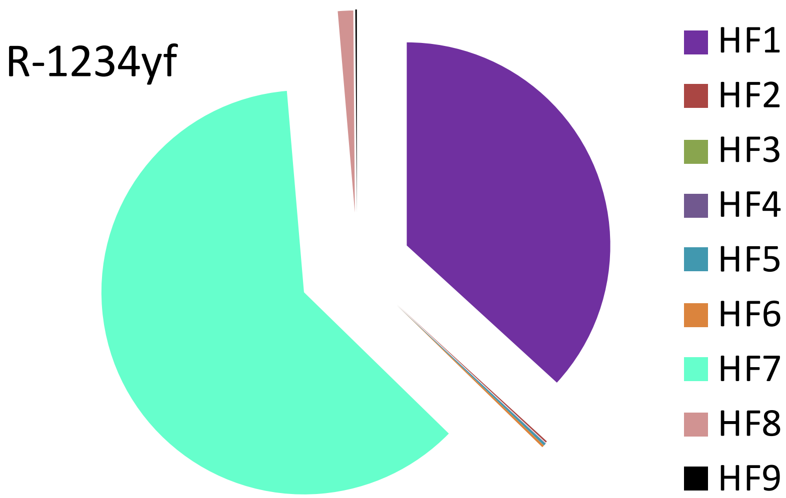
IG1 – collision related release in cabin
IG2 –collision-related release in engine comp.
IG3 –AC system leak in engine comp.

Risk for all three refrigerants is dominated by Fault Tree **IG1**, the scenario involving a collision-related evaporator leak into the cabin

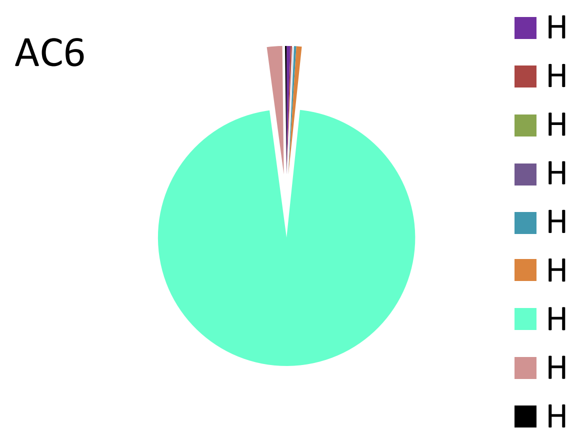
SAE International™

Relative Risk Contribution in FTA

Probability of vehicle occupant/former occupant experiencing HF exposure above health based limits associated with refrigerant ignition/decomposition



Combined risk =2 x 10^{-14}



Combined risk =1 x 10^{-14}

HF1 - collision related release into cabin resulting in HF generation
HF7 - non-AC related fire generating HF in engine comp
HF8 – non-AC related fire generating HF which is aspirated into cabin

Risk is dominated by scenarios involving a collision causing an refrigerant release in the cabin (**HF1**) and a non-AC related vehicle fire (**HF7**).

SAE International™

Supply Chain Issues

- Risks for automotive workers
  - Charging AC systems in assembly plants
  - General assembly plant workers
- Factors to consider
  - Low toxicity, both acute and chronic, OELs comparable to or higher than other chemicals already in use
  - Flammability is key risk (decomposition in absence of ignition is very unlikely)
- Studies of R134a conducted both at GM and Volvo have indicated very low concentrations in vehicle assembly plants
  - GM measurements (personal and area samplers) show concentrations < 10 ppm
  - Volvo measurements (area samplers) indicated concentrations ≤0.1 ppm
  - The R134a results should be applicable for AC5 or AC6
  - Far below the relevant OELs or LFLs
- Risks for chemical manufacturing workers will be managed by their own internal Health & Safety programs

SAE International™

Comparison of Proposed Substitutes for SNAP

- Key criterion is relative overall risk compared to R-12 and R-134a. Overall risk can not be increased

Property	R-12	R-134a	AC6	R-1234yf
Toxicity				
Acute toxicity (LC_{50}, ppm)	600,000	>500,000	>207,000	>405,000
Anesthetic potency (ppm)	25,000	50,000	>166,000	120,000
OEL (ppm)	1,000	1,000	840	500
ASHRAE ATEL	18,000	50,000	57,100	101,000
Flammability	None	None	None below 50° C	weakly flammable
ODP	1.0	0	0	0
100 year GWP (CO_2=1)	10,600	1,430	130	4
Estimated total lifetime annual refrigerant loss rate (grams/year)	--	38	46	38

SAE International™

Overall Risk Assessment Conclusions

- **Use of AC6 in MAC systems poses an extremely low level of risk for vehicle operators and repair workers**
  - **The risks are lower than those estimated for R-1234yf**
  - **A key risk driver involves HF exposure from a non-AC related fire, a risk that is present with current R-134a systems**
- **Based on Risk Assessment to date, AC6 could be an appropriate alternative for R134a and R12 as MAC refrigerants**
  - **Increased risk due to flammability is very small**
  - **Hazard due to toxicity is equivalent or reduced**
  - **Environmental benefits (i.e., GWP, ODP, LCCP) are enhanced as compared to R-134a and R-12**

SAE International™

- Thanks for your attention!