NIST Workshop on Fire Growth and Spread on Objects

Predicting Fire Growth Involving Interior Finish Materials Including the Effects of Lateral Flame Spread and Layer Heating

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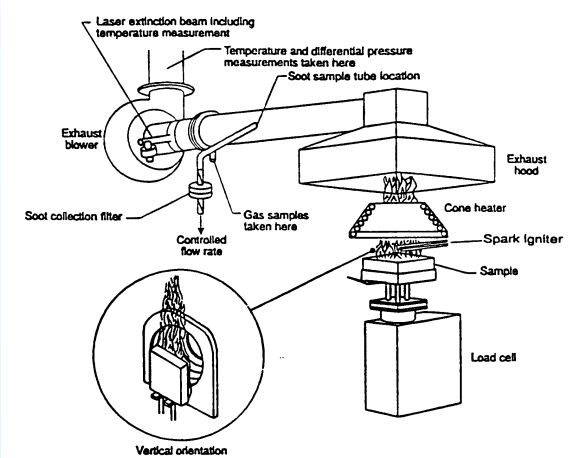
Topics

- Background
- Fire Growth Model Structure
- Flame Spread in Corner Configuration
- ISO 9705 Simulations
- Open Corner Simulations
  - effects of lateral spread
  - effects of layer heating

Background

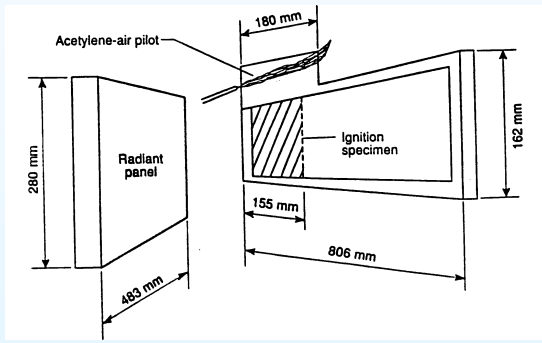
- U.S. Coast Guard and U.S. Navy regulate interior finish materials using ISO 9705 room/corner fire test
- Aid material designers in analyzing fire performance
  - screening material performance in ISO 9705
    - predict regulated values
      - heat release rate
      - smoke production
  - fire hazard analysis for specific geometries
    - conditions in room of origin
    - conditions in spaces outside room of origin

Fire Growth Model Structure



ASTM E1354 Cone Calorimeter

FIRE GROWTH MODEL



ASTM E1321 LIFT

Heat Release Rate

Flame Spread Model (object in CFAST)

CFAST 3.1.2

Gas Temperature

Flame Spread Model

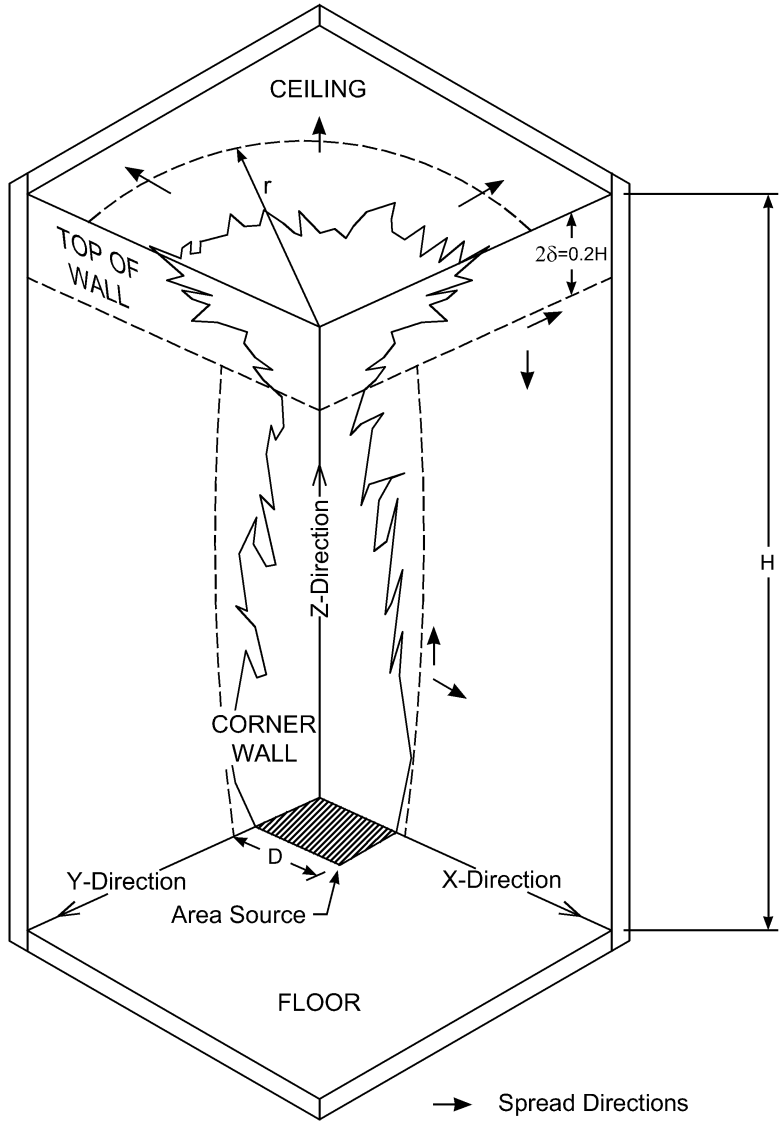
- Uniform size square cells
- Cells in one of three stages
  - pre-heat to ignition
  - burning
  - burnout
- Pre-heat to ignition
  - semi-infinite solid with cubic temperature profile
  - time varying heat flux boundary condition
    - heat flux from fire based on empirical correlations
  - ignition when cell reaches ignition temperature

Flame Spread Model

- Burning
  - time varying heat release rate
    - heat release rate curve for lining material
    - net heat flux into cell
- Burnout
  - total available energy released
- Configurations
  - flat wall
  - corner with and without a ceiling
  - parallel walls

Flame Spread in Corner Configuration

- Corner divided into three regions
  - corner walls
    - wind-aided and opposed flow flame spread
  - top of walls
    - wind-aided and opposed flow flame spread
  - ceiling
    - wind-aided flame spread
- Heat flux correlation required for each spread direction
- Hot gas layer heating included

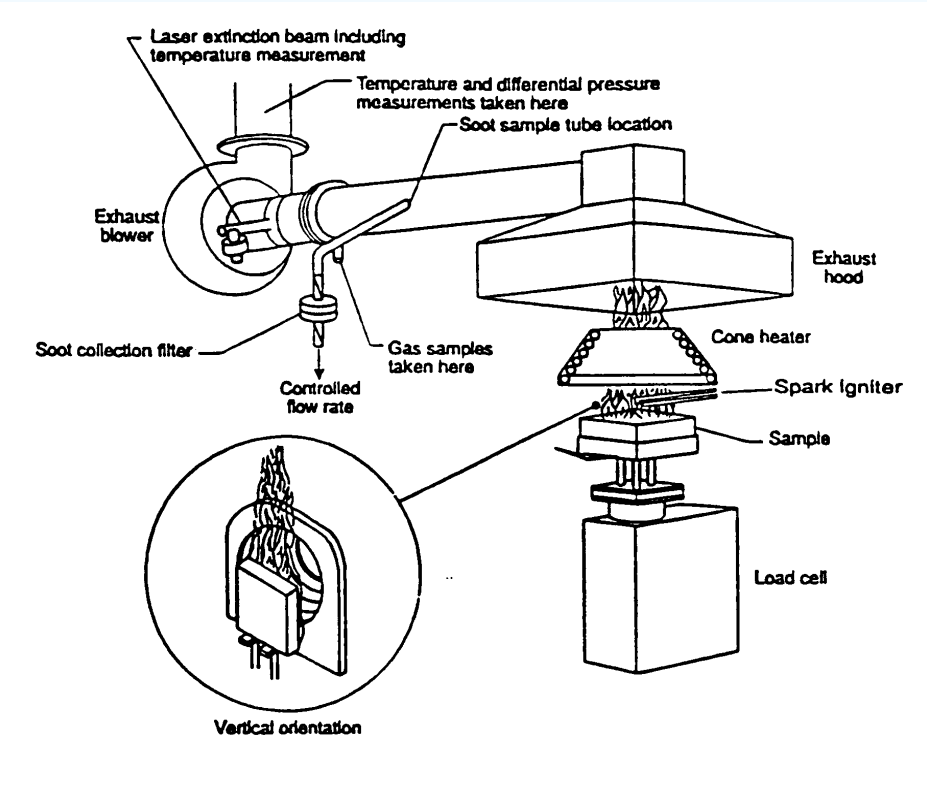


Flame Spread in Corner Configuration

- Flame length and heat flux correlations
  - non-combustible corner fire tests
    - square propane burners
      - 0.17, 0.30, 0.50 m single side
      - 50-300 kW fires
    - L-shaped line burners
      - 0.17, 0.30, 0.50 m single side
      - 25-300 kW fires
- Flame length
  - function of heat release rate and burning width in corner

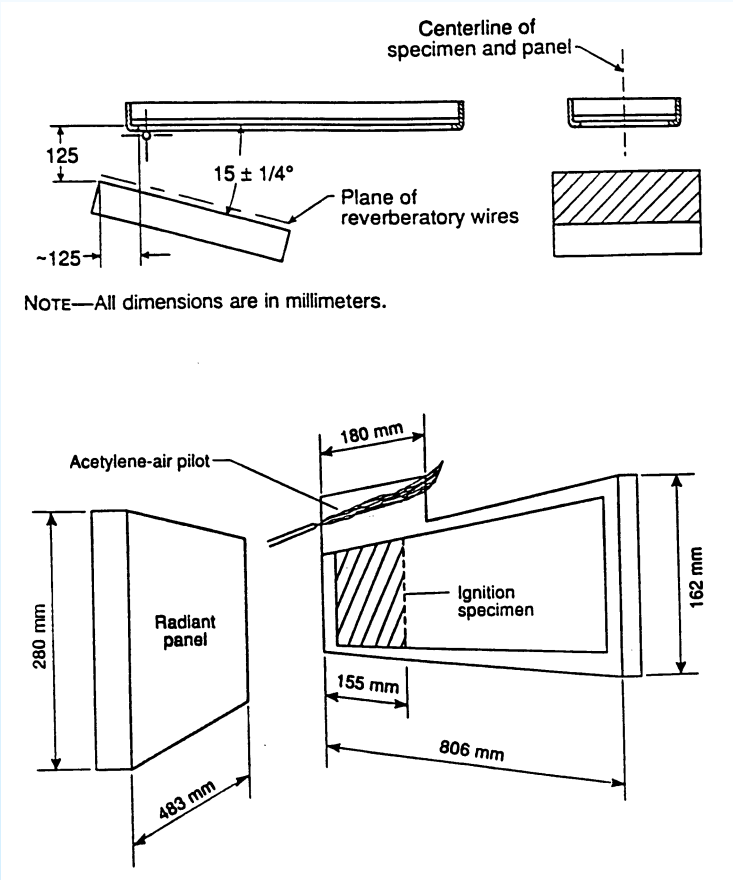
$$L_{f,tip} = 5.9 Q_d^{*1/2} d$$

Combustible Lining Input Data - ASTM E1354 Cone Calorimeter



- Critical heat flux
  - ignition temperature
- Data at different irradiance levels (25, 50, 75 kW/m^2)
  - time to ignition
  - heat release rate curve
  - total heat released
  - smoke and toxic gas production
- Use of data in model
  - $k\rho C$ for piloted ignition
    - ignition temperature
    - time to ignition
  - heat release rate of cell
  - smoke production of cell

Combustible Lining Input Data - ASTM E1321 LIFT



- Lateral flame spread properties
  - flame heating parameter, Φ
  - $k\rho C$ for lateral spread
- Use of data in model
  - lateral flame spread

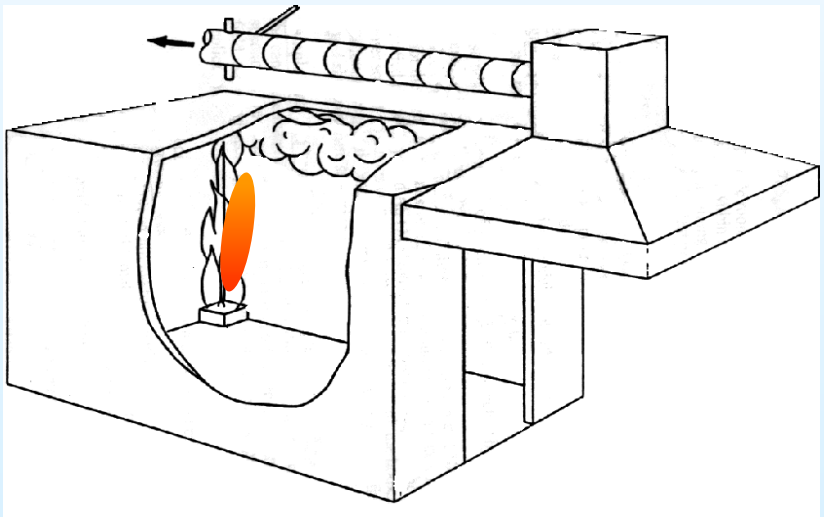
Fire Growth Model - Sensitivity Analysis

- Time step
  - up to 2 seconds without affecting results
- Cell size
  - dependent on geometry
  - ISO 9705 room simulations
    - up to 0.20 m without affecting results
  - open corner
    - up to 0.025 m without affecting results
- Time to Ignition
  - expected error in data can affect results

Fire Growth Model - Sensitivity Analysis

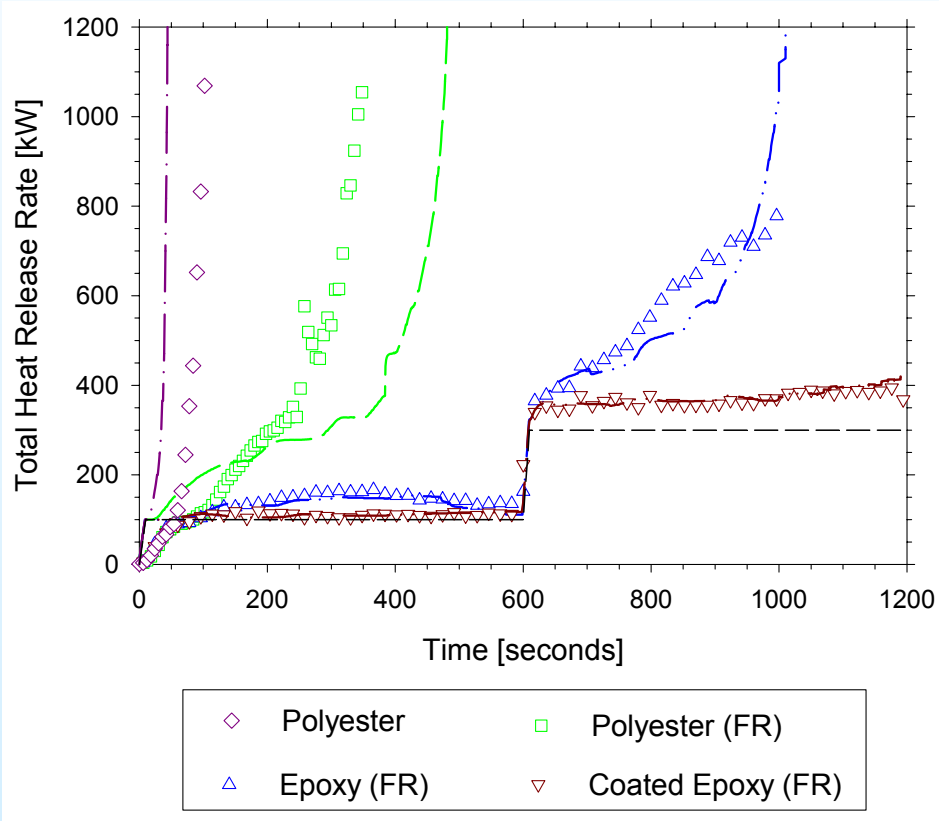
- Critical heat flux (ignition temperature)
  - change within ± 3 kW/m^2 without affecting results
  - due to how $k\rho C$ for piloted ignition is determined
- Smoke data
  - C-to-CO_2 ratio affects gas temperature
    - order of magnitude increase resulted in 75 K temperature drop
- Not sensitivity to CO-CO_2 and hydrogen-to-carbon ratio
- Radiative fraction affects gas temperature

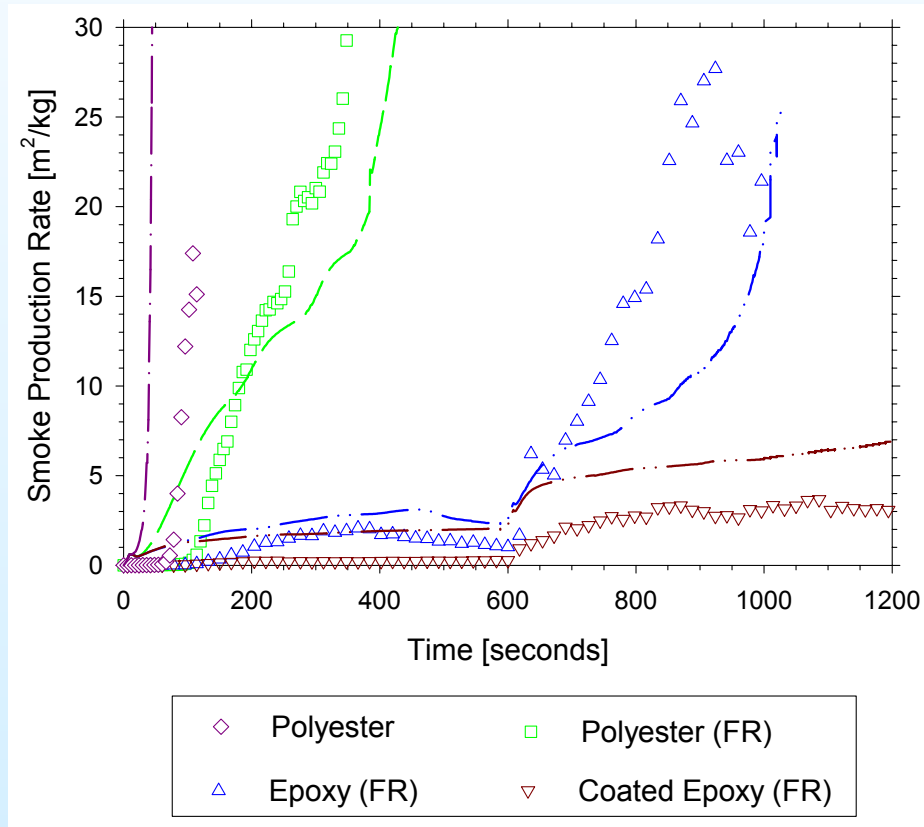
ISO 9705 Room/Corner Test



- Large-scale test to evaluate contribution of wall lining to fire growth
- Initiating fire
  - in back corner
  - 0.17 m square propane burner
  - 100 kW for 600 seconds then 300 kW for 600 seconds
- Two side walls, back wall and ceiling lined with combustible material
- Data
  - overall heat release rate
  - smoke production rate

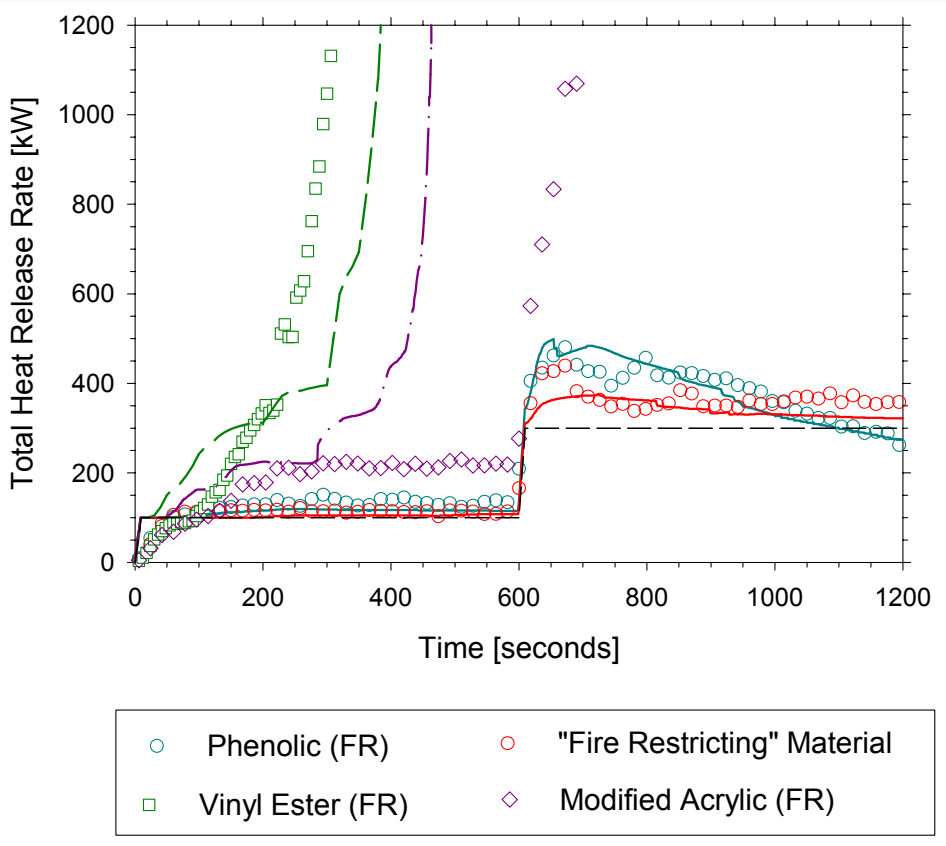
ISO 9705 Simulations Results

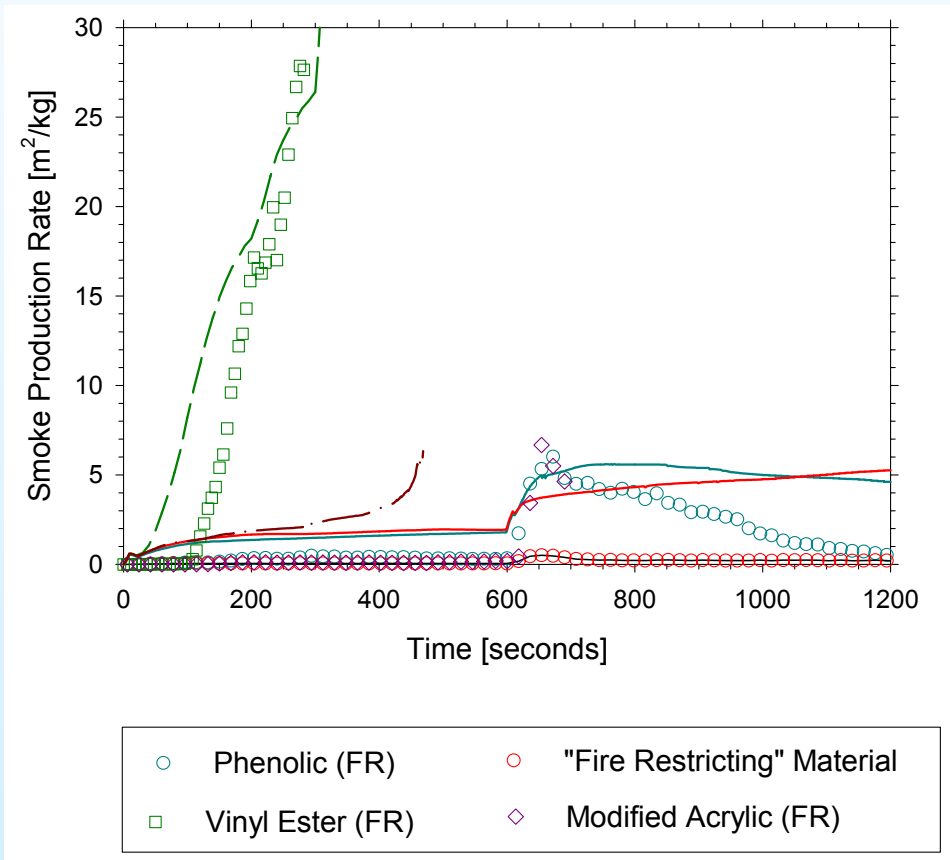




Time Step = 2.0 s
Cell Size = 0.10 m

ISO 9705 Simulations Results





Time Step = 2.0 s
Cell Size = 0.10 m

ISO 9705 Simulation Results

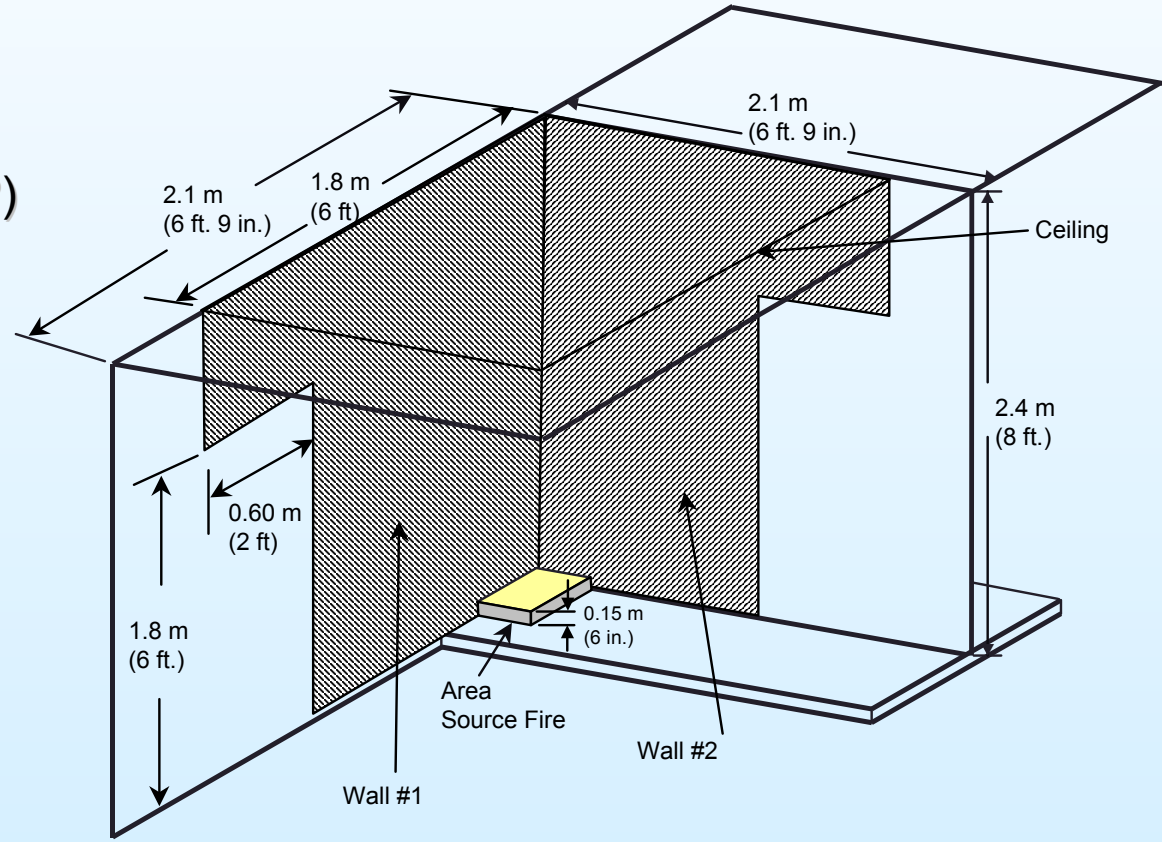
Material No.	Time to Flashover [s][1]		Heat Release Rate [kW]				Smoke Production Rate [m^2/kg]			
			Test Average		Max 30 s Avg.		Test Average		Max 60 s Avg.	
	Test[2]	Model	Test[2]	Model	Test[2]	Model	Test[2]	Model	Test[2]	Model
1	NR	NR	62	61	159	179	1.5	3.2	5.4	5.6
2	NR	NR	31	23	112	73	0.2	3.0	0.5	5.2
3	342	475	203	217	677	697	9.4	14.1	21.7	35.1
4	300	377	224	255	798	726	10.2	19.2	26.3	44.8
5	1002	1008	125	118	454	686	6.7	5.0	26.4	15.7
6	NR	NR	31	42	82	115	1.4	3.6	3.5	6.7
7	102	44	170	152	402	188	2.3	1.3	2.7	1.3
8	682	460	127	169	657	590	0.5	2.1	4.8	3.8
IMO			≤ 100		≤ 500		≤ 1.4		≤ 8.3	

1. Taken to be time at which heat release rate reached 1000 kW
2. Data from Janssens *et al.* (1998)

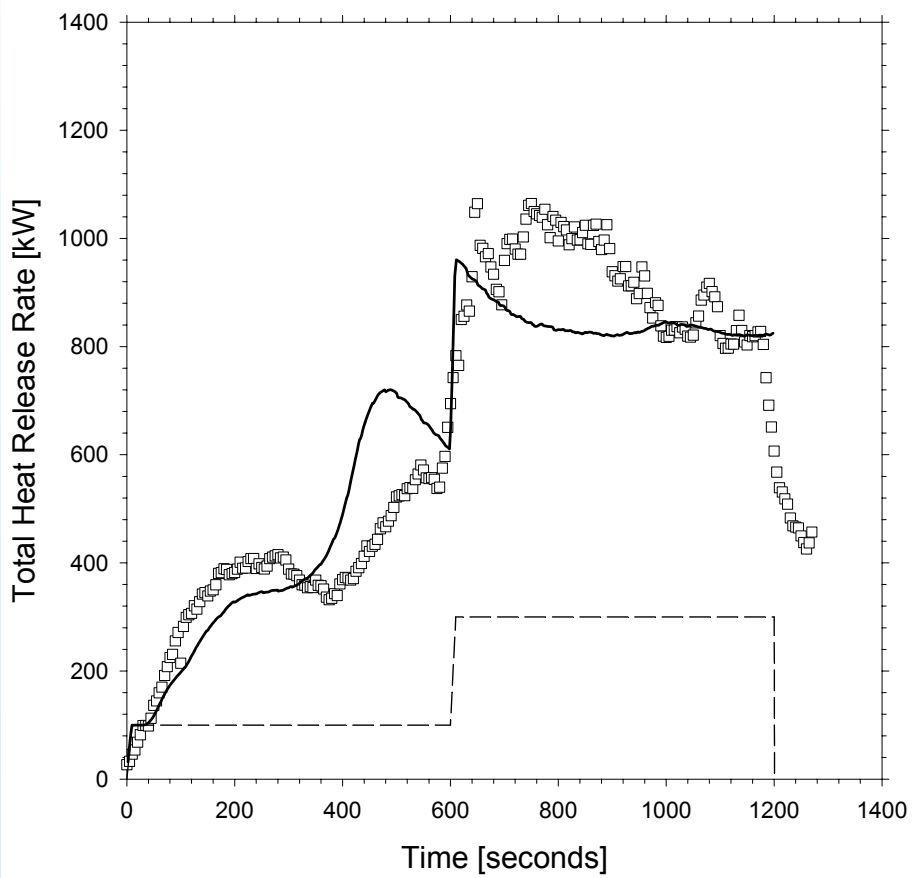
NR = Not Reached

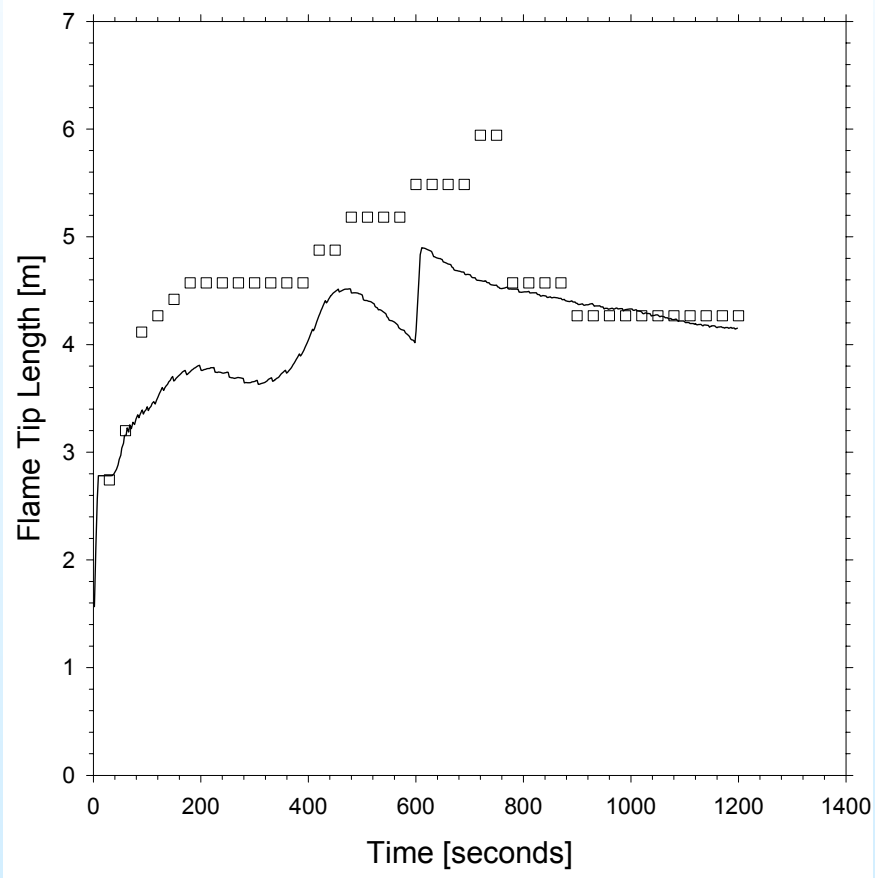
Open Corner Tests

- Lining Materials
  - 9.5 mm plywood
  - 12.5 mm glass reinforced vinyl ester composite (GRP)
  - 87.5 mm sandwich composite
- Initiating fire
  - 0.17 m square propane burner
  - 100 kW for 600 seconds, 300 kW for 600 seconds
- Measurements
  - flame length
  - flame front locations
  - total heat release rate
  - total heat flux to boundaries



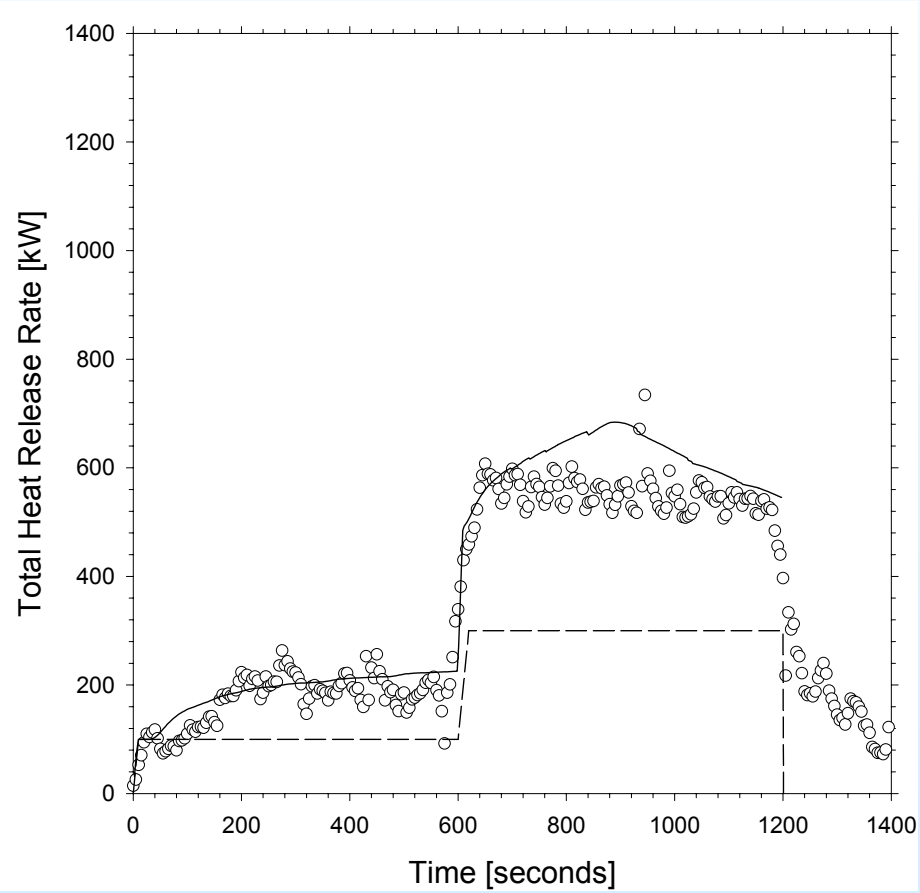
Open Corner Simulations - Plywood

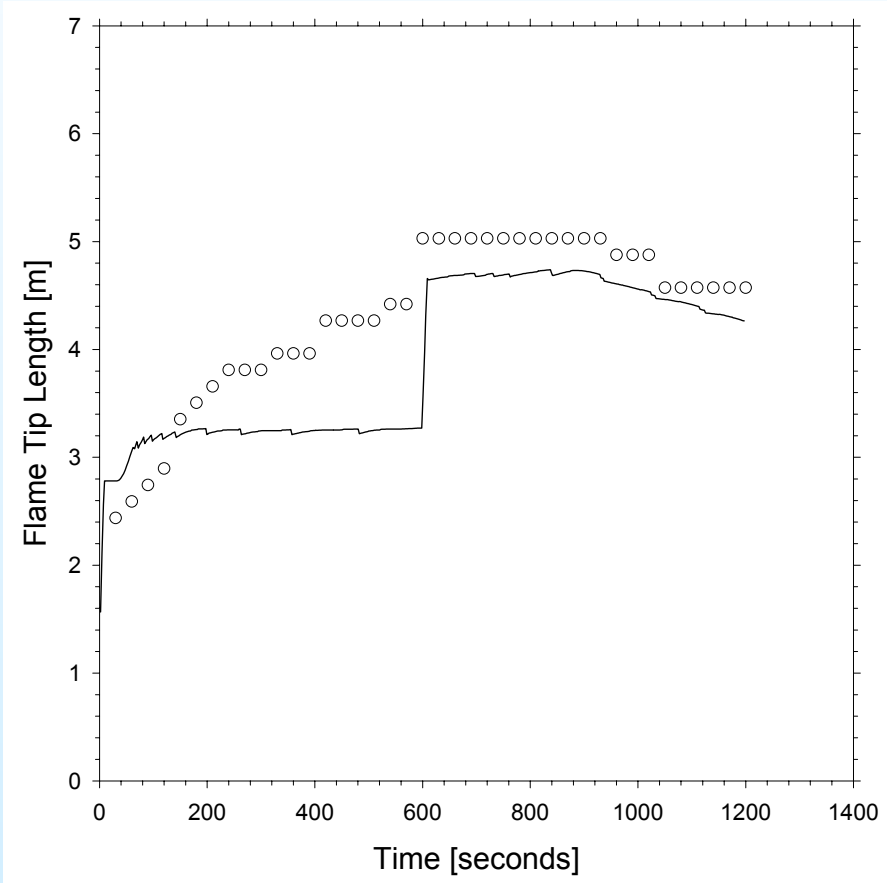




Time Step = 2.0 s
Cell Size = 0.020 m

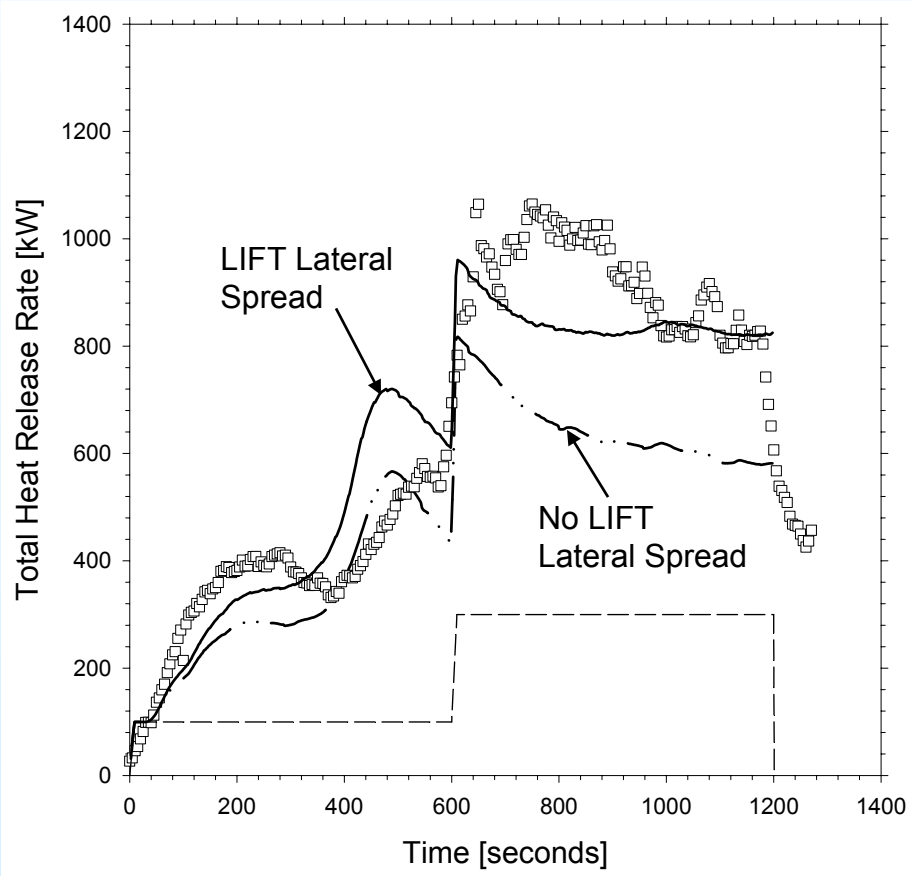
Open Corner Simulations - GRP

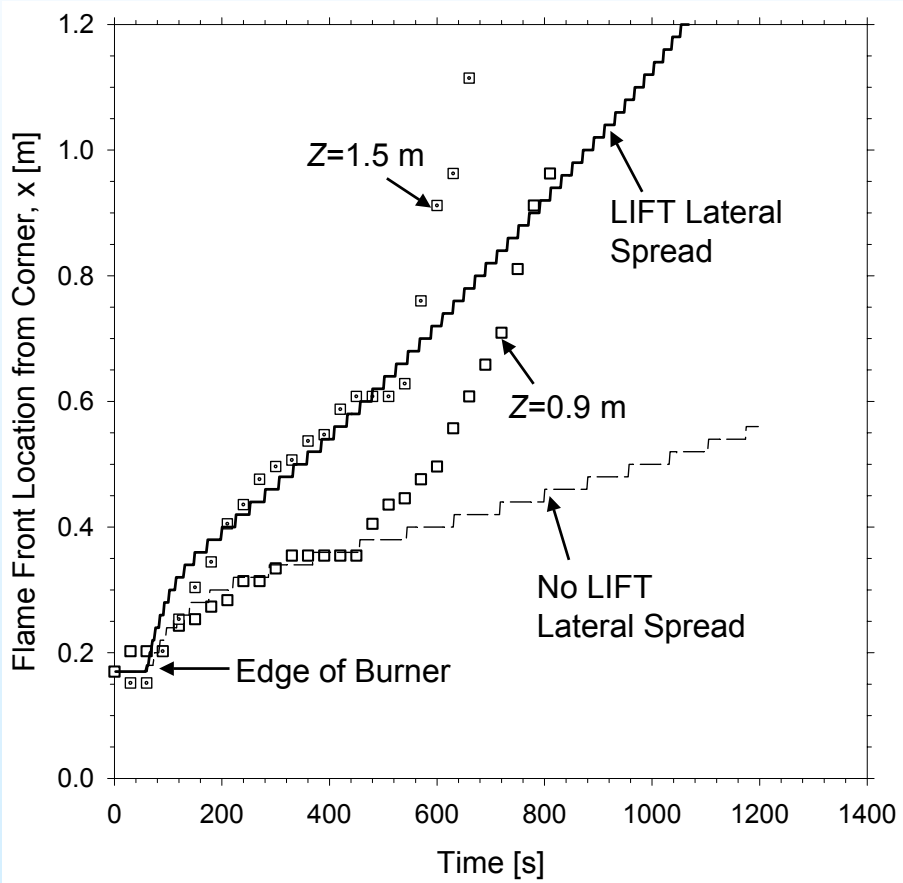




Time Step = 2.0 s
Cell Size = 0.020 m

Effects of Lateral Flame Spread

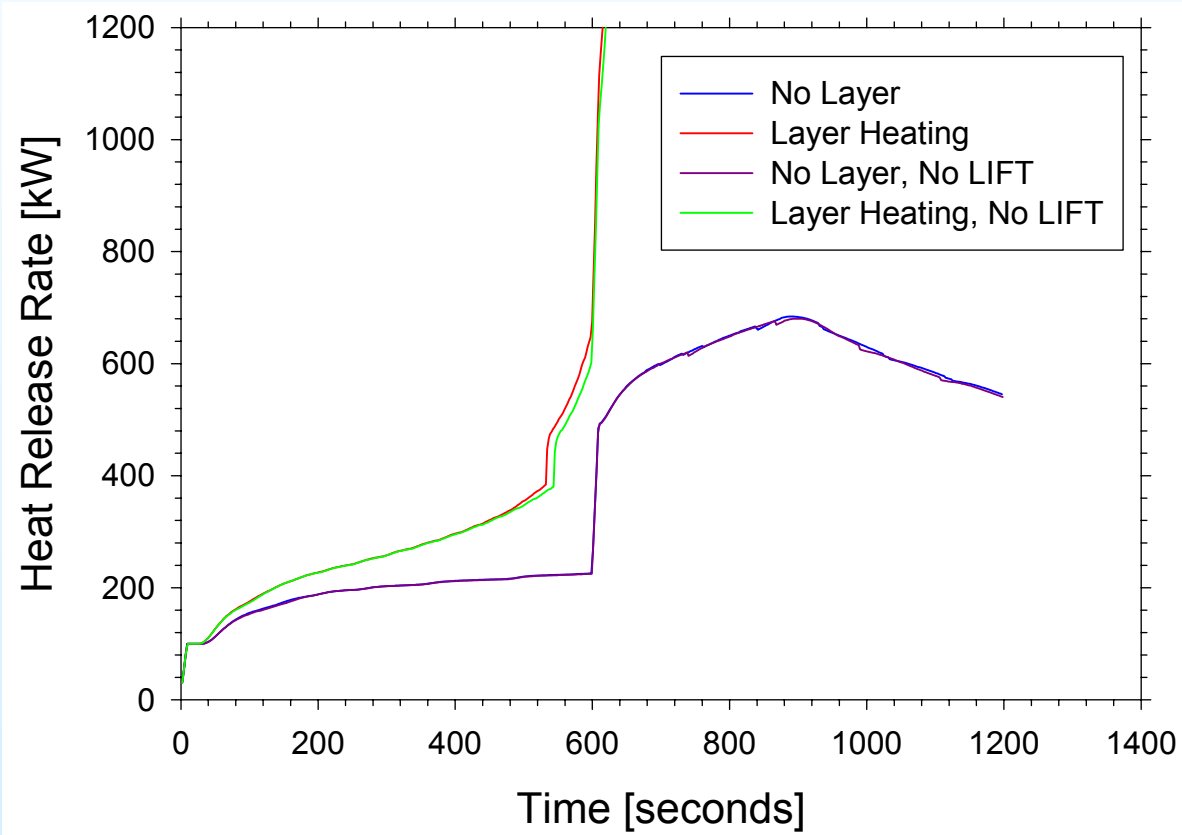




Time Step = 2.0 s
Cell Size = 0.020 m

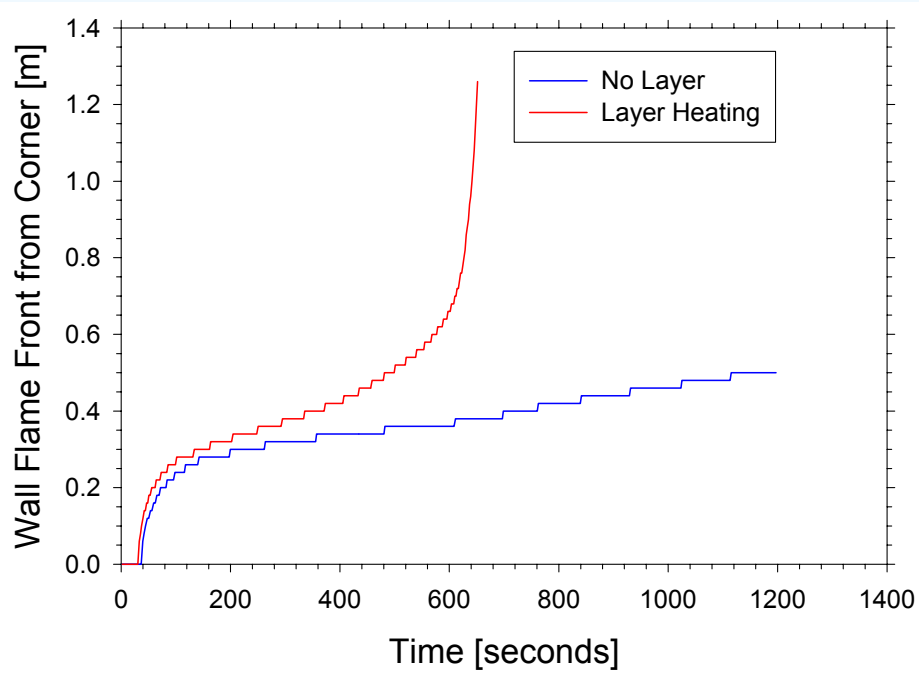
Plywood LIFT Data
$\Phi k\rho C$ = 11.7 kW s$^{1/2}$ / (m K)
T_{ig} = 623 K
$T_{s,min}$ = 448 K

Effects of Layer Heating

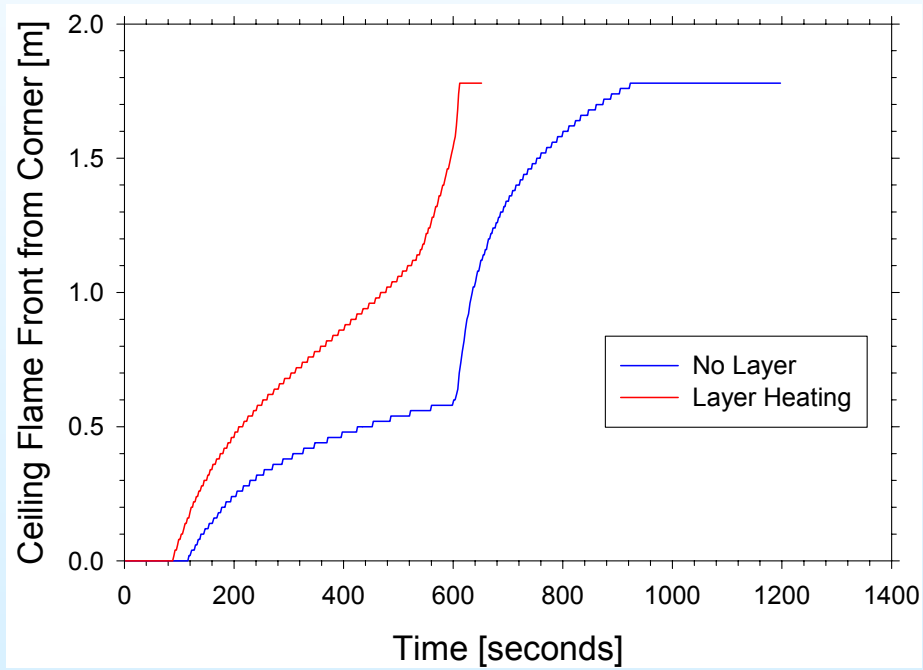


GRP LIFT Data
$\Phi/k\rho C$ = 0.65 kW s$^{1/2}$ / (m K)
T_{ig}= 675 K
$T_{s,min}$=625 K

Effects of Layer Heating



Opposed Flow Flame Spread on Walls



Wind-Aided Flame Spread on Ceiling

Conclusions

- Fire growth model successfully predicts performance in ISO 9705
  - larger cell size without loss of accuracy
  - requires only cone calorimeter data for input
  - predicted trends in heat release rate and smoke production data
  - capable of screening material performance per regulated quantities
  - provides a ±130 s estimate of time to flashover

Conclusions

- Predicting fire growth in open corners (i.e., larger rooms)
  - smaller cells required for converged solution
  - lateral flame spread using LIFT data recommended for conservative solution
    - important for materials with $\Phi/k\rho C$
- Hot gas layers affect results
  - increase heat release rate
  - accelerates flame spread
  - decreases importance of lateral flame spread using LIFT data

ISO 9705 Upper-Layer Gas Temperature