# INERTING TESTING WITH CF3I AND BLENDS WITH OTHER AGENTS

## BLENDS TESTED:
## HFC-125, FK-5.1.12 AND SOLSTICE 1233ZDE

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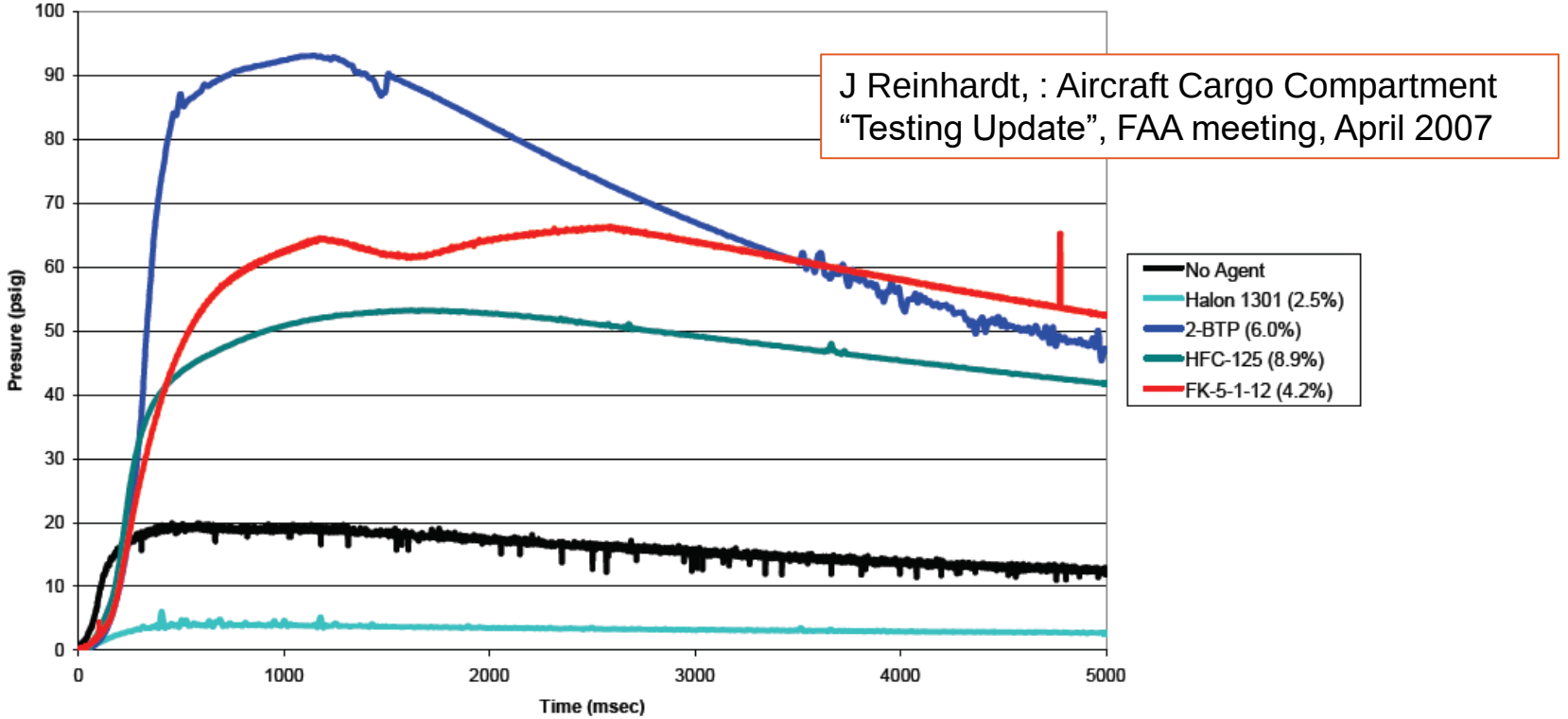
# INTRODUCTION

## WHY ARE WE CARRYING OUT INERTING TESTS?

- **The FAA Aerosol Can Test**
- One of the four elements of the FAA Minimum Performance Standard (MPS)
- Devised to simulate the effects of an aerosol can test containing hydrocarbon propellant exploding in a cargo fire situation, and damaging cargo liners
- Mixture of propane, ethanol & water sprayed across continuously sparking electrodes
- In general agents such as halon 1301 inert this test at a certain concentration which defines their low-rate discharge (LRD) concentration.
- However some halon replacement agents when tested at below their inerting concentration actually made the aerosol can explosion test (ACT) worse, in that higher pressures were developed.

# INTRODUCTION 2

## REPLACEMENT AGENTS TESTED AT SUB-INERTING CONCENTRATIONS




J Reinhardt, : Aircraft Cargo Compartment "Testing Update", FAA meeting, April 2007

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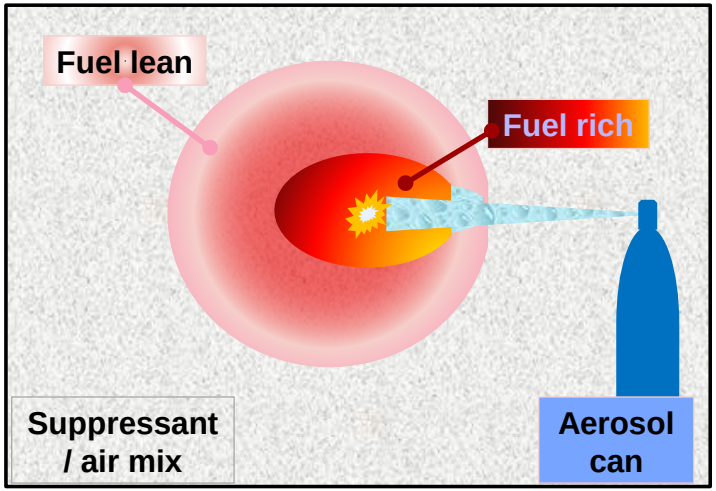
# INTRODUCTION 3

## ISSUES WITH THE FAA AEROSOL CAN TEST

- Full-Scale Test; slow and expensive, not an R&D test
- Uneven fuel distribution (fuel rich near spark, fuel lean further away) means variable stoichiometry.
- Conditions are difficult to control and repeat; modelling of the event is complicated.
- In real life, homogeneous suppressant distribution and concentration are not guaranteed:
- Air leakage / ventilation of cargo hold.
- Distribution obstructed by cargo / containers



# DEVELOPMENT OF A SCREENING TEST

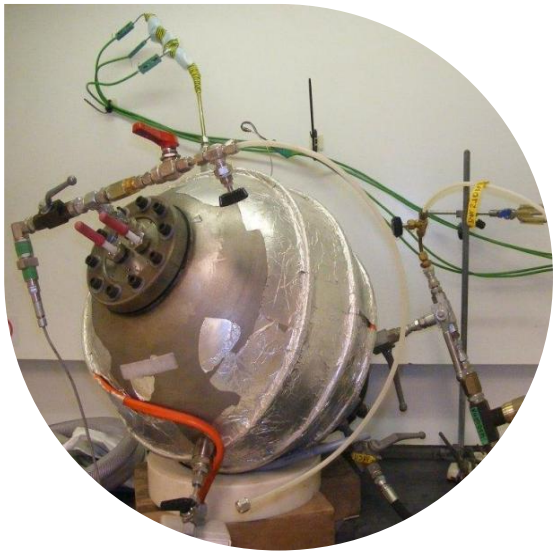
## INFORMATION WANTED

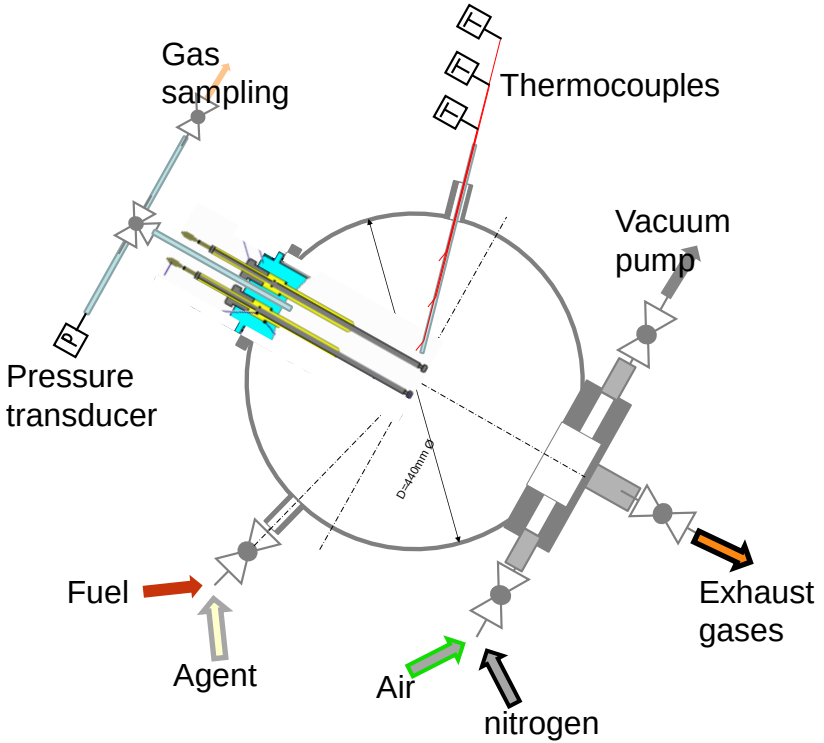
- Performance of agents at various sub-inert concentrations and air/fuel ratios (lean, rich & stoichiometric)
- How to achieve this?
- Back to basics; single fuel tested in more controlled environment
- Propane (gaseous) is easier than ethanol to use
- Kidde devised a test based on internationally accepted Standards to create an easily reproducible screening test which can test small quantities of agent quickly and safely
- This was presented previously at the FAA Meeting in Bremen (May 2014): https://www.fire.tc.faa.gov/pdf/systems/May14Meeting/Gatsonides-0514-HalonAlt.pdf

# DEVELOPMENT OF A SCREENING TEST

## USE OF SMALL SCALE TEST TO PREDICT PERFORMANCE IN AEROSOL CAN TEST

Kidde 43 L Inerting Sphere



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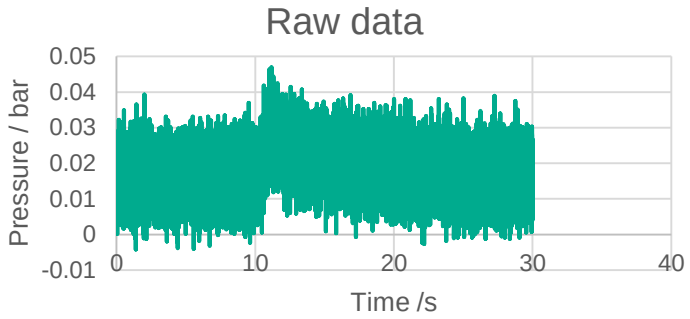
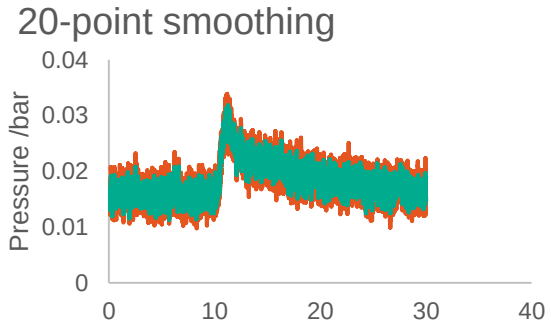
# TEST METHODOLOGY

- Sphere evacuated, propane, agent(s) added stepwise by partial pressure
- Air introduced to achieve 1 atmosphere
- Wait 10 minutes for equilibrium (heat sphere if necessary to disperse less volatile agents)
- Start high speed DAQ
- Discharge igniter for 1 second
- Record results, evacuate and purge sphere
- If testing near pass fail criterion pressure rises are small, so signal noise is an issue
  - 20 point smooth in Excel cleans the data

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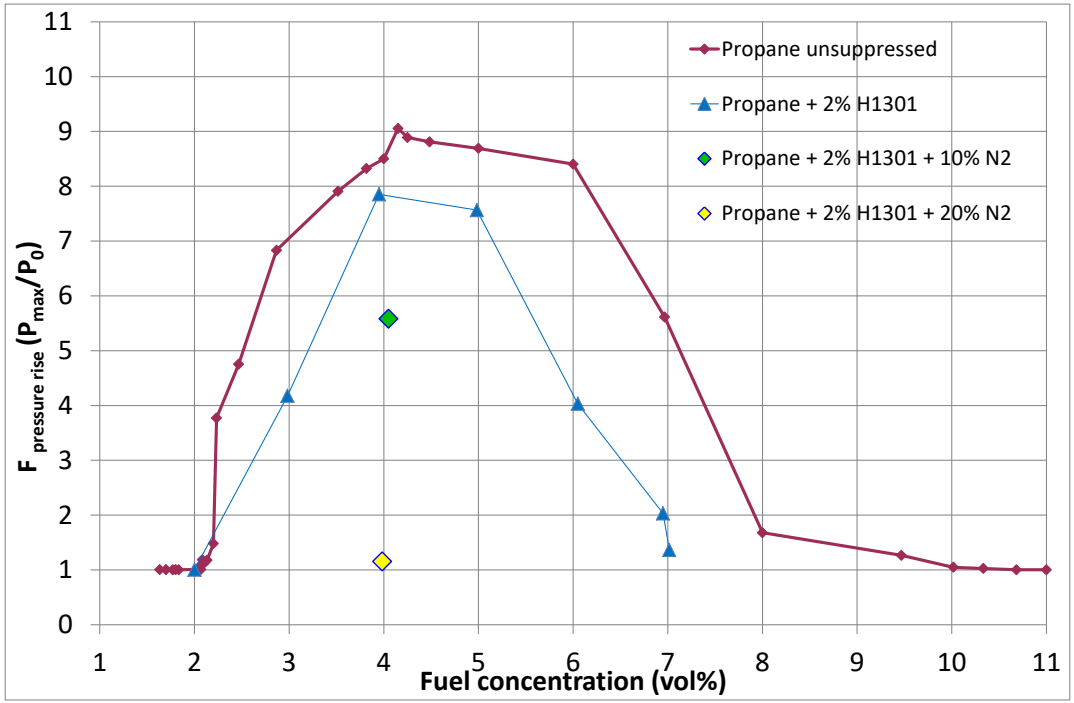
# RESULTS

## UNSUPPRESSED PROPANE AND HALON BASELINE

- **2%** halon 1301 is approx. **0.3x** inerting concentration
- Mitigates propane explosion pressure (peak pressure and flammability limits)
- Additional nitrogen (10% and 20%) aids further suppression
- In other words halon 1301 is behaving as in the FAA ACT in not making the explosion worse

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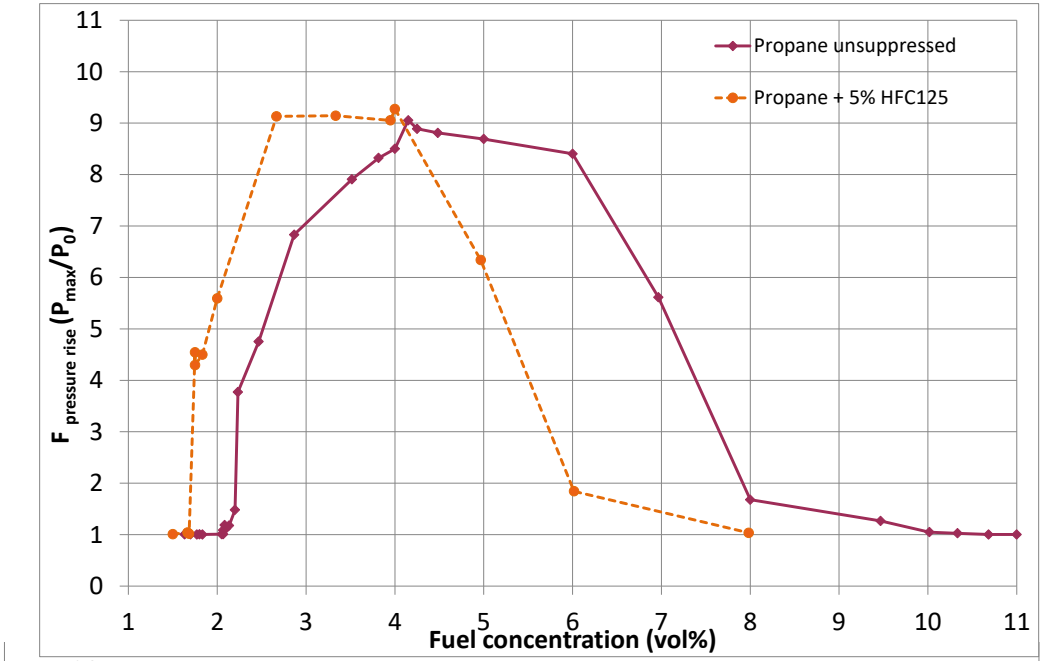
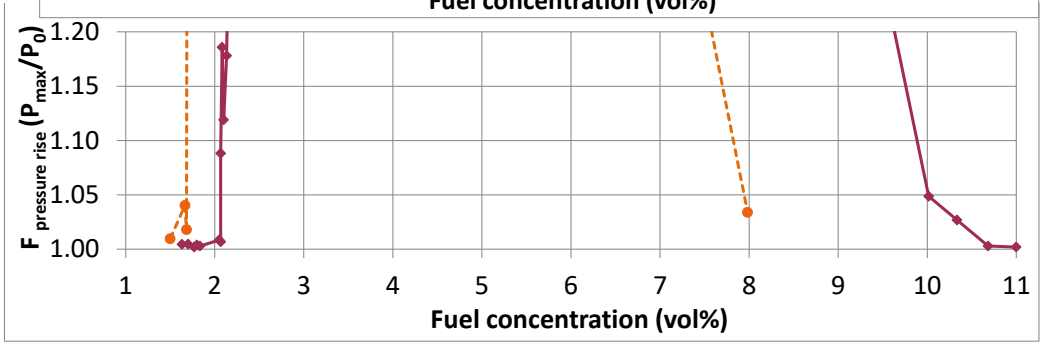
# RESULTS

## HFC-125 TESTING

- Recall that HFC-125 exacerbated the ACT at sub-inerting concentrations
- 5% HFC125 is approx. 0.3x inerting concentration
- Shift to lean side of flammability curve for propane indicates that a low % HFC125 combined with a low % propane acts as fuel
- Above stoichiometric concentration, HFC-125 mitigates flammability as if an overly rich mixture is achieved
- The enhancement at or near the lean limit seems to be following the ACT!

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# RECENT WORK

## CF3I, SOLSTICE-1233ZDE
## BLENDS OF AGENTS
## AND PREDICTION OF PASS / FAIL CRITERIA FOR FAA ACT

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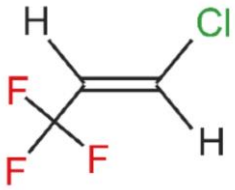
# TESTS CARRIED OUT

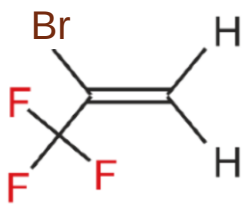
## PURE AGENTS

- Two new agents have been tested:
- CF3I
  - Blend of CF3I and HFCs being proposed in the refrigeration industry (R466A: CF3I, HFC-32 and HFC-125)
  - Renewed interest in CF3I as a cargo compartment agent

- Solstice 1233zdE
  - New Low-GWP HCFO agent,
  - Intended for foam-blowing and solvent applications
  - Structural similarity to 2-BTP
  - Likely to fail ACT, but low molecular weight might make it interesting in blends




HCFO-1233zd




2-BTP

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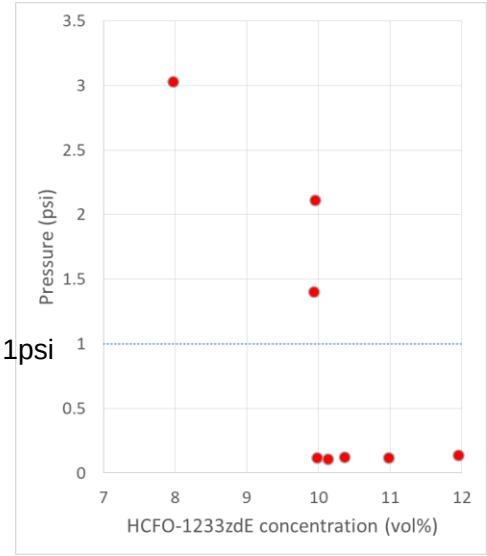
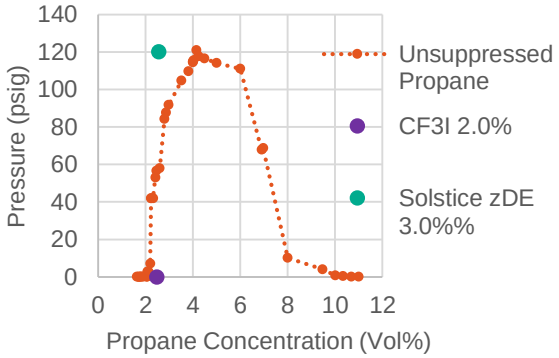
# RESULTS OBTAINED

## PURE AGENTS

- Peak Inerting Concentrations
  - Test carried out at 4.0% propane
  - CF3I Inerting concentration for propane validated at 6.5%
  - Solstice inerting concentration measured to be 10.0%
- Behaviour at sub-inerting concentration (at 2.5% propane)
  - CF3I at 2.5% did not enhance the explosion
  - As expected, CF3I behaving like halon 1301 as an inerting agent
  - Solstice-1233zdE at 3.0% enhanced the explosion significantly
  - As predicted due to its structural similarity to 2-BTP

Pass / fail criterion is 1psi

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# TESTING WITH BLENDS

## BLENDS

- When evaluating blends of a “flammable” agent and a non-flammable agent there are two questions that need to be answered:
  1. *What is the minimum proportion of the non-flammable agent that prevents the enhancement of the propane-air explosion on the lean side?*
  2. *Having established the minimum proportion of the non-flammable agent, what is the inerting concentration of the blend at peak flammability (i.e. 4vol% for propane-air)?*
- Blends tested: CF3I with
  - HFC-125, FK-5.1.12 and Solstice 1233zdE

# BLENDS OF CF3I AND HFC-125

- Answering question 1:
- Ratio of 0.40 fails, whereas 0.50 passes
- So a possible blend is 1:2 CF3I :HFC-125

- Answering Question 2:
- 3.75% CF3I/7.5% HFC-125 is lowest quantity that passes

| Propane (Vol%) | CF3I (Vol%) | HFC-125 (Vol%) | Ratio (CF3I:HFC-125 | Pressure (psig) |
|---|---|---|---|---|
| 2.57 | 1.96 | 5.02 | 0.40 | 59.2 |
| 2.65 | 4.11 | 5.12 | 0.80 | **0.3** |
| 2.50 | 3.05 | 5.13 | 0.61 | **0.3** |
| 2.48 | 2.51 | 4.94 | 0.51 | **0.4** |
| 2.45 | 0.99 | 2.01 | 0.50 | **0.3** |

| Propane (Vol%) | CF3I (Vol%) | HFC-125 (Vol%) | Ratio | Pressure (psig) |
|---|---|---|---|---|
| 3.9 | 3.08 | 5.30 | 0.58 | 3.5 |
| 4.0 | 3.87 | 6.97 | 0.56 | **0.4** |
| 4.4 | 3.26 | 6.64 | 0.50 | 1.5 |
| 3.9 | 3.45 | 6.92 | 0.49 | 2.2 |
| 4.0 | 3.76 | 7.51 | 0.50 | **0.2** |
| 4.1 | 3.18 | 7.03 | 0.46 | 2.0 |

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# BLENDS OF CF3I AND NOVEC 1230

- Answering question 1: what is optimum ratio of CF3I/Novec 1230?
- 0.95 (~1)fails, whereas 1.25 passes
- So a possible blend is 5:4 CF3I : Novec 1230

| Propane (Vol%) | CF3I (Vol%) | Novec (Vol%) | Ratio | Pressure (psig) |
|---|---|---|---|---|
| 2.5 | 2.0 | 2.1 | 0.95 | 68.5 |
| 2.4 | 3.0 | 2.2 | 1.36 | 0.1 |
| 2.4 | 2.5 | 2.0 | 1.25 | 0.1 |

- Answering Question 2: What is peak inerting concentration of this blend?
- 4.4% CF3I/3.5% Novec is lowest quantity that passes

| Propane (Vol%) | CF3I (Vol%) | Novec (Vol%) | Ratio | Pressure (psig) |
|---|---|---|---|---|
| 4.0 | 4.4 | 3.5 | 1.25 | 0.2 |
| 4.0 | 3.8 | 3.0 | 1.25 | 2.7 |
| 4.0 | 4.0 | 3.3 | 1.21 | 2.8 |
| 4.0 | 4.1 | 3.3 | 1.25 | 2.8 |
| 4.0 | 4.2 | 3.4 | 1.25 | 2.8 |
| 4.0 | 4.3 | 3.5 | 1.24 | 0.5 |

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# BLENDS OF CF3I AND SOLSTICE 1233ZDE

- Answering question 1:
  - Ratio of 1.25 chosen as starting point
  - This result is not as good as Novec 1230 (0.1 psi) so we are close to the limit
  - So a possible blend is 5:4 CF3I : Solstice zdE
- Answering Question 2:
  - 4.4% CF3I/3.5% Solstice zdE is lowest quantity that passes

| Propane (Vol%) | CF3I (Vol%) | 1233 zDE (Vol%) | Ratio | Pressure (psig) |
|---|---|---|---|---|
| 2.43 | 2.51 | 1.95 | 1.29 | 4.06 |

| Propane (Vol%) | CF3I (Vol%) | 1233 zDE (Vol%) | Ratio | Pressure (psig) |
|---|---|---|---|---|
| 3.96 | 4.29 | 3.45 | 1.24 | 5.33 |
| 3.92 | 4.32 | 3.42 | 1.26 | 2.74 |
| 3.98 | 4.40 | 3.56 | 1.24 | 1.52 |
| 3.41 | 4.43 | 3.56 | 1.24 | **0.88** |
| 3.98 | 4.39 | 3.50 | 1.25 | **0.22** |
| 3.95 | 4.24 | 3.37 | 1.26 | 1.58 |
| 3.97 | 4.37 | 3.52 | 1.24 | **0.22** |

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# SUMMARY

## BLENDS COMPARED

- 5:4 mixture CF3I / HCFO-1233zdE appears promising in weight / volume terms
  - Low density of HFC-125 impacts volume
  - High MW Novec impacts weight and volume
- Benefits of blend with Solstice :
  - Blend could mitigate the toxicity effects of CF3I by almost a factor of 2
  - Minimal weight/volume impact compared to Halon 1301
  - Agent cost benefits?
- More testing required

| Agent or Blend* | Inerting Qty. | | Ratio to Halon | | Ratio to CF3I | |
|---|---|---|---|---|---|---|
| | kg/m$^3$ | L/m$^3$ | Mass | Volume | Mass | Volume |
| **Halon 1301** | 0.408 | 0.265 | 1 | 1 | 0.73 | 0.99 |
| **CF3I** | 0.562 | 0.268 | 1.38 | 1.01 | 1 | 1 |
| **$CF_3I$ / HFC-125 1:2** | 0.726 | 0.302 | 1.78 | 1.84 | 1.29 | 1.83 |
| **$CF_3I$ / Novec 1230 5:4** | 0.862 | 0.302 | 2.11 | 1.82 | 1.53 | 1.80 |
| **$CF_3I$ / HCFO-1233 5:4** | 0.567 | 0.302 | 1.39 | 1.24 | 1.01 | 1.23 |

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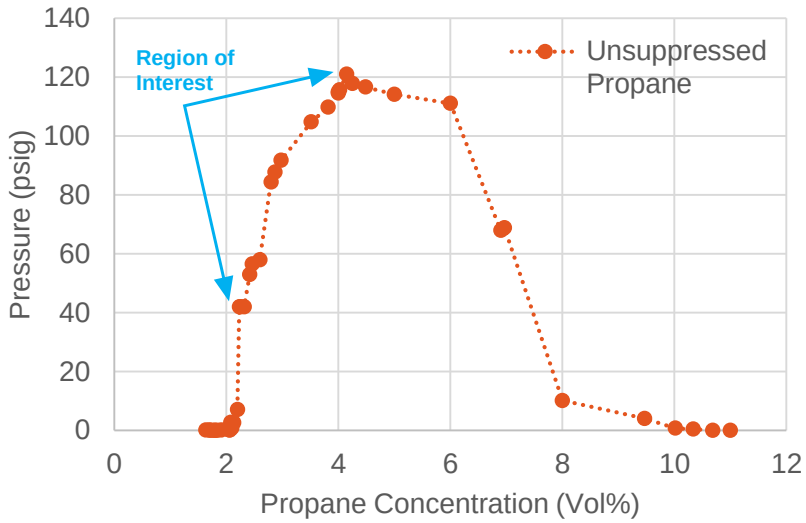
# REFINING THE SCREENING TEST

## PREDICTION OF PERFORMANCE IN ACT

- Having established blends that are not likely to make ACT worse, can we devise a test to predict Pass / Fail criterion?
- The ACT has an overall “severity” somewhat less than stoichiometric propane / air
- There ought to be a propane / air ratio that has similar severity to the ACT
- Evaluate performance of halon 1301 (3%) against various concentrations between LFL (~2% propane in air) and peak limit (4% propane in air)
- Use this concentration to test new agents

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# REFINING THE SCREENING TEST

## PREDICTION OF PERFORMANCE IN ACT

- Testing with Halon 1301 various propane / air stoichiometry were evaluated such that 3% halon could successfully suppress the explosion but less than 3% could not
- 3.3% Propane /Air was chosen
- The concentration was then selected to evaluate CF3I.
- 3.2% CF3I appears to be equivalent to 3% Halon 1301 in its ability to control a fuel lean propane / air explosion
- Suggests that this concentration should also control Aerosol Can Test

| # | Test | Propane % | CF3I % | Pressure / bar | Pressure / psi |
|---|---|---|---|---|---|
| 83 | Propane 3.3% CF3I 3.2% | 3.34 | 3.23 | 0.018 | 0.3 |
| 84 | Propane 3.3% CF3I 3% | 3.34 | 3.01 | 0.209 | 3.0 |

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# SUMMARY & CONCLUSIONS

- Testing agents at fuel–lean stoichiometry in the 42 L Sphere mimics behaviour in the full scale FAA ACT
  - Stable Agents (halon 1301, CF3I) control at sub-inerting concentrations
  - Less Stable agents (HFC-125, Novec 1230, Solstice zdE) do not
- Blends of stable and less stable agents can be created that can control the ACT
  - One blend in particular (CF3I/Solstice) appears attractive in weight terms
- Testing at intermediate propane air concentrations appears to offer a screening test to define likely pass / fail criteria for the full scale aerosol can test
  - CF3I at 3.2% should be capable of passing the Aerosol Can Test

# ACKNOWLEDGEMENTS


- Co workers at Kidde
  - Josephine Gatsonides – set up the original test at Kidde Research in the UK
  - Terry Simpson – useful discussions and suggestions for blends
  - Travis McCue, Harlan Hagge – assisting with the tests
  - Bob Royer, Jerry Jackson, the technicians who actually carried out the tests
- Honeywell – providing the Solstice 1233zdE