Evaluation of a Tropodegradable Bromofluorocarbon for Aviation Applications

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The Advanced Agent Working Group

- Research consortium looking for a drop-in replacement for Halon 1301
- Members include US North Slope Oil Producers, US DoD, NMERI, UK MoD, QinetiQ, AmPac and Kidde
- Approach
  - select likely candidate agents
  - conduct initial toxicity screening on paper
  - procure selected agents
  - test for toxicity & fire suppression effectiveness
- Agent selected: 2-bromo-3,3,3-trifluoropropene (2-BTP / NMERI #873)

Physical properties of 2-BTP

Name	Halon 1301	Halon 1211	2-BTP
Chemical Formula	CF_3Br	CF_2BrCl	CH_2CBrCF_3
ODP	10	3	<0.0005*
Atmospheric Lifetime (years)	65	11	0.008
Molecular Weight	148.90	165.36	174.95
Boiling Point (°C)	-57.8	-4	34
Vapour Pressure (bar(a) at 25°C)	16.0	2.8	0.74
Liquid Density ($g.cm^{-3}$ at 25°C)	1.54	1.8	1.60

* ODP varies with latitude. Value listed covers N America, EU, and most of Asia

Laboratory-Scale Evaluation

Cup-burner testing, small-scale fire testing
& decomposition products analysis

Cup burner & lab-scale testing

	Halon 1301	2-BTP	HFC-227ea
Cup Burner / Vol%	3.6	4.6	6.8
Small Scale Class A	1	1.1	2.6
Small Scale Class B	1	1.2	2.8

Small scale Class A & B are relative results by mass

Decomposition products

- Comparison using results from class A testing
- Fire size to room volume: 6.9 $kW.m^{-3}$

	Good Suppression			Poor Suppression		
Agent	**Agent Conc. (volume%)**	**Fire-out time (s)**	**Peak Acid Gas (ppm)**	**Agent Conc. (volume%)**	**Fire-out time (s)**	**Peak Acid Gas (ppm)**
FM-200	6.4	16	6000	5.1	95	12000
2-BTP	2.8	6	650	2.3	80	1900
Halon 1301	2.4	18	125	2.2	41	560

Cardiotoxicity testing of 2-BTP

- Carried out by Huntingdon Life Sciences, Cambridge, UK
- NoAEL = 0.5 vol%
- LoAEL = 1.0 vol%
- Cup burner is 4.6 vol%, so this agent cannot be used for total flooding in normally occupied spaces
- BUT these NoAEL/LoAEL values are **identical** to Halon 1211
- ***Is 2-BTP a viable Halon 1211 replacement?***

Evaluation as a hand extinguisher agent

Pan fire and hidden fire tests

Pan fire tests

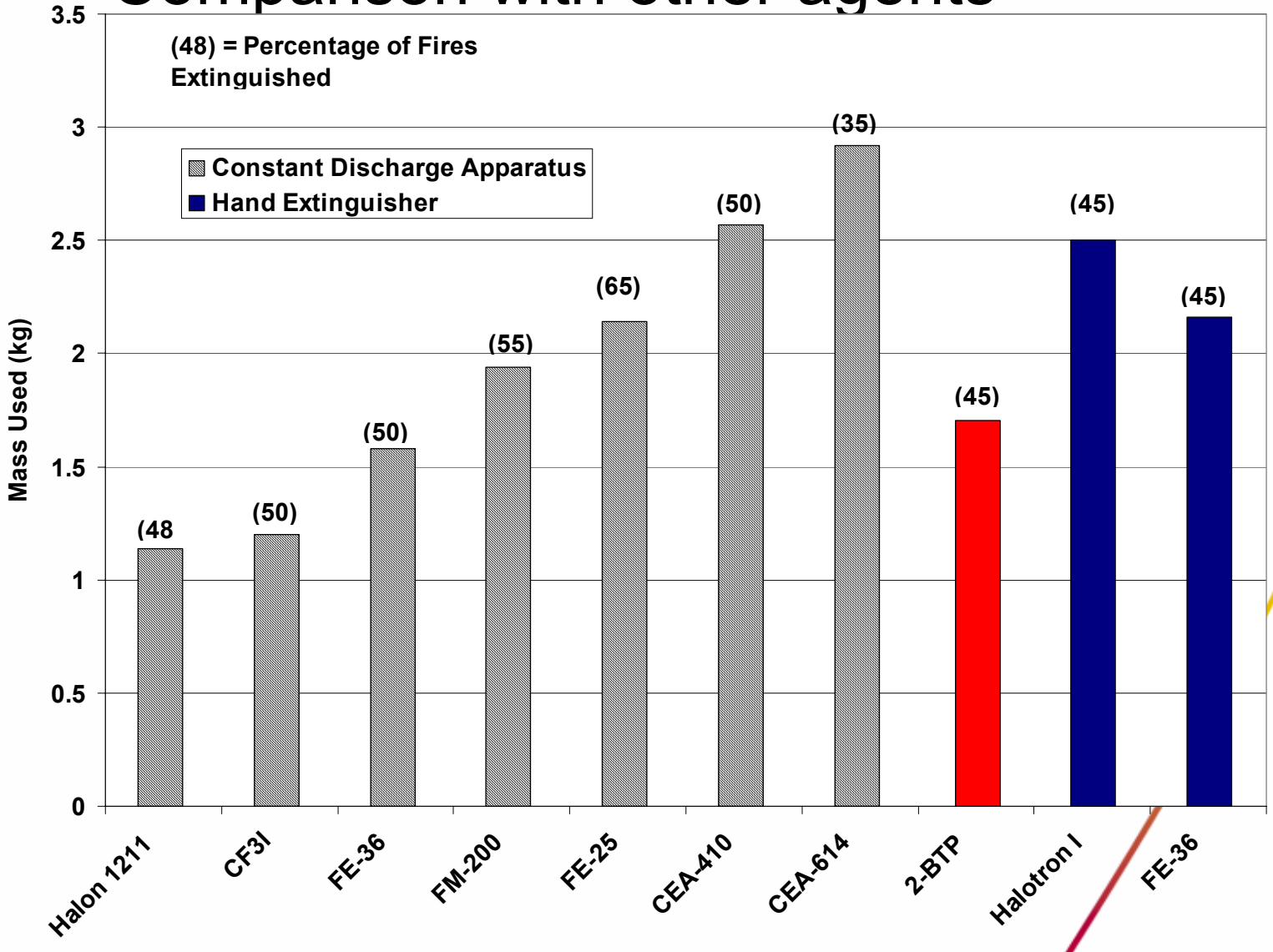
- Testing carried out at ULC, Toronto
- Target = UL 5B, achieved with 2.5 lb Halon 1211
- Over 90 tests carried out
- Many hardware variations tested
- Extinguishment achieved with 3.75 lb repeatedly
- One configuration extinguished fire with 1.7 lb agent (!)
- Most promising hardware combination (cylinder, hose, nozzle) selected for hidden fire testing

Hidden fire test

- Developed by Kidde Research in 1995 to quantify performance of Halon 1211 against “hidden fires”
- Adopted by FAA as part of Hand Extinguisher MPS[1]
- A matrix of 20 small heptane cup fires is used to evaluate agent / hardware combination
- Baseline performance of 2.5 lb Halon 1211 = 45% extinguishment (9 out of 20 fires)
- 3.75 lb 2-BTP achieved 45% Extinguishment

1. H Webster, *Development of a Minimum Performance Standard for Hand-Held Fire Extinguishers a a Replacement for Halon 1211 on Civilian Transport Category Aircraft*, Federal Aviation Administration, **DOT/FAA/AR-01/37**, August 2002.

Comparison with other agents



Conclusions thus far…

- Small scale laboratory testing and full scale hand extinguisher testing confirmed that BTP is a near drop-in replacement for Halon 1211
- Both agents share a similar toxicological profile
- Therefore 2-BTP is an effective and environmentally acceptable alternative to Halon 1211
- To make commercialisation feasible, additional applications needed to be found
  - Unmanned Halon 1301 applications
  - Cargo compartment, engine nacelle

Cargo compartment testing

Bulk load and aerosol can tests

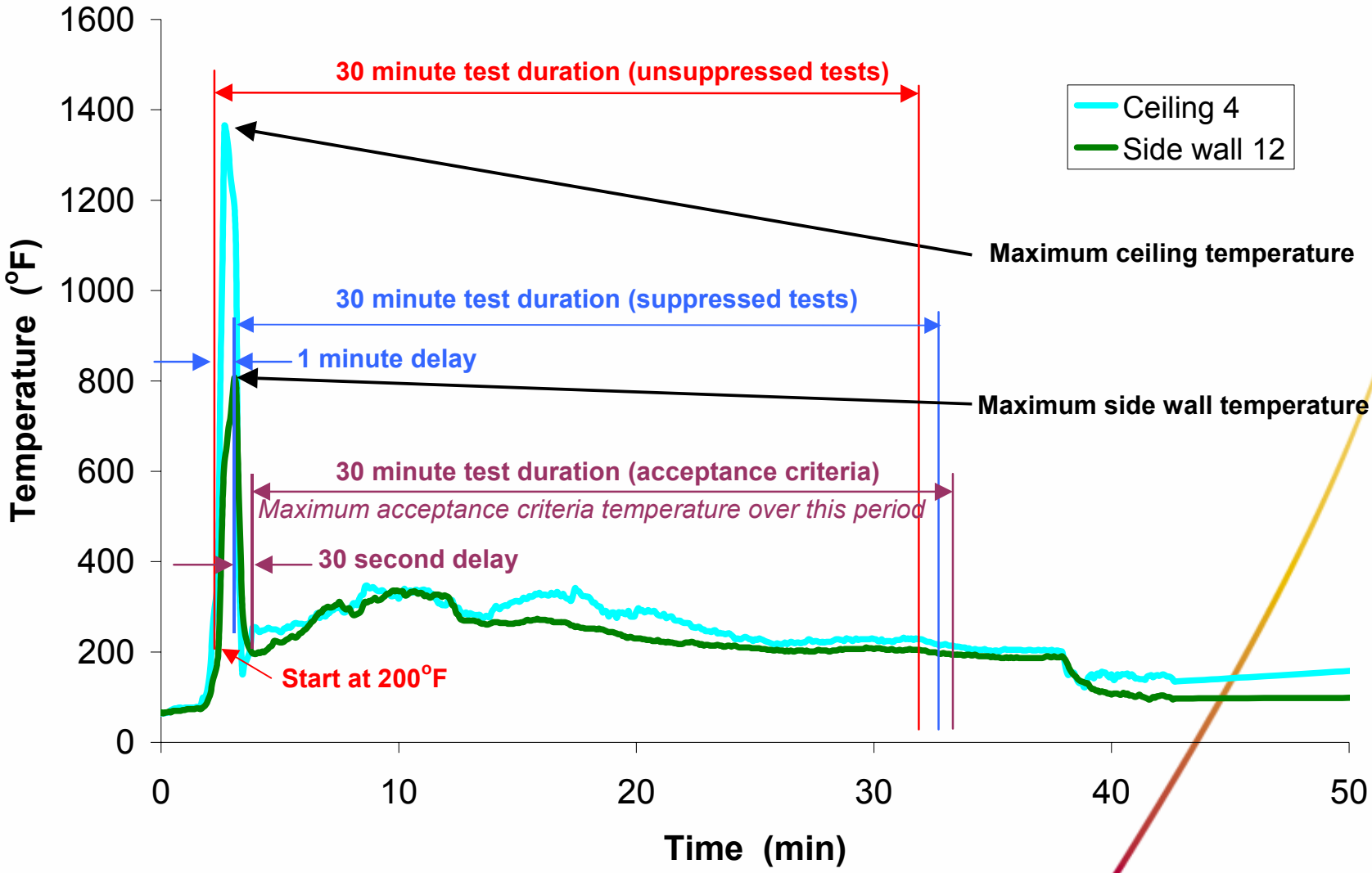
Bulk load tests

- 1/10 scale chamber constructed at KR test facility, Colnbrook, UK.
- Volume = 5.6m^3 (200ft^3)
- Airflow = 280 l/min
- Fire Threat = 25 x 16” boxes
- Thermocouples mounted near ceiling, sidewall *etc.*
- HRD & LRD discharges scaled accordingly

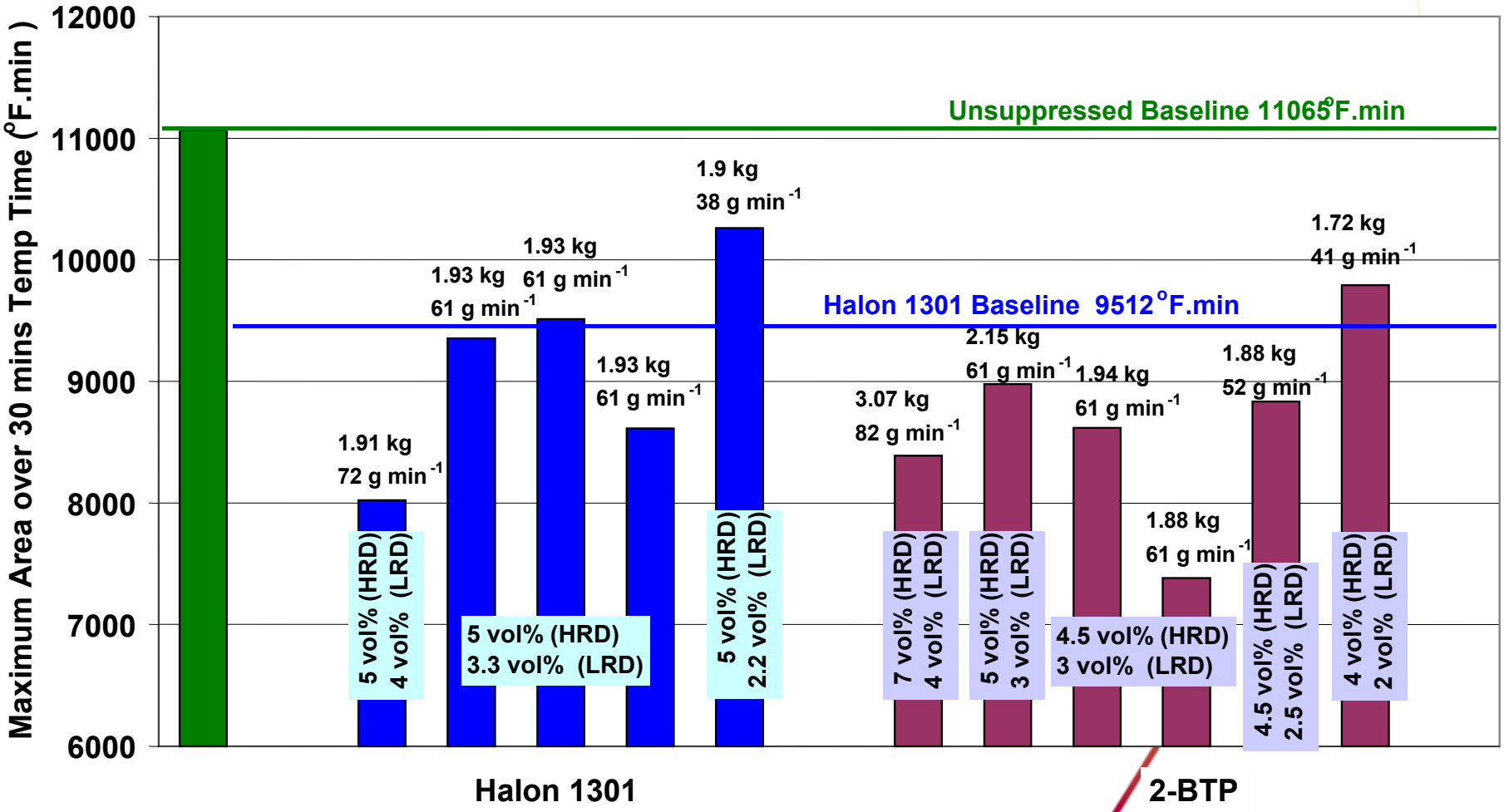
Development of test protocol

- 21 range-finding tests carried out to derive similar test severity to MPS
- Overall temperature-time profile lower than in MPS
- Gave repeatable results
- Sensitive to agent concentration (Halon 1301 baseline tests)
- Conclusion…
- Suitable for screening replacement agents

Presentation of results



Performance of 2-BTP

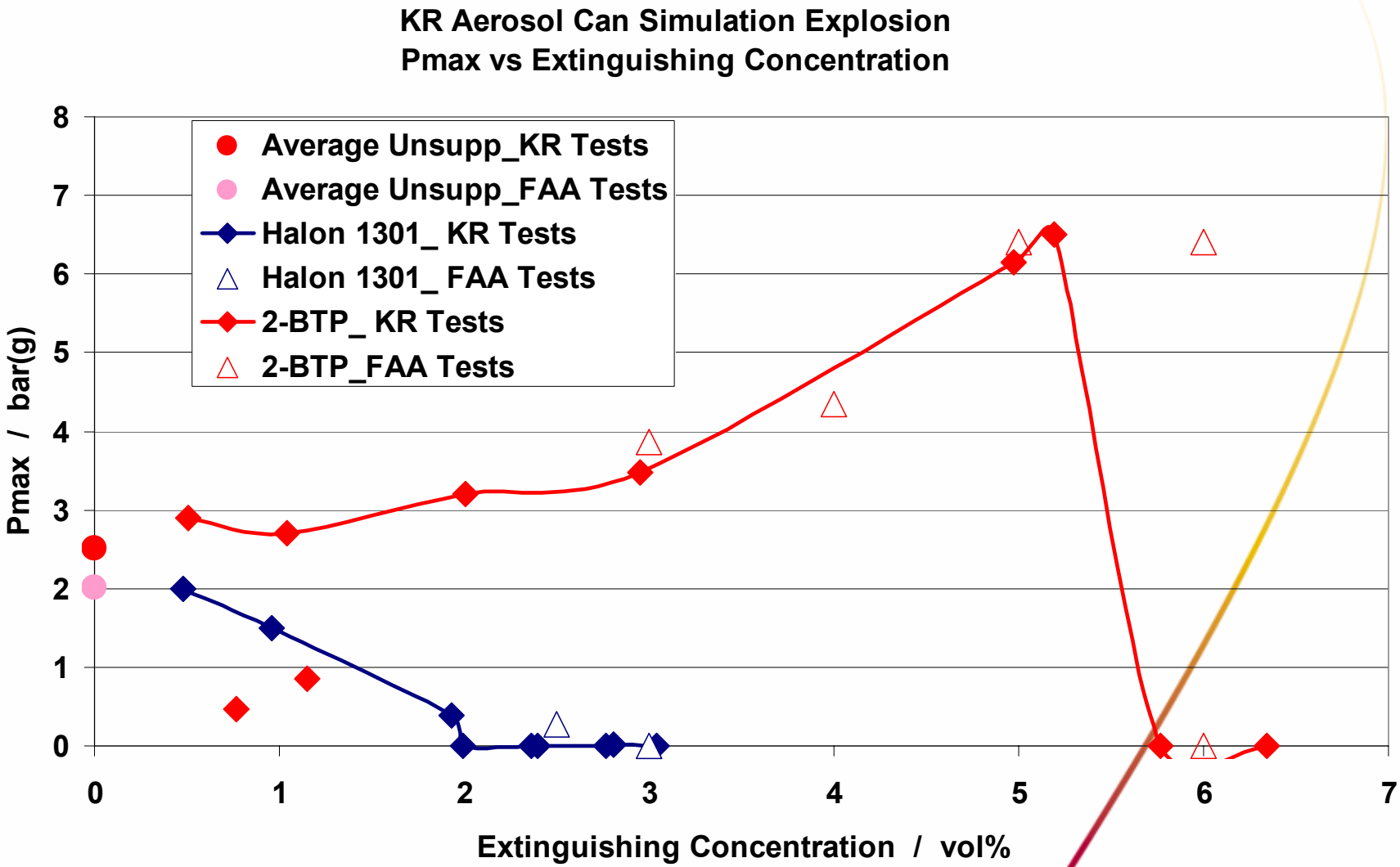


Aerosol can tests

- Testing at FAA, reported by Reinhardt[1]
  - showed that at concentrations below inerting level the combustion severity was enhanced
  - Applies to both 2-BTP and HFC-125
- Apparatus was cloned for KR, further tests carried out
- FAA results confirmed

1. J W Reinhardt, *Behaviour of Bromotrifluoropropene and Pentafluoroethane when Subjected to a Simulated Aerosol Can Explosion*, Federal Aviation Administration, **DOT/FAA/AR-TN04/4**, 2004.

Comparison of FAA results with KR



Engine Nacelle Tests

Kidde Aerospace SSAEFS

FAA Nacelle Simulator

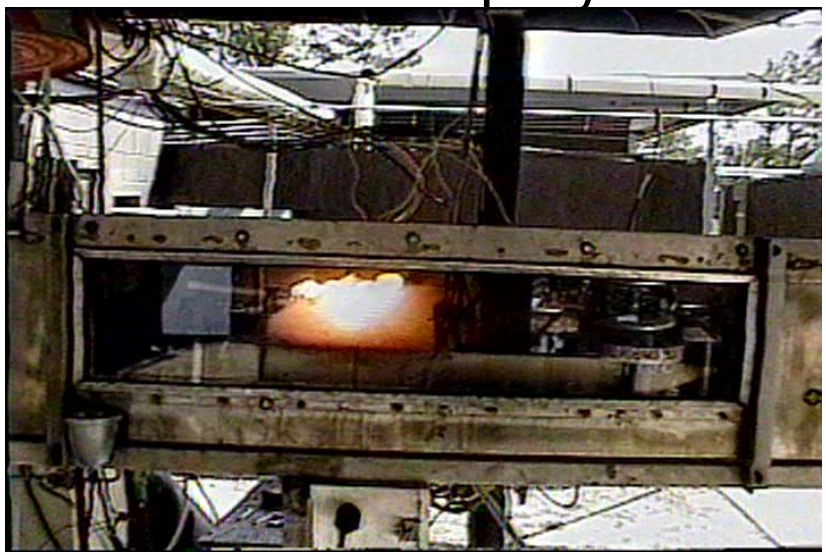
Small Scale Aircraft Engine Simulator (SSAES)

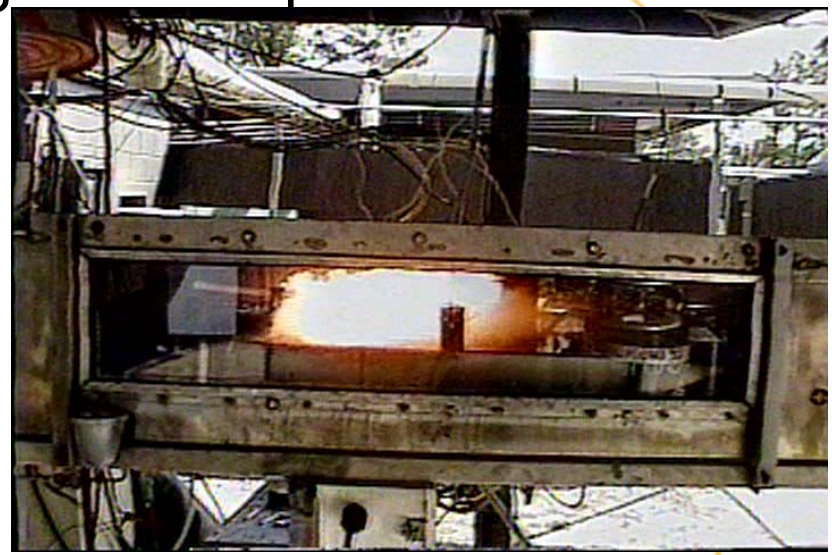
- Development efforts accomplished at KA facility for gaining confidence in agent performance
  - Pool and spray fire testing using JP-8, and Mobil Jet Oil II (spray fire only)
  - Spray fire testing using JP-8 with reduced 2-BTP concentrations
  - Looking for issues similar to aerosol event
  - 4 different airflow levels (1140, 515, 305, and 90 fpm)

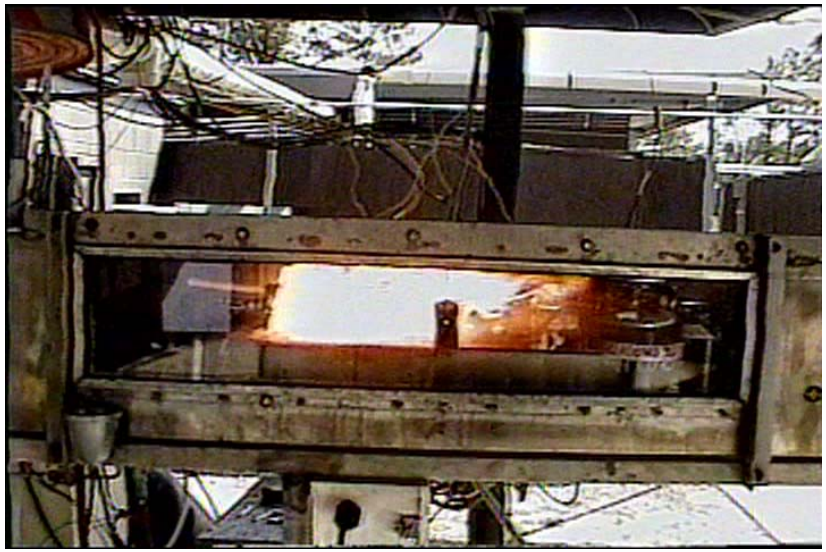
SSAES (con't.)

- Test results provided confidence for moving forward with full scale testing
  - A total of 61 pan and spray fire baseline tests accomplished using Halon 1301
  - A total of 124 pan and spray fire tests using 2-BTP
- Average pan fire Re-ignition Time Delay (RTD):
  - Halon 1301 = 1.825 sec
  - 2-BTP = 2.423 sec
- Average spray fire RTD:
  - Halon 1301 = 2.939 sec
  - 2-BTP = 2.785 sec
  - No unusual behavior observed during any SSAES testing

- SSAES Fuel Spray Fire Re-ignition Sequence







MPSE Testing Accomplished at FAA-TC

- Initial high air flow testing was accomplished with minor event noted in exhaust duct
  - Extensive developmental concentration testing was accomplished to optimize agent distribution
  - High and low air flow spray fire testing using JP-8, Mobil Jet Oil II, or Skydrol and 2-BTP (65 tests total)
  - Equivalence obtained at ~1.5 x Halon 1301 volumetric concentration
- Low air flow testing with JP-8 repeatedly yielded re-ignition events at the atmospheric coupling.
- Testing was discontinued.

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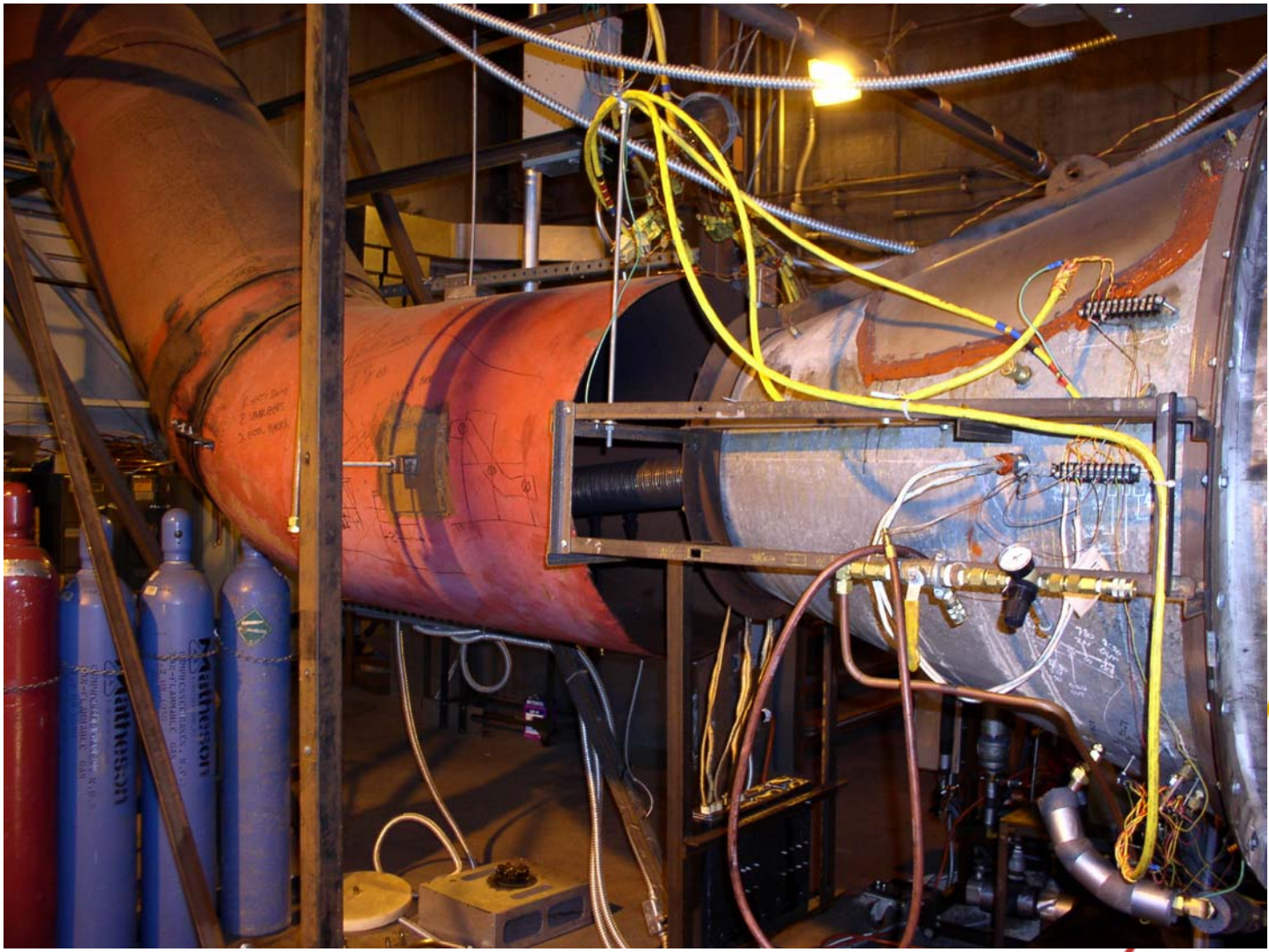
- MPSE Exhaust Duct Atmospheric Coupling



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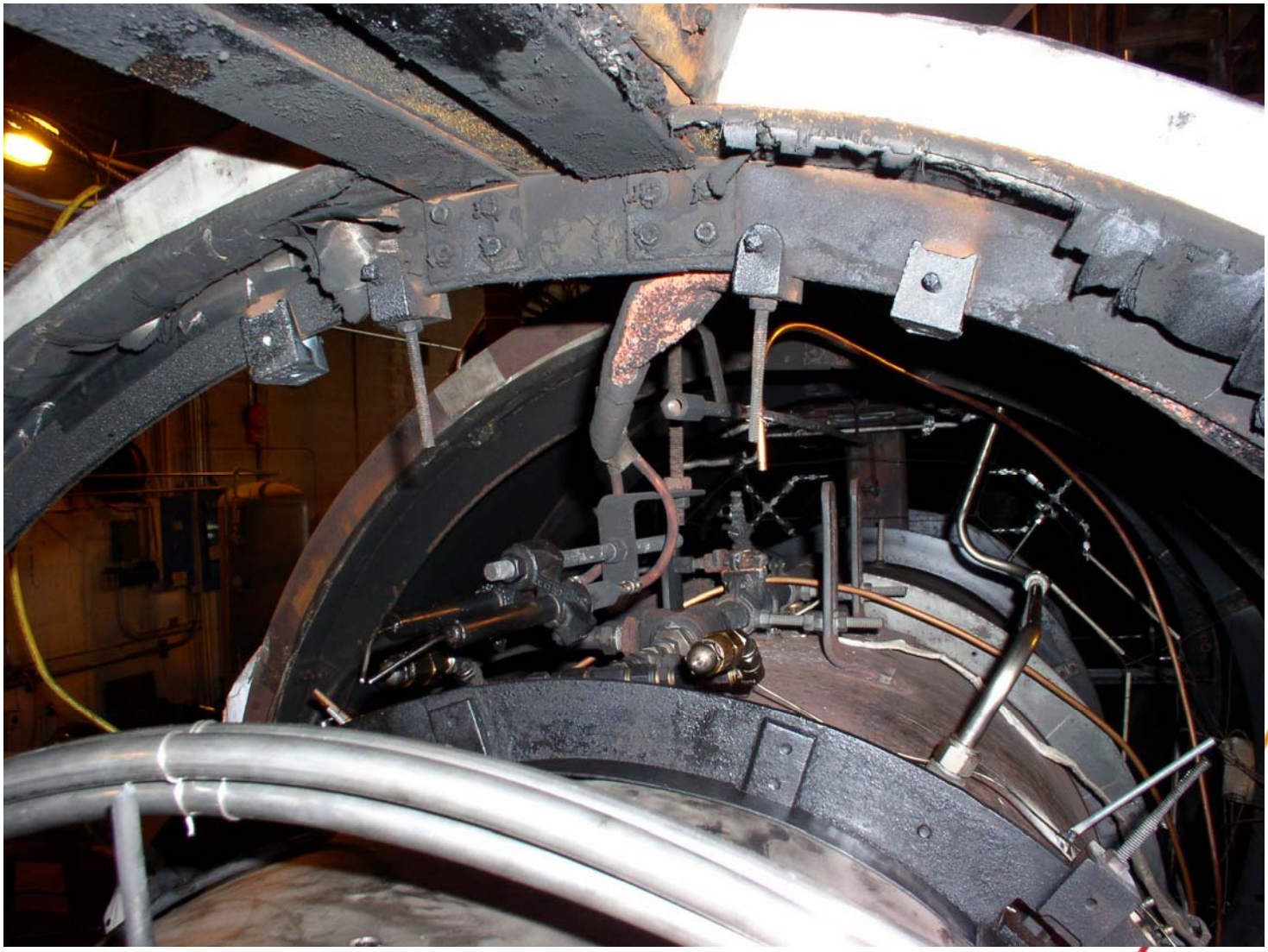
- MPSE Fuel Spray Fire Test Configuration



MPSE Fuel Spray Re-ignition Sequence (Test 04922-012)

Test Conditions: 4.4 lb 2-BTP, 1.0 lb/s airflow, JP-8 Fuel Spray

Discussion

- Everything went well up to and including bulk fire test
- Aerosol can and engine nacelle tests caused excessive agent decomposition, leading to increase in severity of event
- *WHY?*
- Event severity believed to act on one or both of the following:
  - Agent stability
  - Fuel-like character of the agent

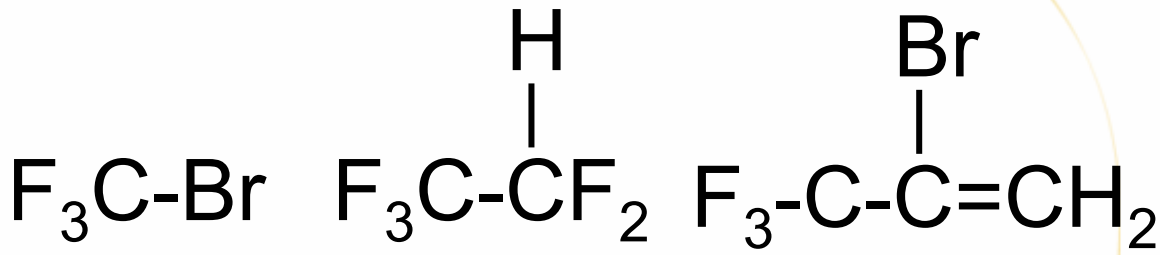
Intrinsic event severity

- The aerosol can explosion has an emissive power density (EPD) of ~ 2.2 MW/m^3
- This is clearly enough to cause partial decomposition of the 2-BTP and HFC-125 at low concentrations, but not Halon 1301
- The same may be true of the reflash phenomenon in the nacelle tests

Intrinsic agent stability

- Halon 1301 is stable to 900°C
- 2-BTP is less stable
  - Evidence of thermal decomposition in injector port of GC/MS (T~250 C)
  - Agent will break down under typical storage conditions
  - Additives were developed to mitigate this issue
  - Consequence of tropodegradable aspect of the molecule
- For each agent there will be a critical temperature x time integral that will cause decomposition
  - For example, we know that when used to suppress violent diesel fuel spray explosions anything less than 14 vol% Halon 1301 results in total agent decomposition

Fuel-like character?



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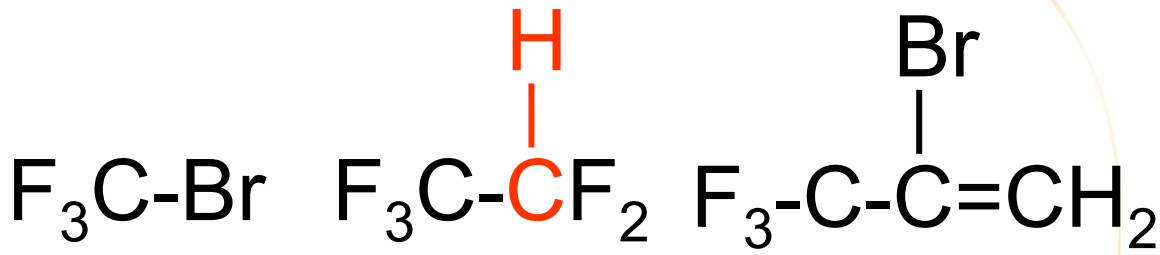
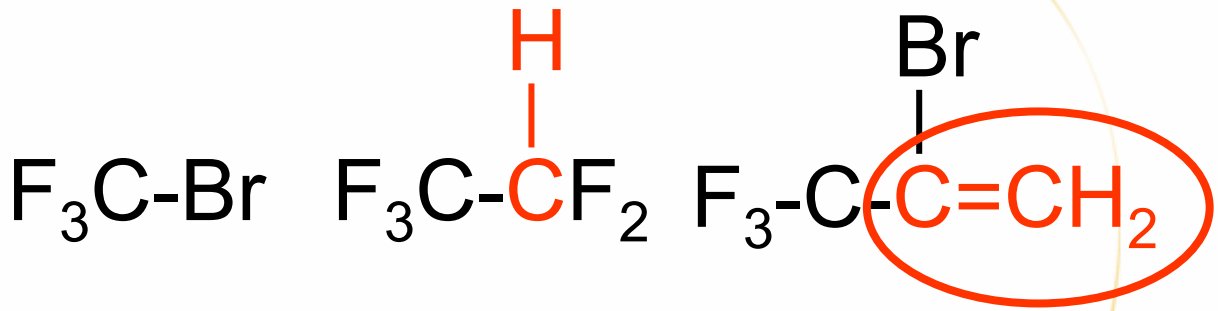
Fuel-like character?



Fuel-like character?



	Halon 1301	HFC-125	2-BTP
"% Suppressant"	100	89	85
"% Fuel"	0	11	15
% Halogen	92	79	78

- The additional fuel-like character of HFC-125 and 2-BTP may be available during lower energy events

Summary

- Cardiotoxicity values of 2-BTP are identical to Halon 1211
- Environmental characteristics (ODP / GWP) are acceptable
- 2-BTP is less stable than Halon 1301
- Under fuel-lean conditions (aerosol can and nacelle) low agent concentrations can be viewed as contributing fuel, and if the ignition event is severe enough, the combustion event is enhanced

Summary (cont.)

- 2-BTP still a viable hand extinguisher agent
  - Opportunities for industrial applications
  - Initial testing shows it is good at extinguishing wood cribs etc.
  - Commercialisation issues
- Kidde now has apparatus for evaluating agents for aviation applications
  - SSAES
  - Bulk load test facility
  - Aerosol can test facility

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