Aalto-yliopisto
Insinööritieteiden
korkeakoulu

Effectiveness of Sprinklers in the Fire Protection of Hospital Rooms

Rescue Services Research Days 5.6.2019
Simo Hostikka, Aalto-yliopisto

Project partners and sponsor

- Teknologian tutkimuskeskus VTT Oy
- Aalto-yliopisto
- Suomen palopäällystöliitto ry
- Sysmän kunta

- Eurofins Expert Services Oy
- Päijät-Hämeen Pelastuslaitos
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Background & motivation

- **Sprinklers are expected to limit the fire, not to extinguish it.**
- **Smouldering fire will continue to produce toxic gases.**
- **What if a person cannot escape, but must wait for help?**
  - Relevant question for health care environment.
  - Expected fire service response time ~ 15 min
- **Previous experiments on the patient tenability assessment at post-sprinkler activation were done at 70's.**
  - CO threshold exceeded in sprinklered patient room fire.

O'Neill, J. G., Hayes, W. D., & Zile, R. H. (1980). Full-scale Fire Tests with Automatic Sprinklers in a Patient Room: Phase II. US Department of Commerce, National Bureau of Standards.

Scope

The effectiveness of the sprinklers in protection of a person in a patient room was investigated experimentally by

1) **Carrying out 30 experiments in 16 rooms and measuring the concentrations of toxic gases,**
2) **Assessing tenability (incapacitation) by Fractional Effective Dose (FED) and Fractional Irritant Concentration (FIC), and**
3) **Estimating the probability of survival.**


PH423
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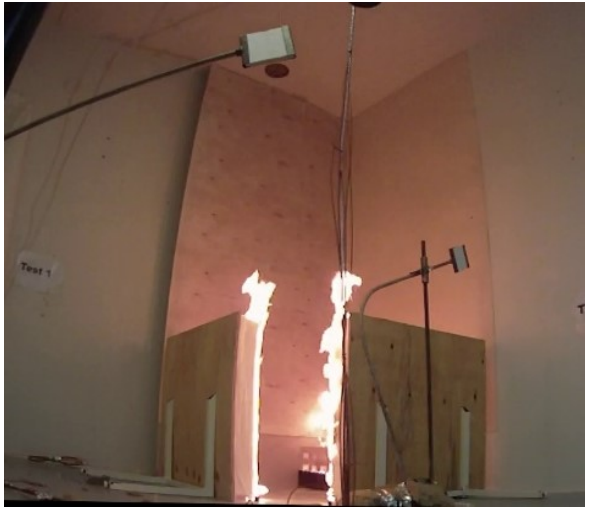
Test site

All rooms equipped with SFS 5980 –class water based suppression system (fast response, K=60.5 L/min/bar$^{1/2}$, T_{act}=68°C, RTI = 35 (ms)$^{1/2}$)

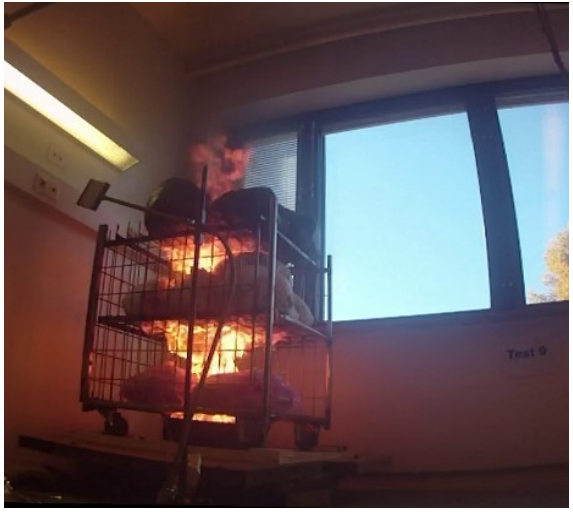
Methods – Fire loads

Duration = 15 min



UL1626
14 Sprinklered
+ 2 Free

150 kW textile
6 Sprinklered
+ 1 Free



1500 kW textile
6 Sprinklered
+ 1 Free

Methods - Measurements

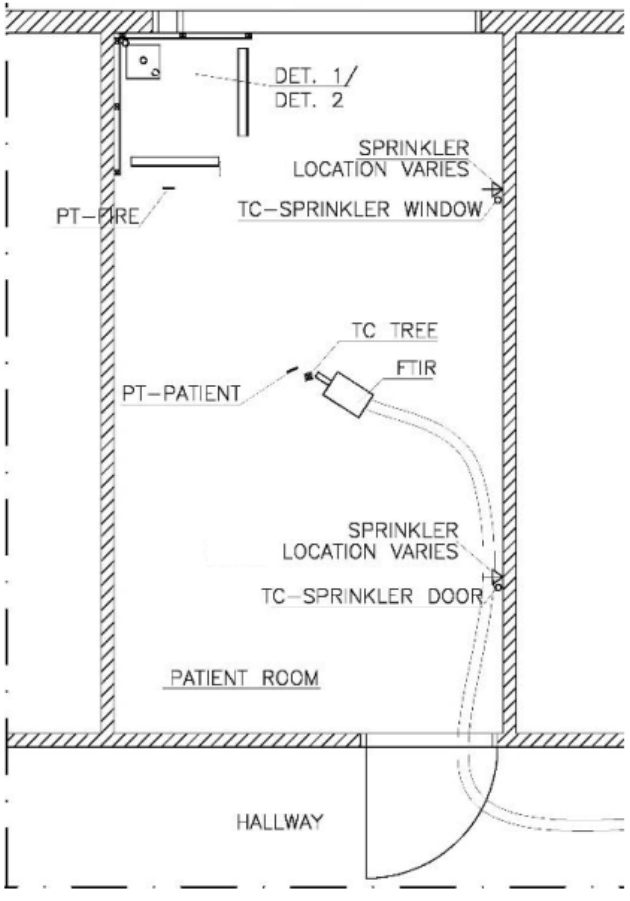
Thermocouple temperatures

Plate thermometers

Gas concentrations

- **FTIR spectrometry**
- **> 20 gas species**

Sprinkler water pressure



Fractional Effective Dose (FED)

Compares the cumulative dose of different inhaled gases to observed thresholds of incapacitation.

$$FED_{in}(t) = \int_0^t \left[\left(F_{I,CO} + F_{I,CN} + F_{I,NOx} + FLD \right) V_{CO2} + F_{O2} \right] dt \qquad FLD(t) = \sum_{i=1}^{N} \frac{X_i(t)}{FLD_i}$$

Gas	Lethal Doses FLD_i (ppm×min)
HCl	114 000
HBr	114 000
HF	87 000
SO_2	12 000
NO_2	1900
C_3H_4O (Acrolein)	4 500
CHOH (Formaldehyde)	22 500

Purser, D.A., & McAllister, J.L. (2016) Assessment of hazards to occupants from smoke, toxic gases, and heat. In: SFPE handbook of fire protection engineering, fifth edition. Springer, New York, NY, p. 2308-2428.

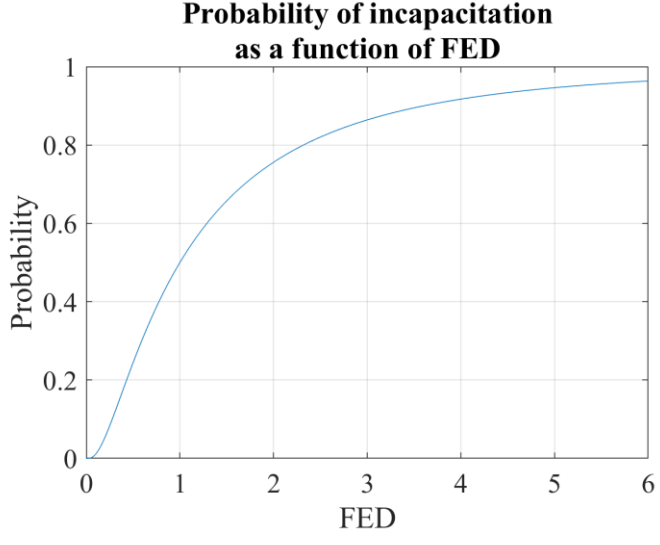
What does FED mean?

Incapacitating = to make someone unable to work or do things normally (Purser, 2016)

Common ”safe limit”
FED = 0.3

Conservative ”safe limit”
FED = 0.1

FED	Estimated portion of incapacitated population
0.0 – 0.3	0 – 11 %
0.3 – 1.0	11 – 50 %
1.0 – 3.0	50 – 89 %



Fractional Irritant Concentration (FIC)

Ratio of present and incapacitating concentrations of irritant gases. Assumes additive nature:

$$FIC(t) = \sum_{i=1}^{N} \frac{X_i}{FIC_i}$$

Gas	Lethal Doses FLD_i (ppm×min)	Incapacitating Concentration FIC_i Purser (ppm)	Incapacitating Concentration FIC_i ISO 13571 (ppm)
HCl	114 000	900	1 000
HBr	114 000	900	1 000
HF	87 000	900	500
SO_2	12 000	120	150
NO_2	1900	350	250
C_3H_4O (Acrolein)	4 500	20	30
CHOH (Formaldehyde)	22 500	30	250

What does FIC mean?

David Purser: ***FIC > 1 reduces significantly the escape efficiency of exposed people. FIC > 5 causes incapacitation for 50 % of the population.***

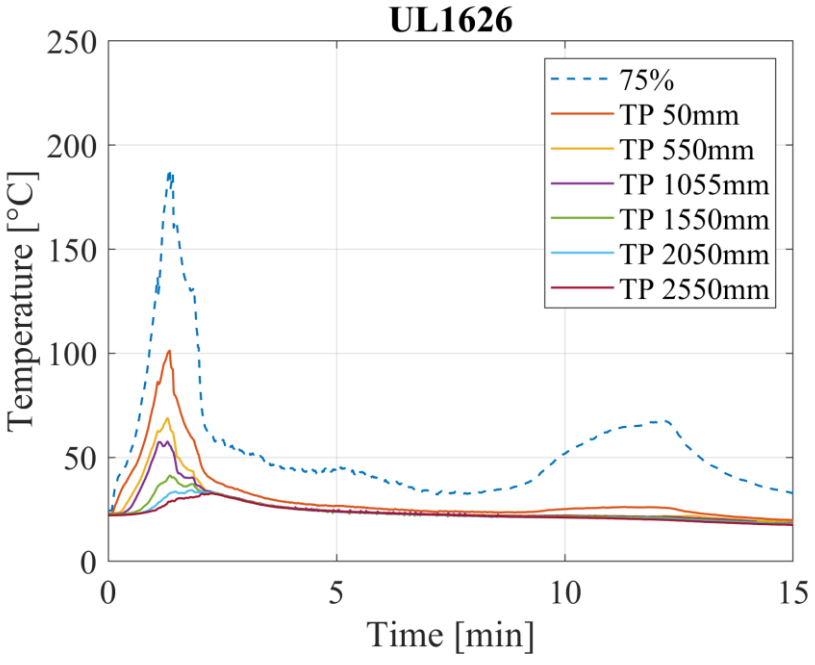
ISO 13571: ***FIC > 1 causes incapacation for 50 % of the population.***

Results – UL1626

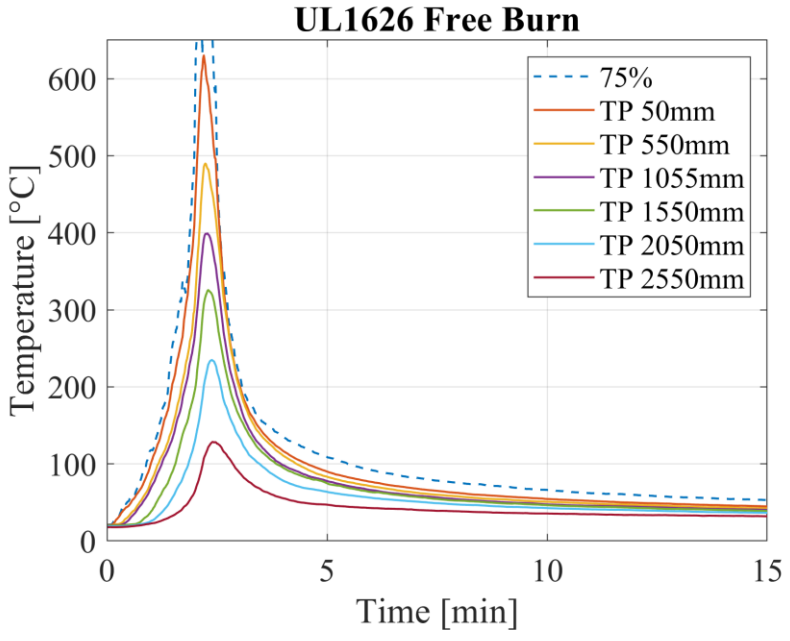
UL1626

UL1626 Freeburn

Results - Temperature



UL1626



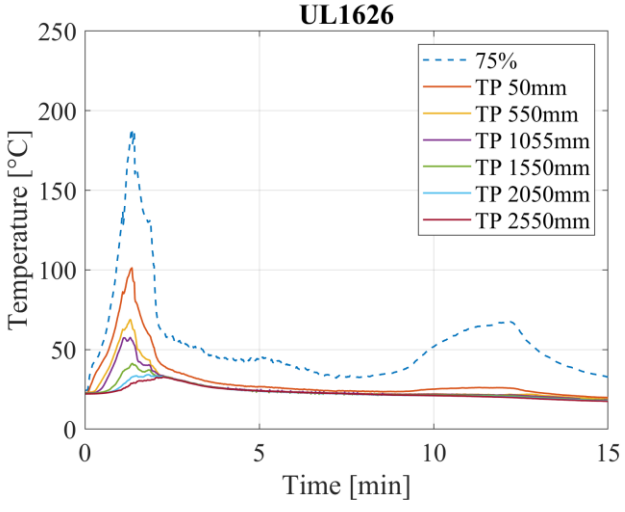
UL1626 Freeburn

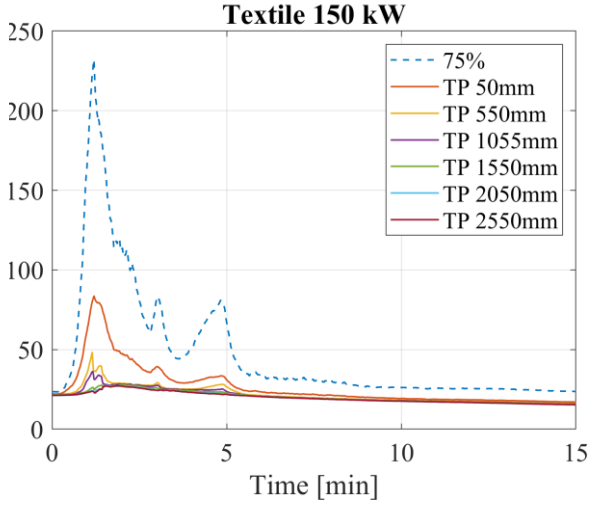
Results – 1500 kW Textile

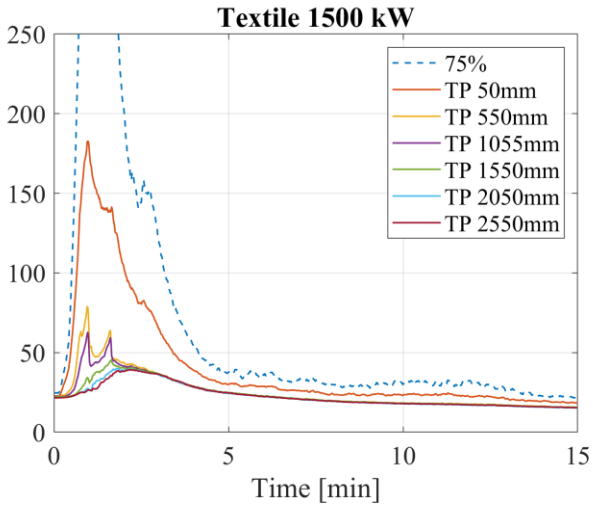
TEX 1500

TEX 1500 Free

Results - Temperatures



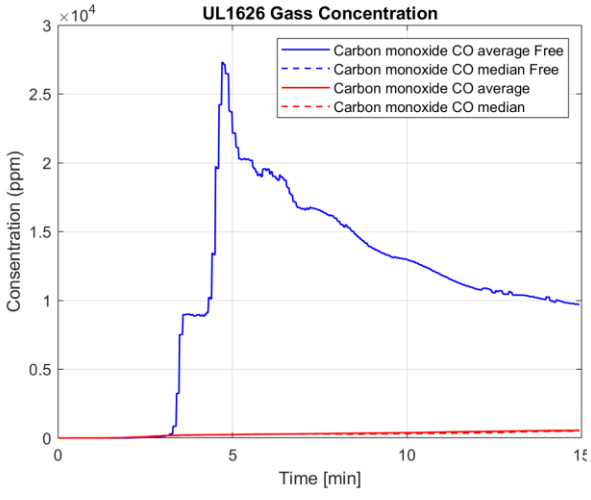


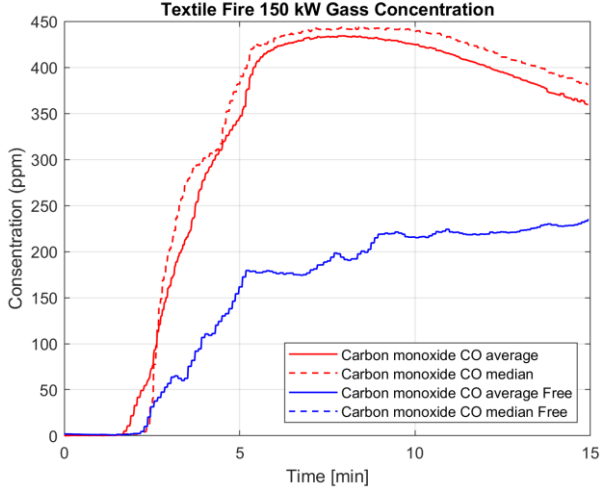


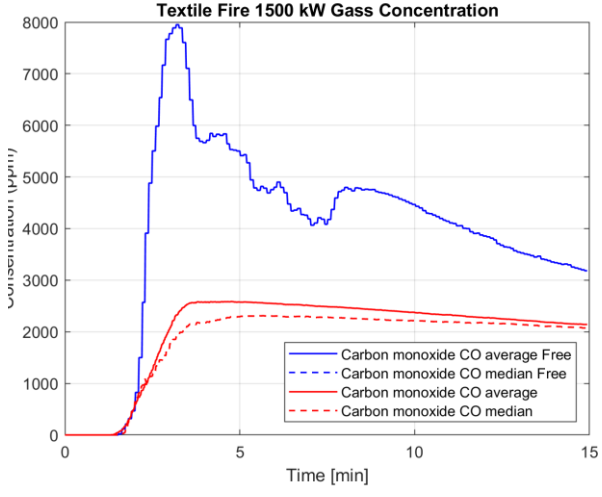
UL1626 **150 kW TEX** **1500 kW TEX**

Average CO

Blue = freeburn, Red = sprinkler

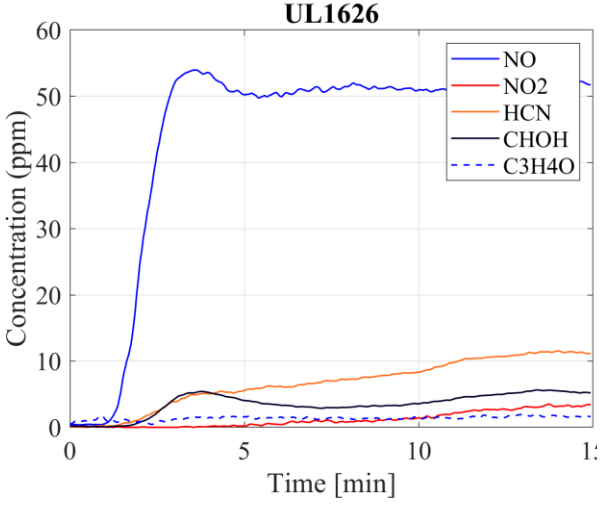


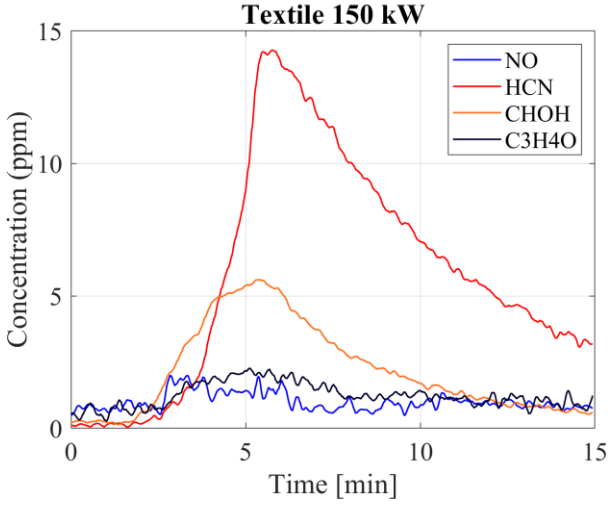


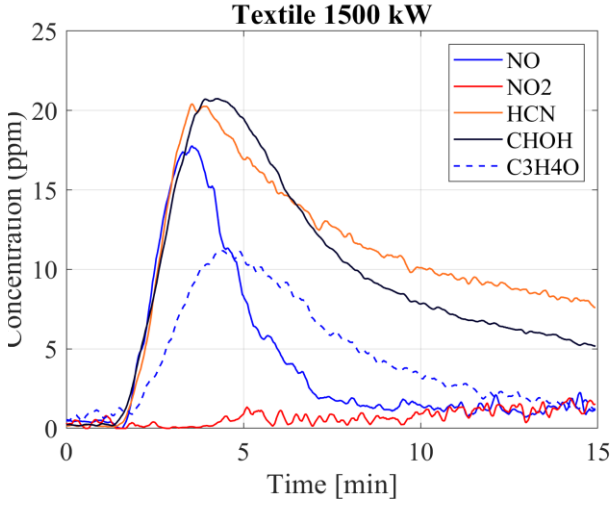


UL1626 **150 kW TEX** **1500 kW TEX**

Other gases than CO



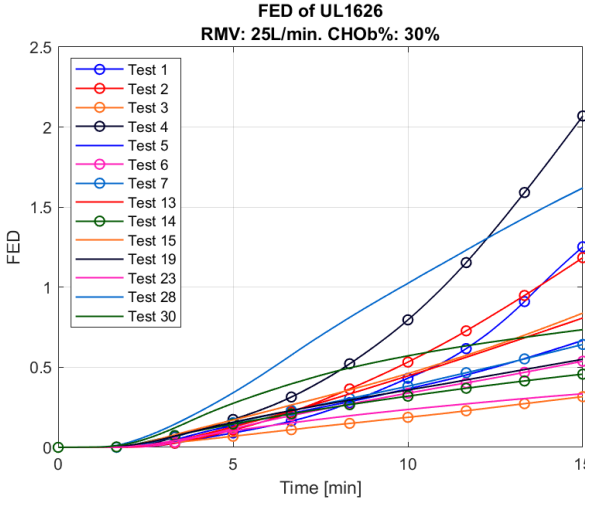


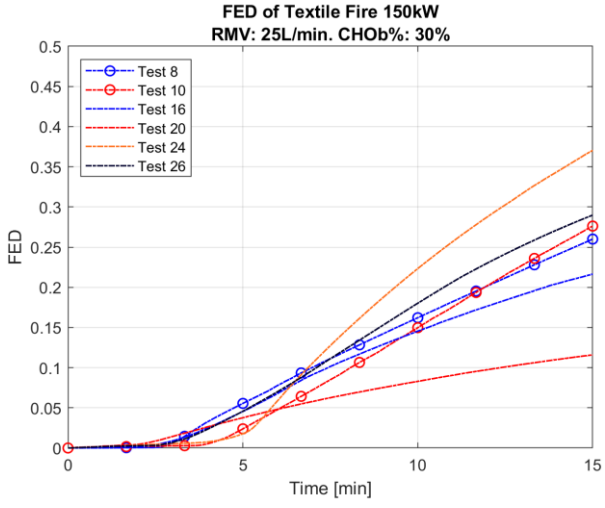


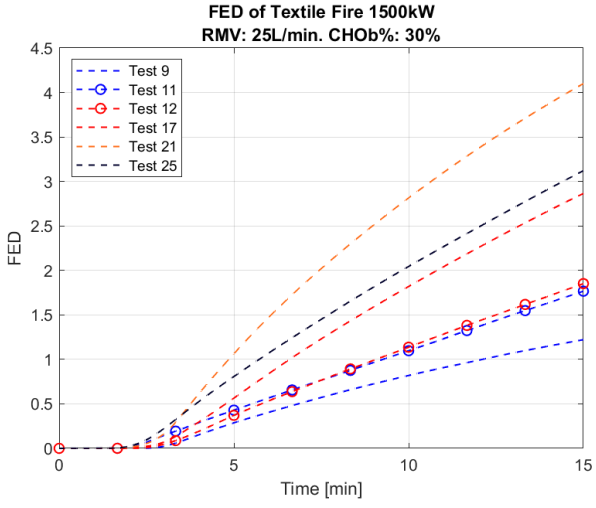
UL1626 **150 kW TEX** **1500 kW TEX**

FED Results

Light Work



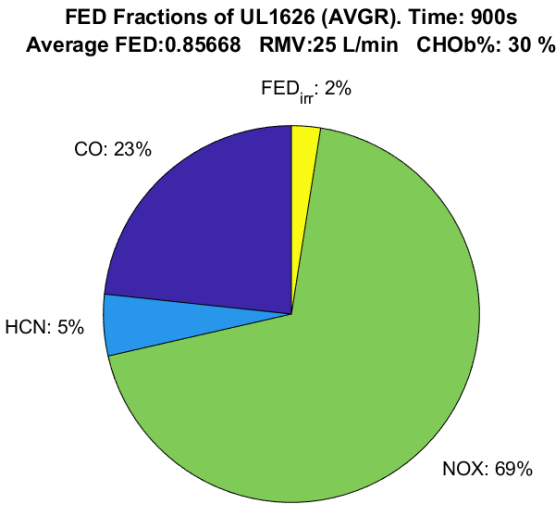




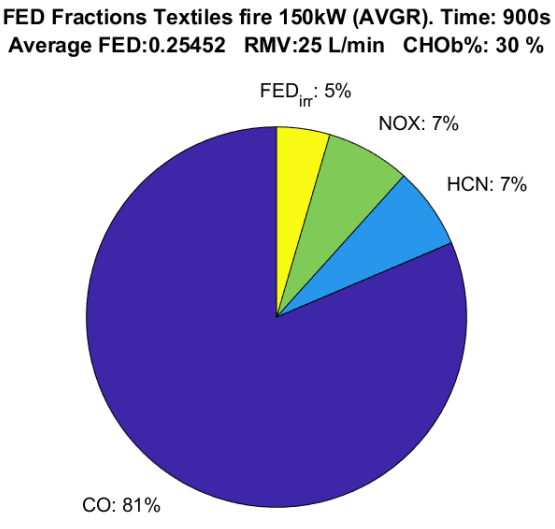
UL1626 **150 kW TEX** **1500 kW TEX**

FED Contributing gases

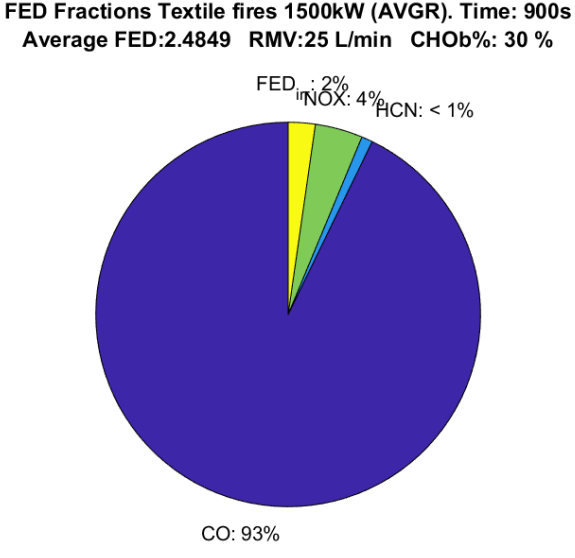
Light Work



UL1626



150 kW TEX

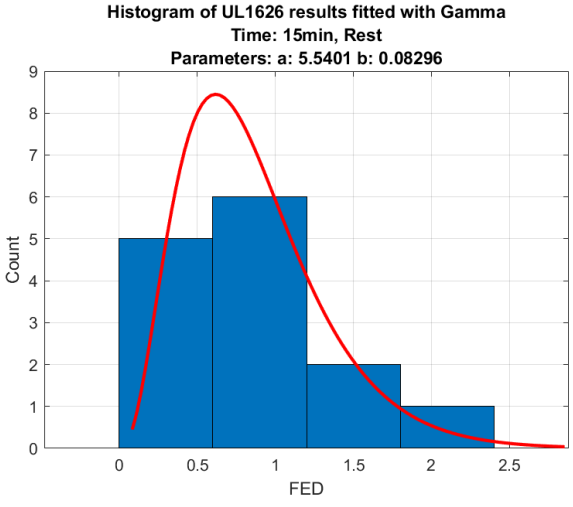


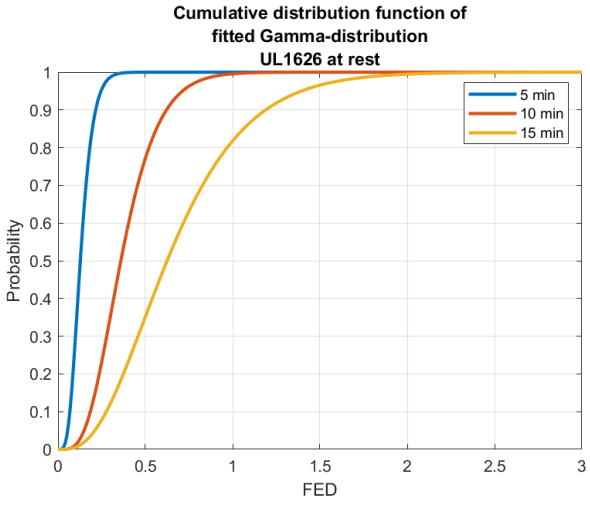
1500 kW TEX

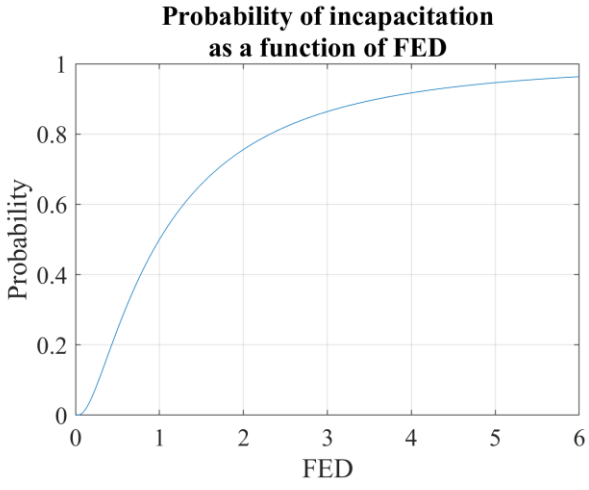
FED Results

Test / FED(avrg)	Rest @ 15 min	Light Work @ 15 min	Highest contribution
UL1626 Sprink	0.69	0.86	NOx
UL1626 Freeburn	275	275	HCN
150 kW Textile Sprink	0.1	0.25	CO
150 kW Textile Freeburn	0.14	0.22	NOx
1500 kW Textile Sprink	0.77	2.5	CO
1500 kW Textile Freeburn	5.16	13	CO

Probability of survival



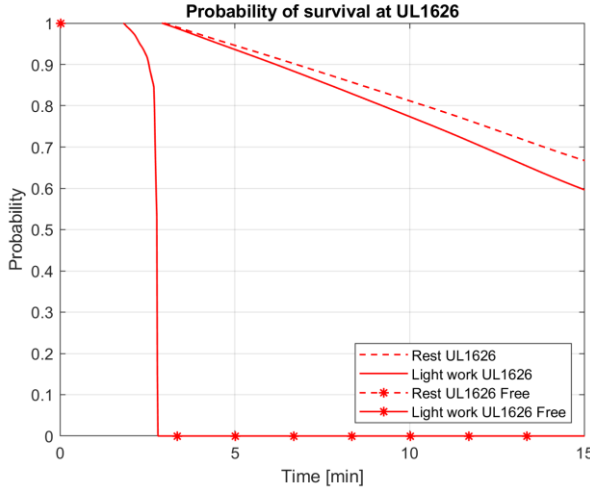


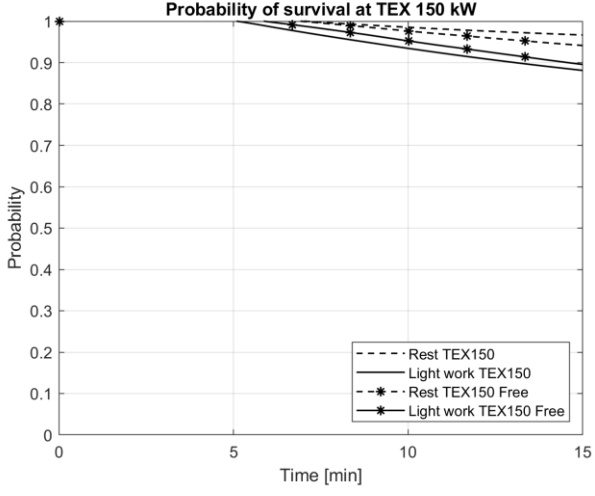


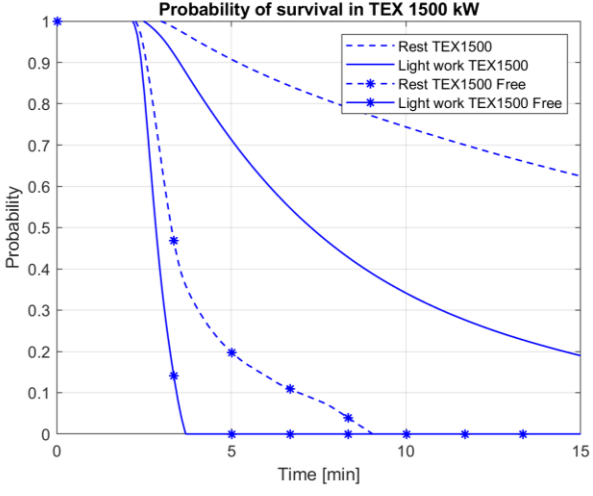
$$P_{in}(t) = \int_0^{\infty} \left[P_{FED}(x,t) \times P_{FED,I}(x) \right] dx$$

Probability of survival

$$P_{in}(t) = \int_0^{\infty} \left[P_{FED}(x,t) \times P_{FED,I}(x) \right] dx$$

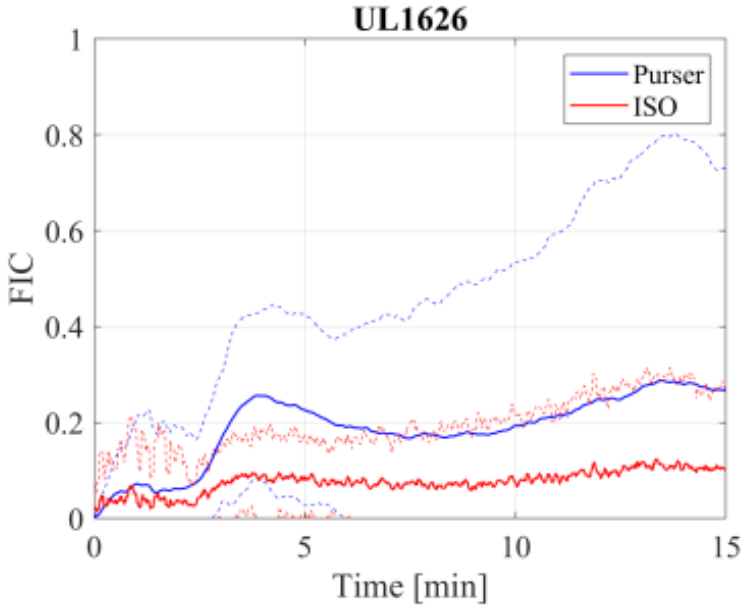


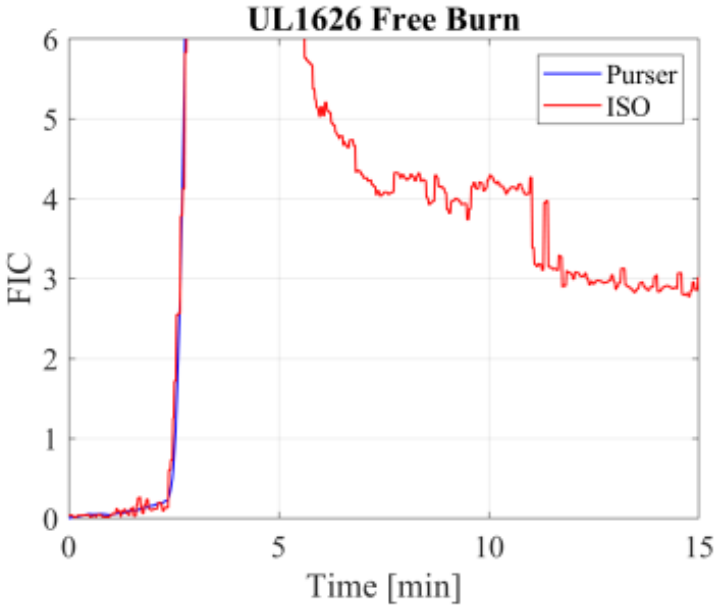




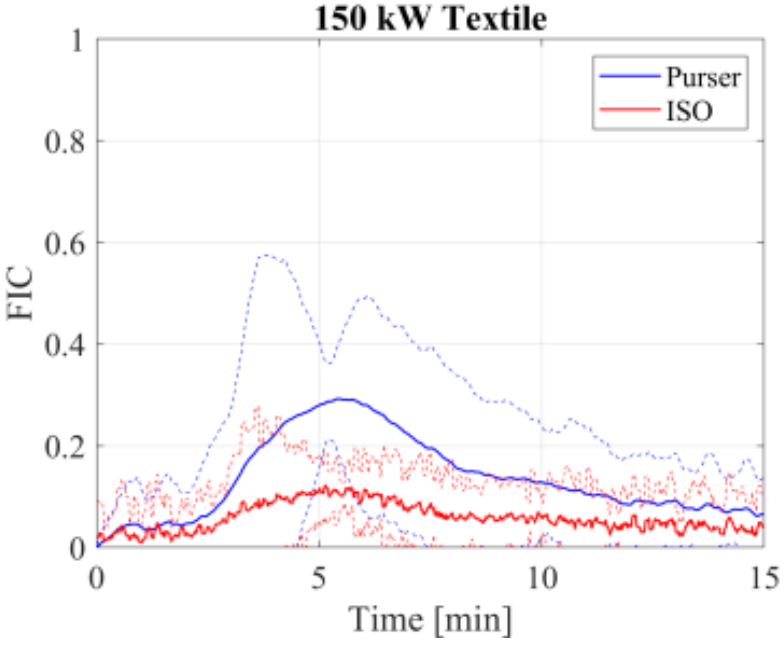
UL1626 **150 kW TEX** **1500 kW TEX**

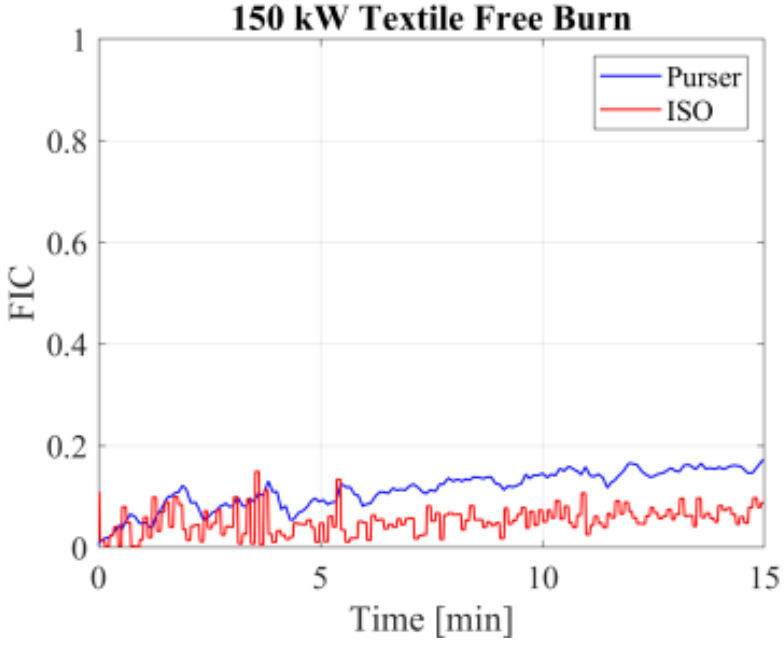
FIC – UL1626


UL1626
Purser
ISO
FIC
Time [min]
0
0.2
0.4
0.6
0.8
1
0
5
10
15

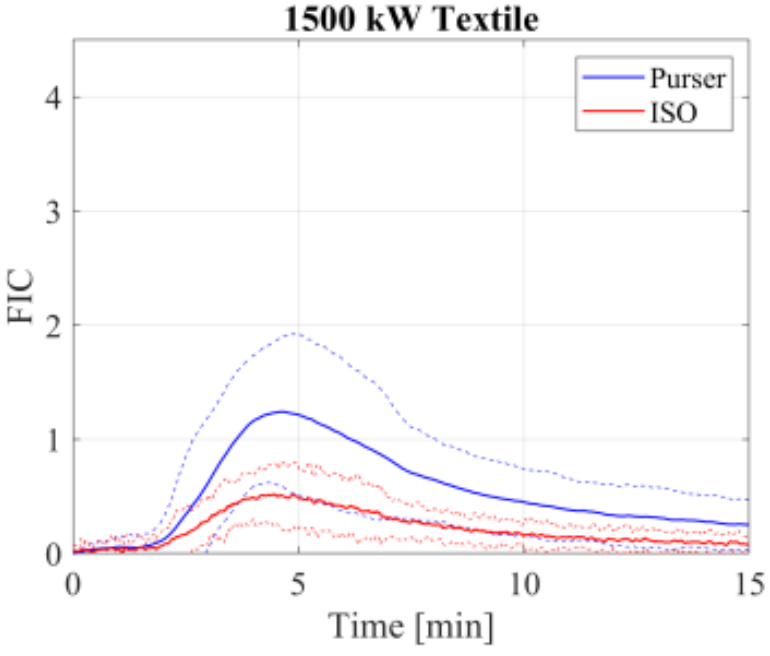

UL1626 Free Burn
Purser
ISO
FIC
Time [min]
0
1
2
3
4
5
6
0
5
10
15

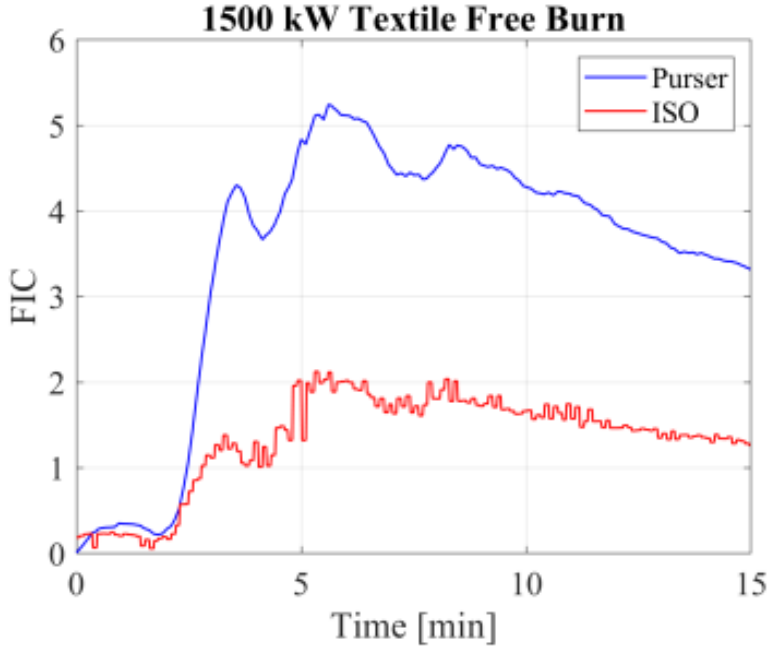
FIC – 150 kW TEX





FIC – 1500 kW TEX





Conclusion

1. **Sprinklers prevented fire growth. Extinction in < 25% of fires.**
2. **In strong fires, sprinklers reduced the asphyxiant (and irritant) effects significantly, increasing escape time by minutes, but did not remove the risk of incapacitation.**
   - E.g. in bigger textile fires, 50-80 % of population would have been incapacitated even with sprinklers.
3. **In small fires, sprinkler could not improve the survival probability.**
4. **The assumption that CO and HCN are the only important incapacitating gases should be abandoned.**


H10
Test 27
Test 2