Fire Propagation in Buildings

1. The context
2. Combustion Science and Fire Science
3. Ignition, Flame spread, pool fires.
4. An Indian context for fire research?

UL-JLI Workshop on Fire
February 26, 2010
H S Mukunda

The context

- Industries using fuel or producing fuel
- High rise buildings with individual dwellings of varying content – depending on “richness”
- Houses/apartments fashioned after the west (with larger fraction of wooden panels, flooring, draperies)
- Textile stores, shops – highly loaded “fuel” small spaces
- Poor dwellings closely spaced with thatched roof

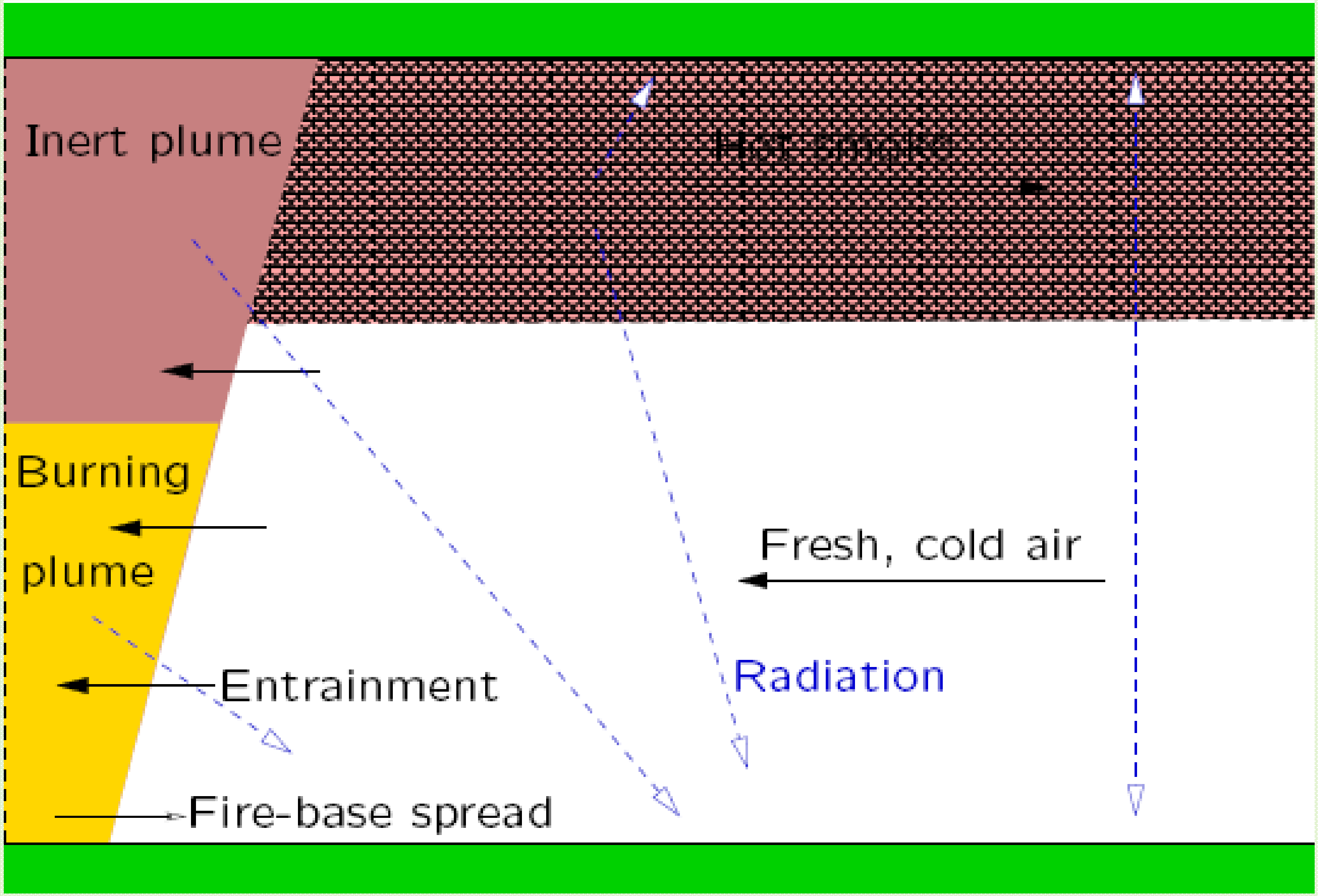
…Perhaps some cannot be helped. Those that can be helped should be…

The context…

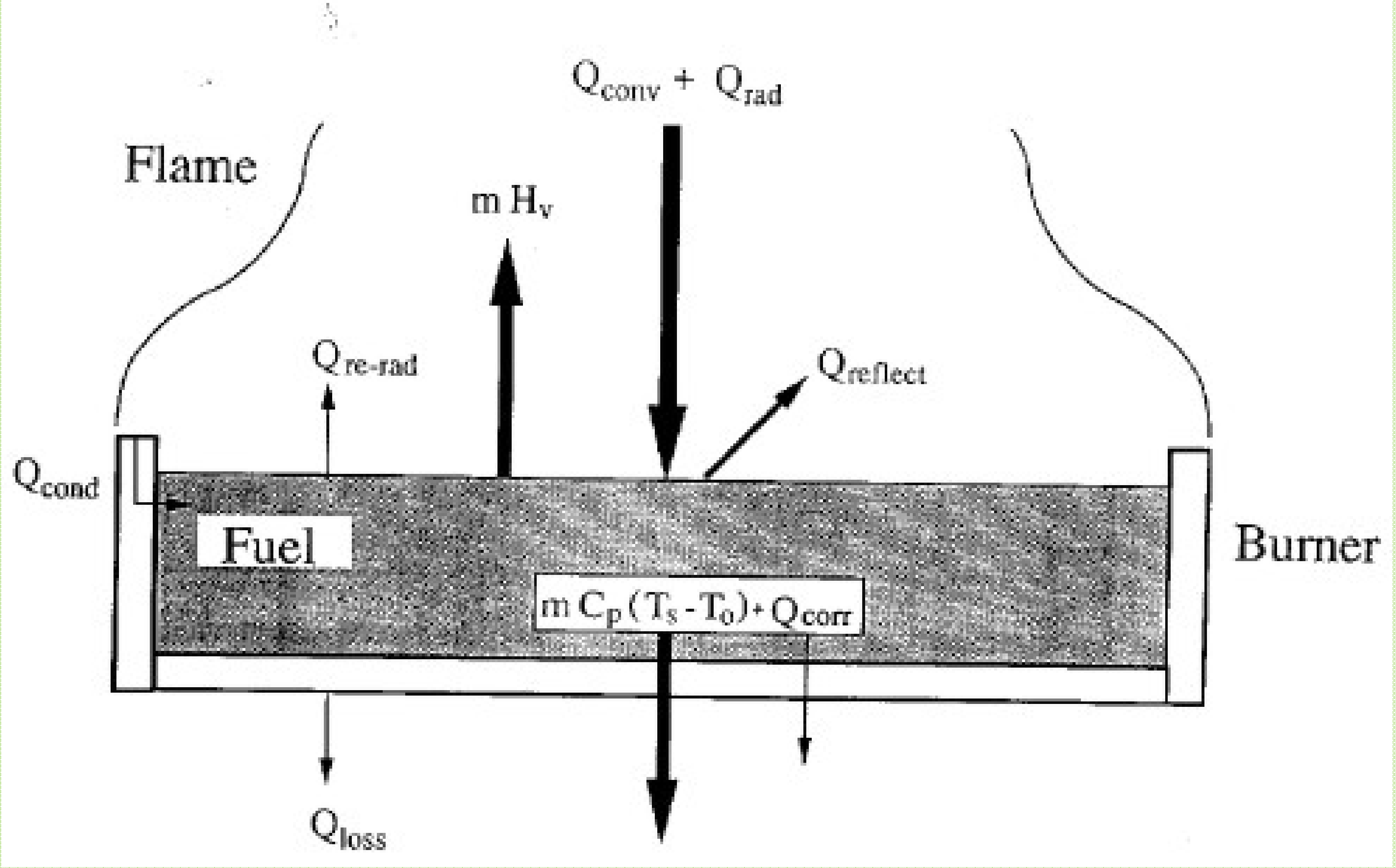
Beyond "common sense" can we state what "fire loading" of what kind can lead to what problem so that legislation can then take over to prevent occurrences of fire?

Building codes are not static. They must keep pace with new materials and understanding based on experiments, modeling and computations.

It is not material development alone; Ignition, fire spread, flash-over, fire movement out and into building space all matter. These need to be calculated, calibrated with experiments on model situations and used as tools for design.



Whether inside the flame/fire or outside, heat balance occurs because of convection – radiation - re-radiation - gasification with solid/liquid fuels



Heat balance in a pool fire – liquid or a whole solid piece burning

Feature	POM	PMMA	PP	PS
Flame base, m	0.305 square	0.305 x 0.31	0.305 square	0.305 square
Base area, m^2	0.093	0.095	0.093	0.093
Mass burn flux, g/m^{2}s	6.5	10.5	8.5	14.5
A/F]$_{stoich}$ -	4.6	8.3	14.8	13.0
Surface temp, °C	312	385	479	438
Heat of Combustion, MJ/kg	15.5	24.9	43.4	39.8
Heat of phase change, MJ/kg	2.43	1.61	2.03	1.76
Transfer No, B -	1.23	1.57	1.16	1.44
Combustion completeness, %	100	85	87	57
Radiation fraction, %	15	34	38	35
Theoretical. Heat release, kW	9.3	24.8	34.3	53.7
…rate kW/m^2	100	222	321	329
Convective heat flux, kW/m^2	17.5	7.6	6.8	2.9
Radiative heat flux, kW/m^2	5.0	20.1	28.7	37.2
Surface re-radiation, kW/m^2	6.7	10.7	18.2	14.6
Gasification flux, kW/m^2	15.8	17.0	17.3	25.5
Flame radiation temp, K	1400	1400	1350	1190

Poly oxymethlyene (POM) through Polymethyl methacrylate (PMMA), Poly Propylene (PP) to Polystyrene (PS)

A/F increases, Radiation fraction, sooting tendency Increases.

Effective radiation temperature decreases… From De Ris, Comb symp, 1978

$$\dot{q}''_{\mathrm{f,Rad}} = \sigma T_{\mathrm{f}}^{4}[1 - \exp(-\kappa_{\mathrm{s}} L)]$$

$$\chi_{\mathrm{R}} = \frac{\dot{Q}_{\mathrm{Rad}}}{\dot{Q}_{\mathrm{c}}} = \frac{A_{\mathrm{f}}\sigma T_{\mathrm{f}}^{4}[1 - \exp(-\kappa_{\mathrm{s}} L)]}{A_{\mathrm{s}} \Delta H_{\mathrm{c}} \dot{m}''_{\mathrm{s}}}$$

Combustion Science, Fire science

1. Combustion science is aimed at examining how to engineer heat release with little emissions – Radiation is important, but usually influences the behavior qualitatively or at 10 to 15 % level.
2. Enhanced mixing between fuel/ox is created intentionally
3. Fires are usually unintended. They occur with little mixing between fuel/oxidant (unless the material has both – chemicals/explosives with fuel-oxidants in the same molecule). They are usually very fuel rich. This leads to sooting. Sooting mechanisms are complex – chemistry controlled; some aspects still being understood. They also radiate extensively.
4. Combustion scientists: fire scientists = 2000:100

Ignition,
Flame spread,
Pool fires.

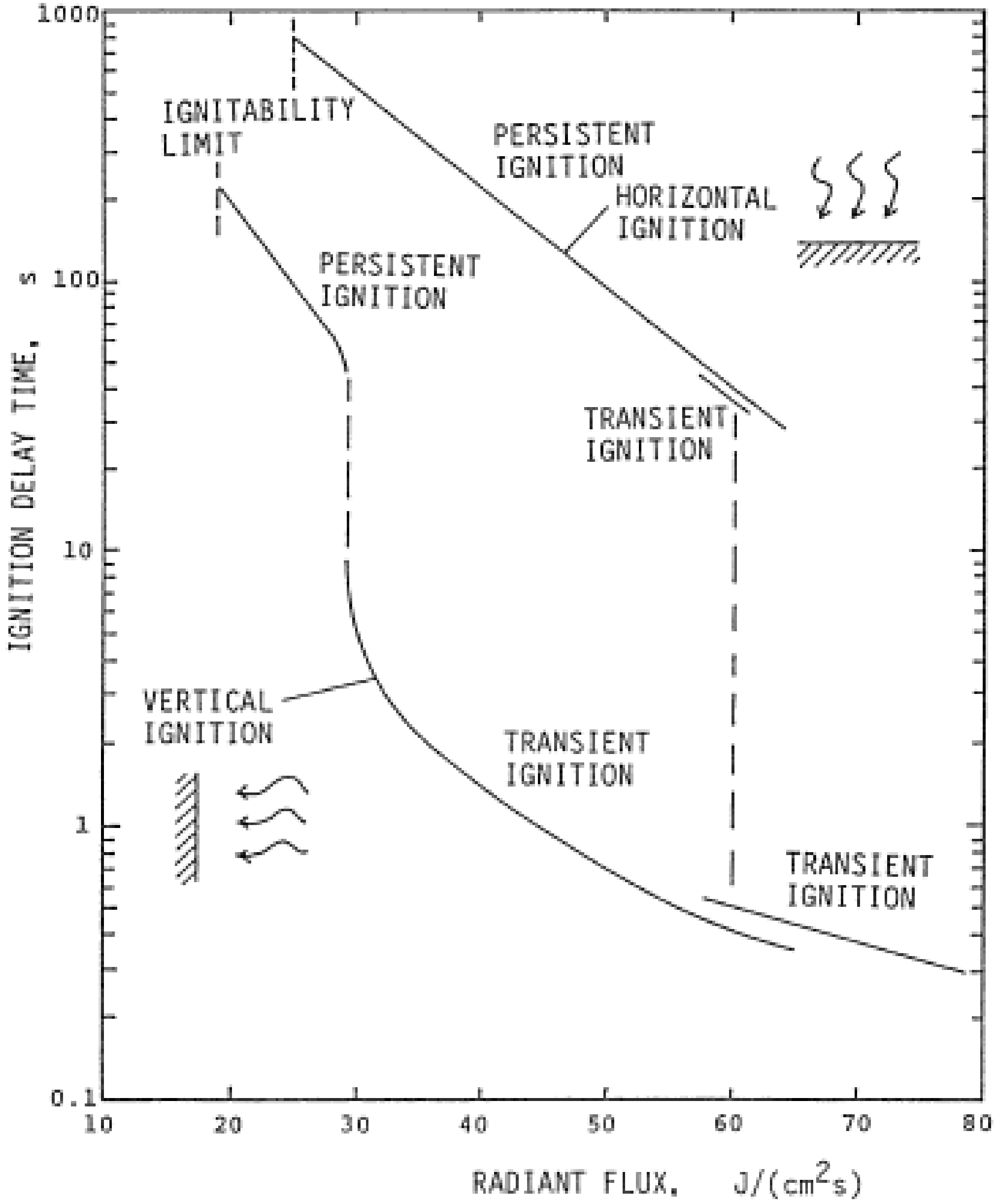
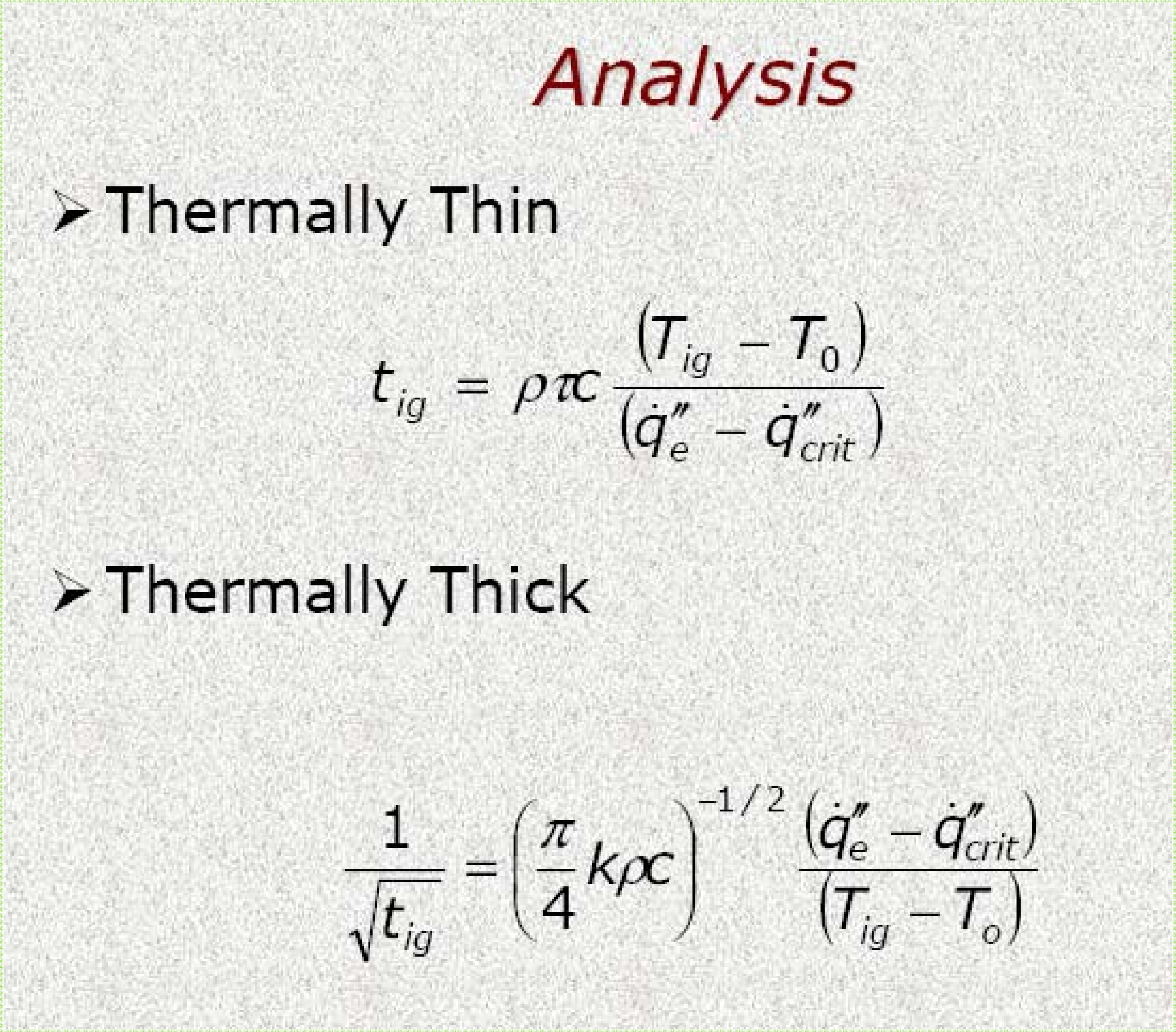


FIG. 1. Ignition delay time for radiative ignition of a slab of polymethylmethacrylate [22].

From:
Hirano,
International
Comb Symp,
2002

Ignition theory – Time for igniting thin and thick materials



Analysis

- Thermally Thin

$$t_{ig} = \rho \tau c \frac{\left(T_{ig} - T_0\right)}{\left(\dot{q}''_e - \dot{q}''_{crit}\right)}$$

- Thermally Thick

$$\frac{1}{\sqrt{t_{ig}}} = \left(\frac{\pi}{4} k \rho c\right)^{-1/2} \frac{\left(\dot{q}''_e - \dot{q}''_{crit}\right)}{\left(T_{ig} - T_o\right)}$$

From
Charlie
Fleischmann

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t_{ig} = ignition time, *ρ* = density, *c* = specific heat, *τ*= thickness;
T_{ig} = Ignition temperature, *k* = conductivity, T_0 = ambient temperature,

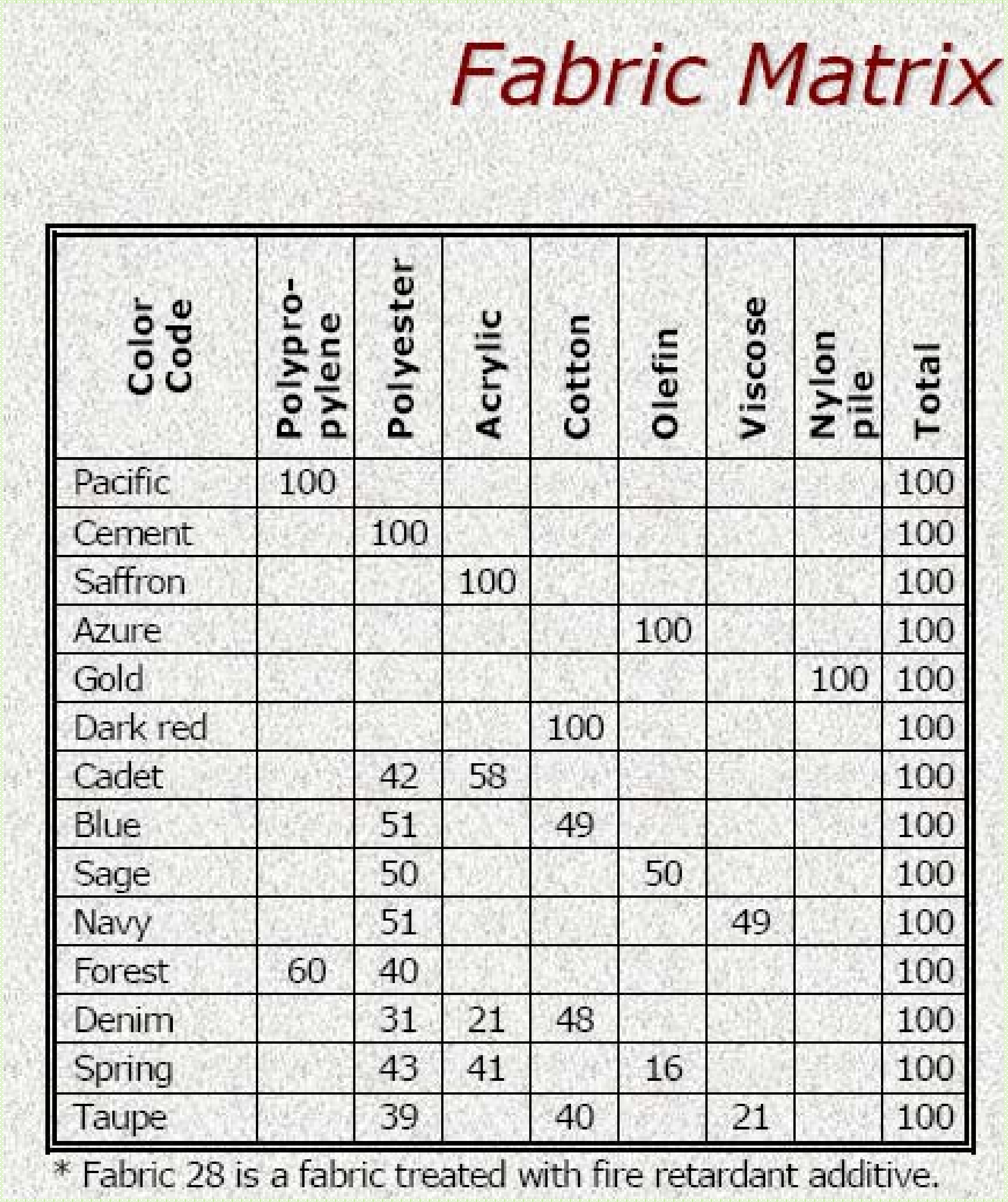
Furniture Styles


1


6


7

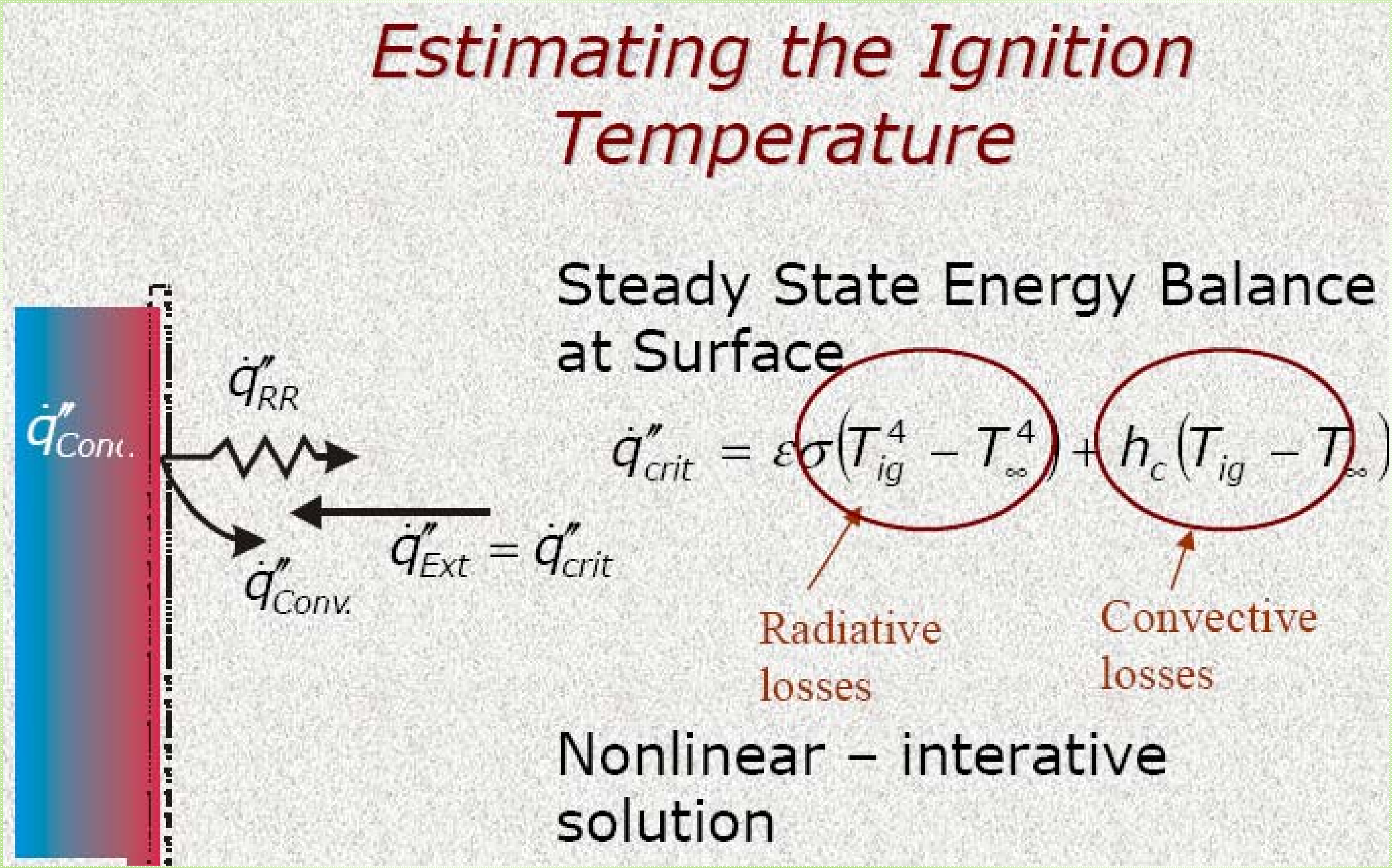

8



Fabric Matrix

Color Code	Polypro-pylene	Polyester	Acrylic	Cotton	Olefin	Viscose	Nylon pile	Total
Pacific	100							100
Cement		100						100
Saffron			100					100
Azure					100			100
Gold							100	100
Dark red				100				100
Cadet		42	58					100
Blue		51		49				100
Sage		50			50			100
Navy		51				49		100
Forest	60	40						100
Denim		31	21	48				100
Spring		43	41		16			100
Taupe		39		40		21		100

* Fabric 28 is a fabric treated with fire retardant additive.



Estimating the Ignition Temperature

Steady State Energy Balance at Surface

$$\dot{q}''_{crit} = \varepsilon\sigma\left(T_{ig}^4 - T_\infty^4\right) + h_c\left(T_{ig} - T_\infty\right)$$

Radiative losses

Convective losses

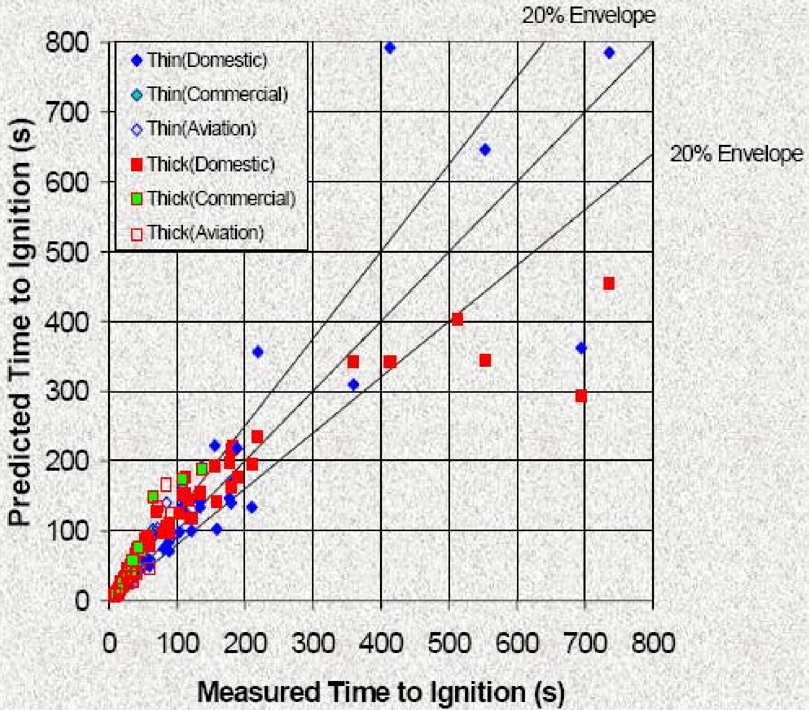
Nonlinear – interative solution

Measure the surface temperature vs. time in tests

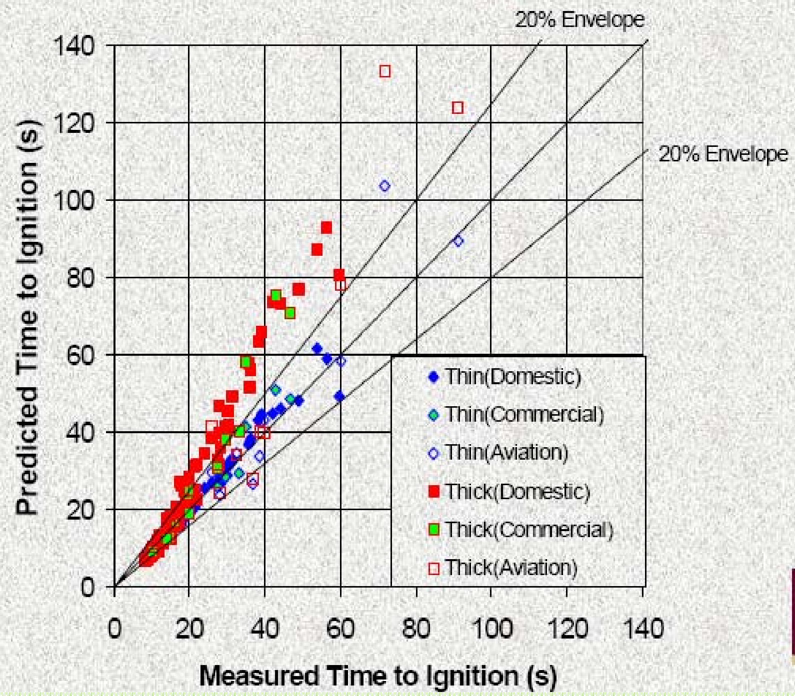
Check by varying the radiant flux the flux at which ignition occurs.

Check this formula then.

Results $7kW/m^2 \le q''_e \le 40kW/m^2$

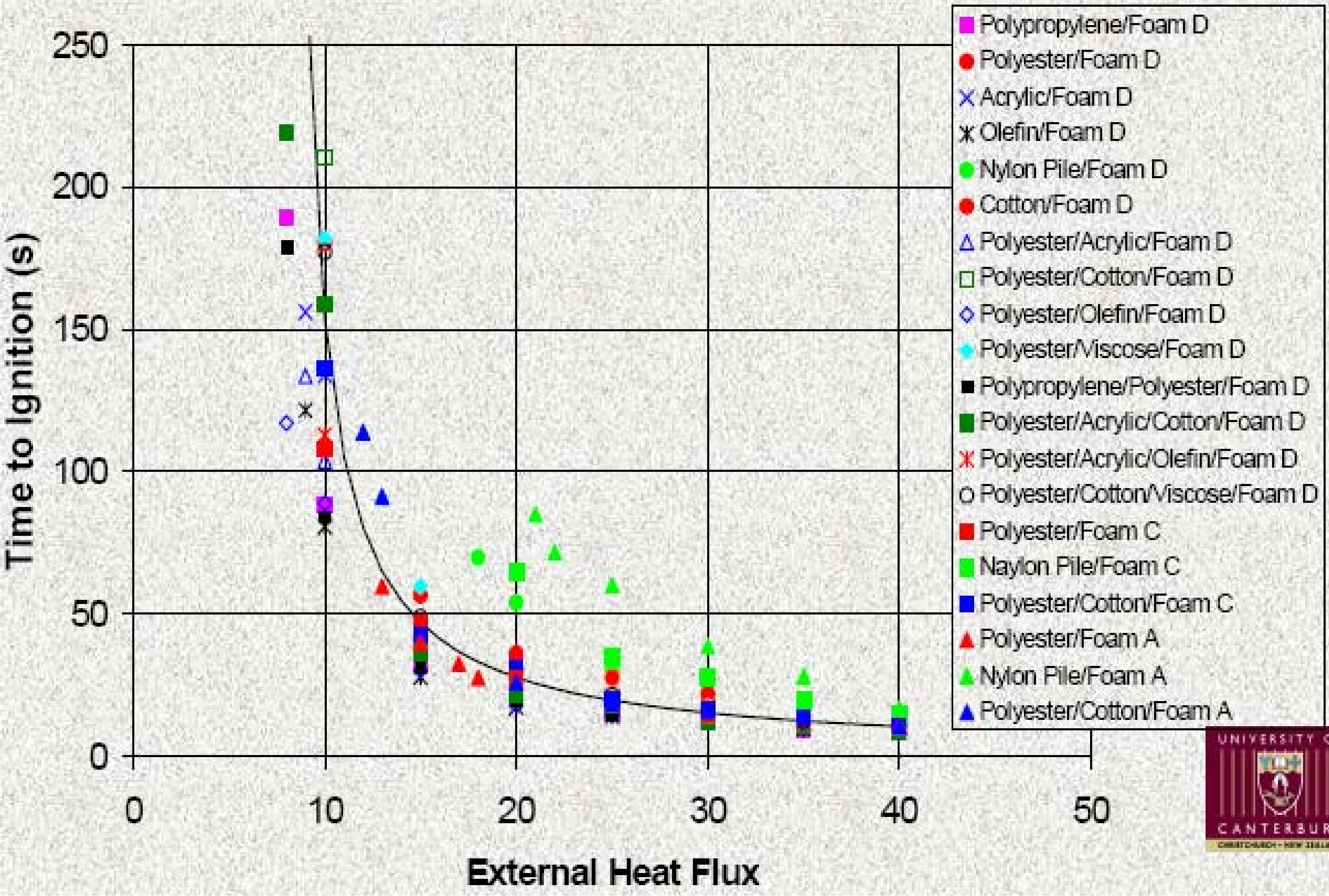


Results $15kW/m^2 \le q''_e \le 40kW/m^2$



$$t_{ig} = \frac{338}{(\dot{q}''_e - 7.8)}$$

Generic Results



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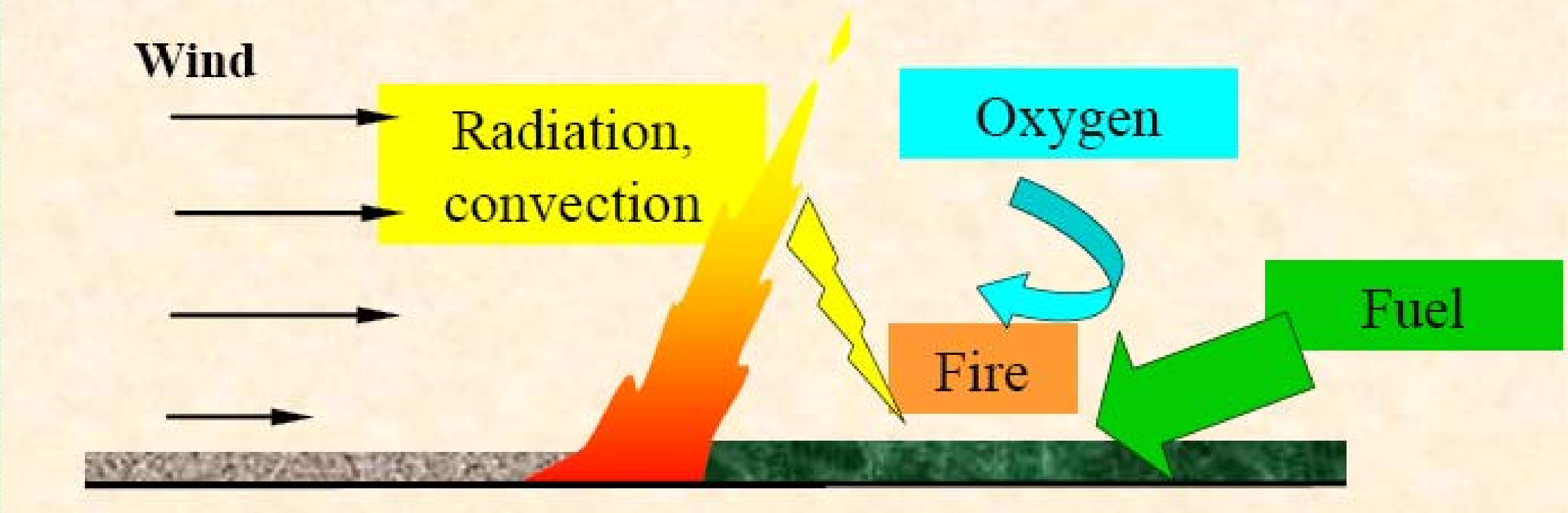
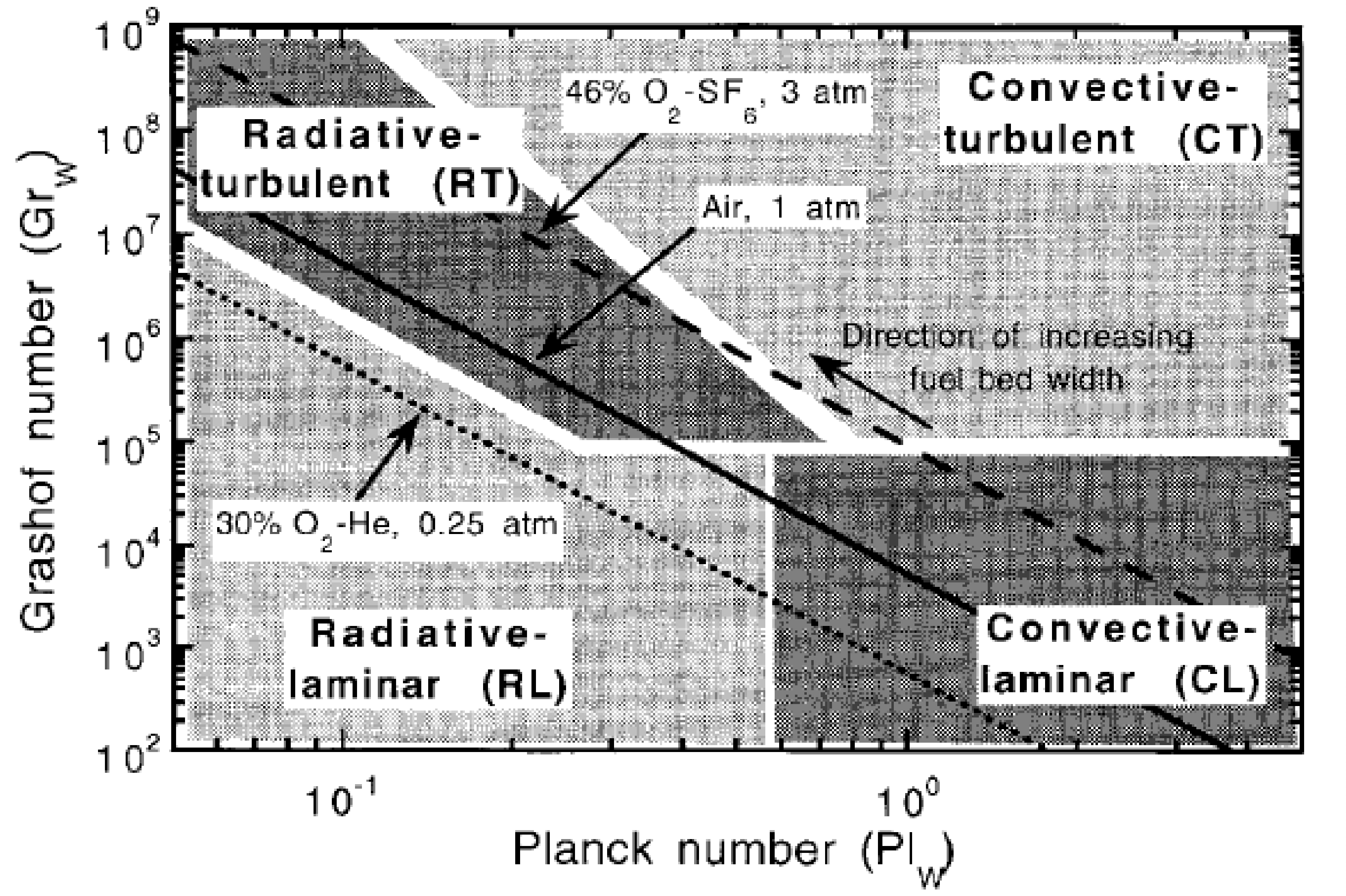
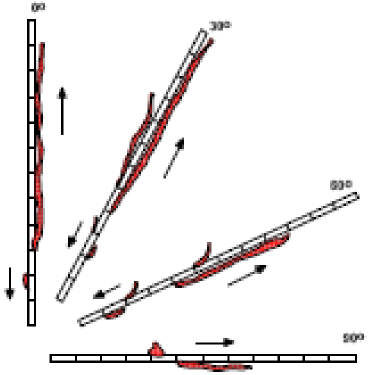
Fire spread mechanisms



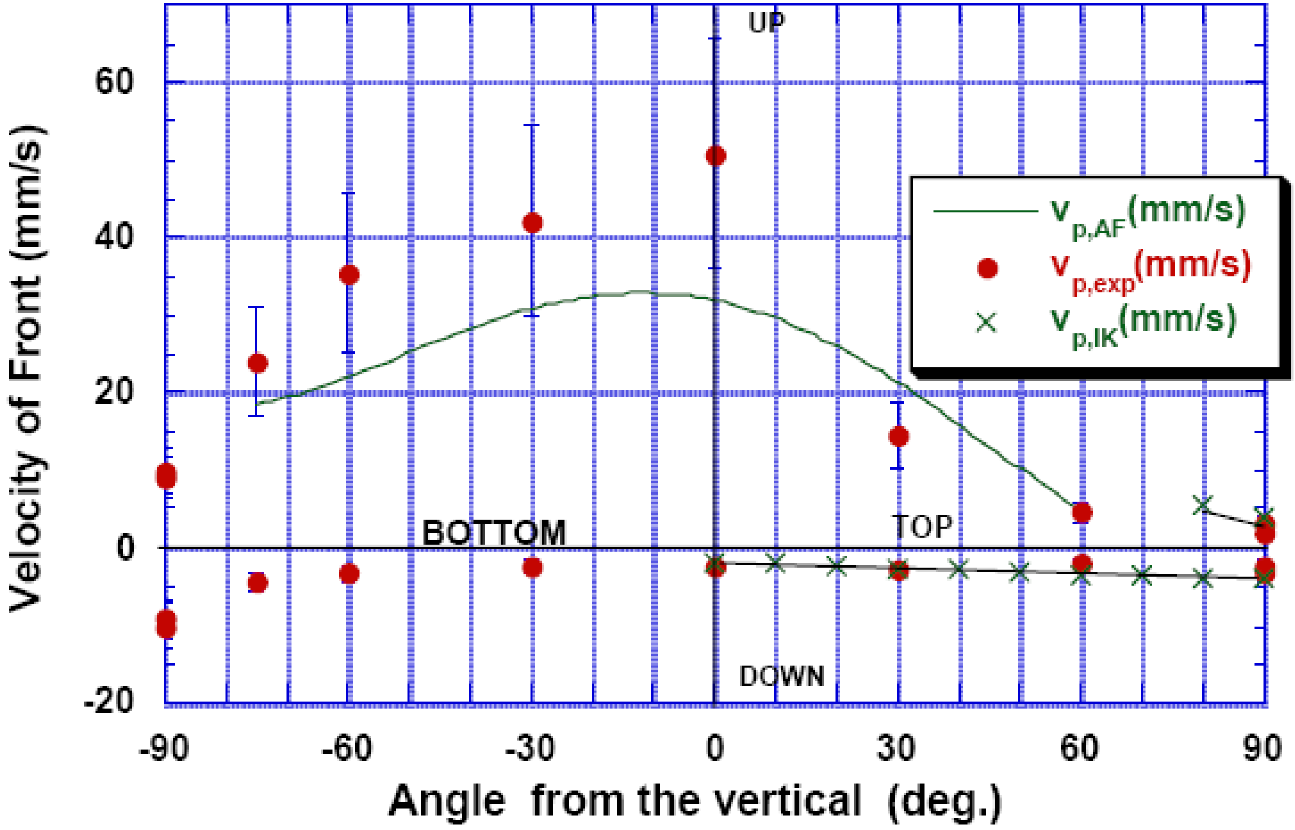


Flame spread regimes on Grashof number – Planck number plot
Grashof number = g β ΔT L^3/ v^2 and Planck number = k ΔT/L εσ ΔT'^{4}
From Honda and Paul Ronney, Comb symp, 2000

Prediction



Calculated Flame Speed compared to Napkin Data



From Quintierrie

Critical Flame Heat Flux for increasing spread rate and Flashover

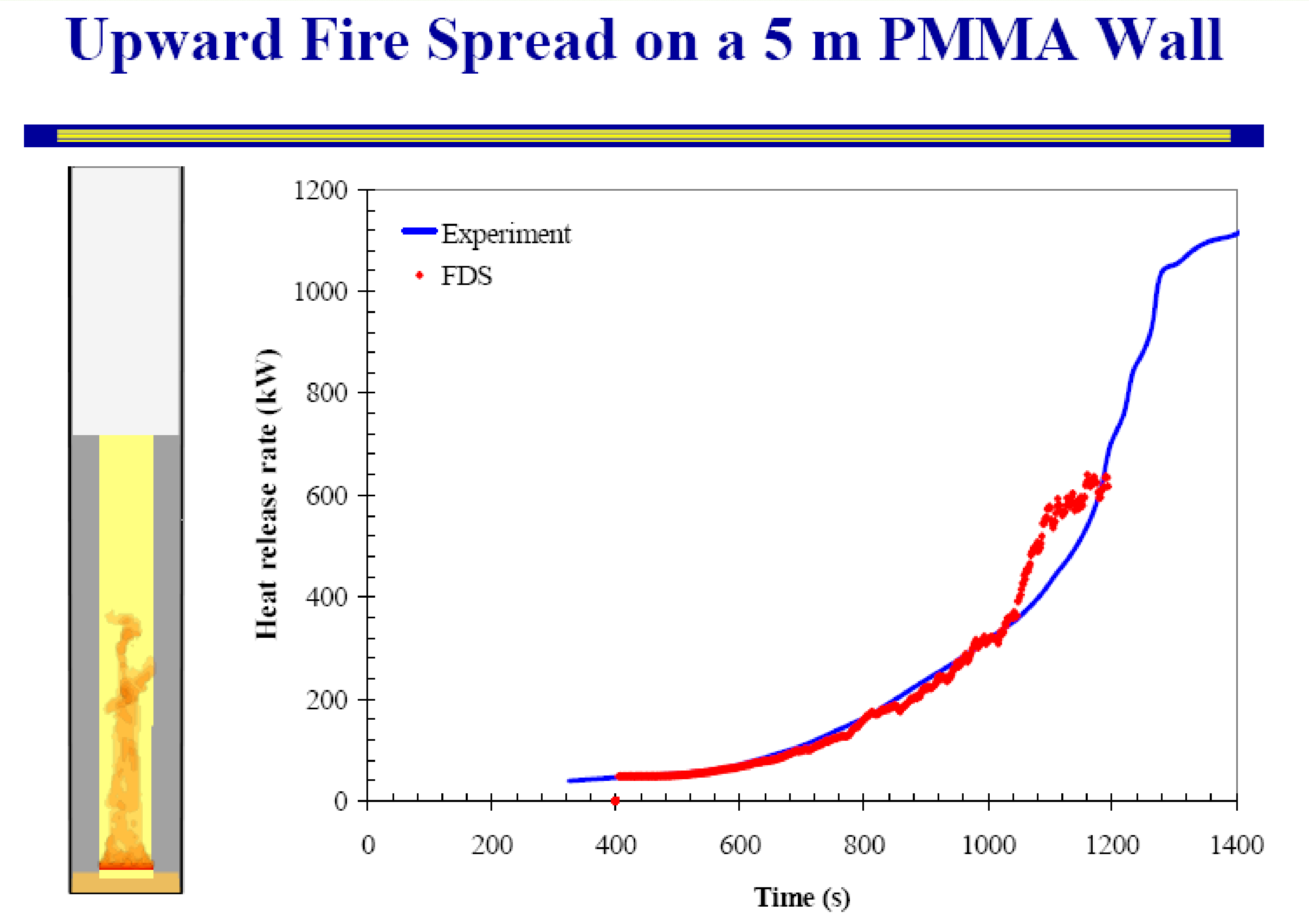
$$\dot{q}''_{f,critical} = \sigma T_{ig}^4 + \left(\frac{L}{\Delta H_c}\right)\left(50 + 100\left(\frac{t_{ig}}{t_b}\right)\right), \text{kW/m}^2.$$

The heat flux from the ignition burner in the room corner test is about 60+/-20 kW/m^2.

- Flame spread can be computed
- Property data are needed
- Correlations are needed
  - Flame Heat Flux
  - Flame Length
- Igniter heat flux can be crucial

All the elements are put together
in a complex reactive fluid-flow-
(including radiation) software
called Fire dynamics software
Some results from other labs….

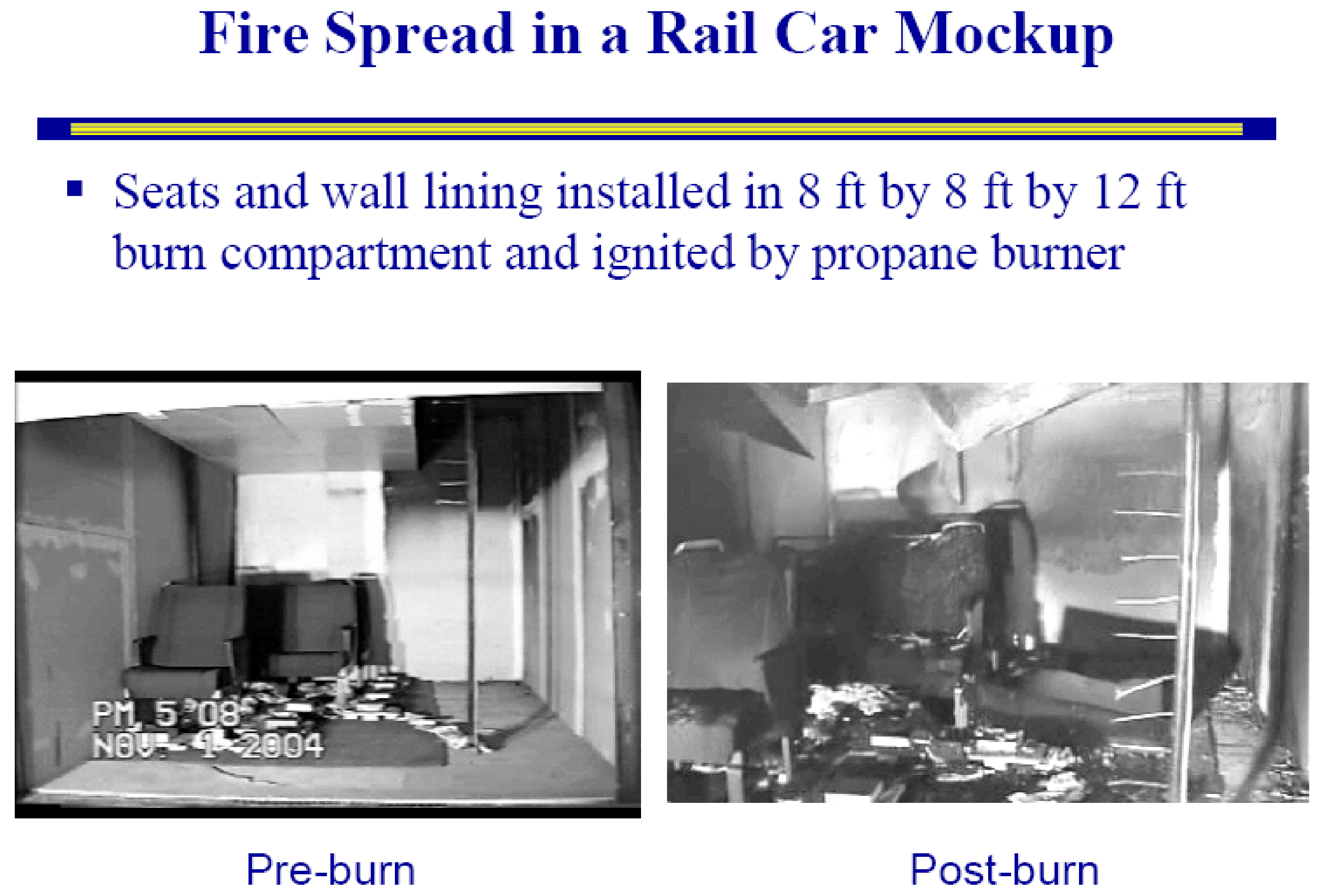
From: October 2008 presentation by Lauterberger, Uni. California



Upward Fire Spread on a 5 m PMMA Wall

FDS – Fire Dynamics software prediction

From: October 2008 presentation by Lauterberger, Uni. California



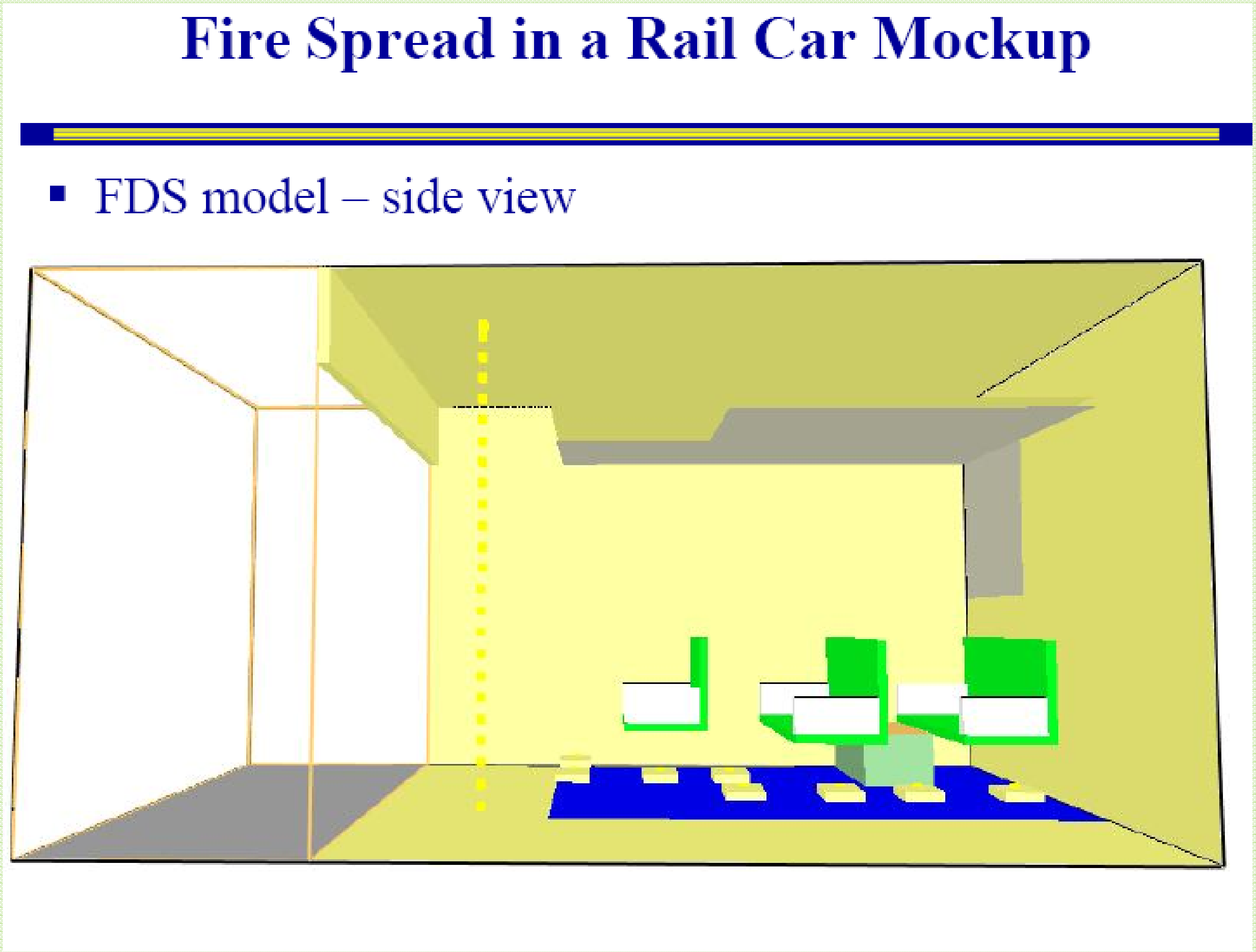
Fire Spread in a Rail Car Mockup

- Seats and wall lining installed in 8 ft by 8 ft by 12 ft burn compartment and ignited by propane burner

Pre-burn

Post-burn

From: October 2008 presentation by Lauterberger, Uni. California



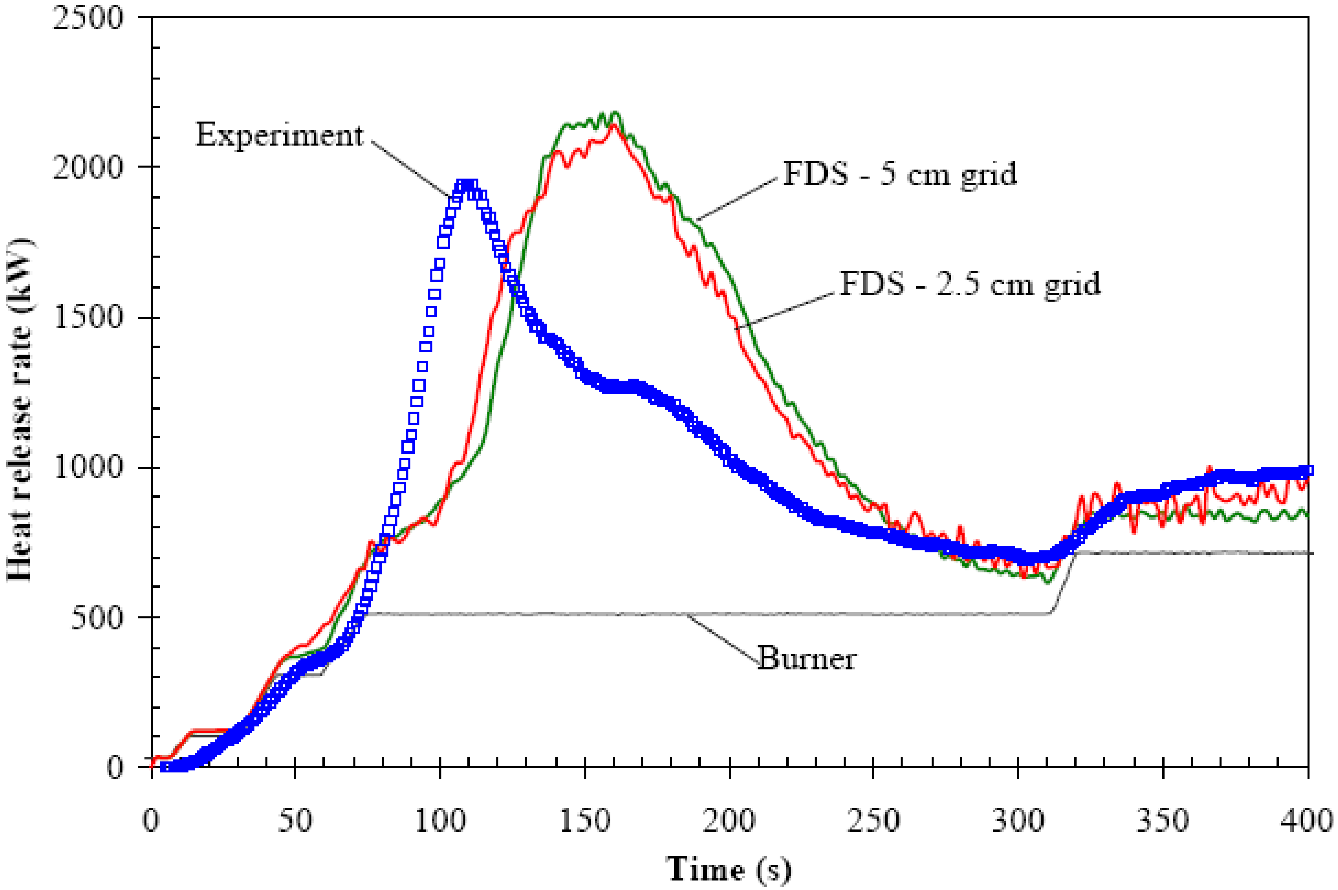
Fire Spread in a Rail Car Mockup

- FDS model – side view

From: October 2008 presentation by Lauterberger, Uni. California

Fire Spread in a Rail Car Mockup

- Measured and modeled heat release rate



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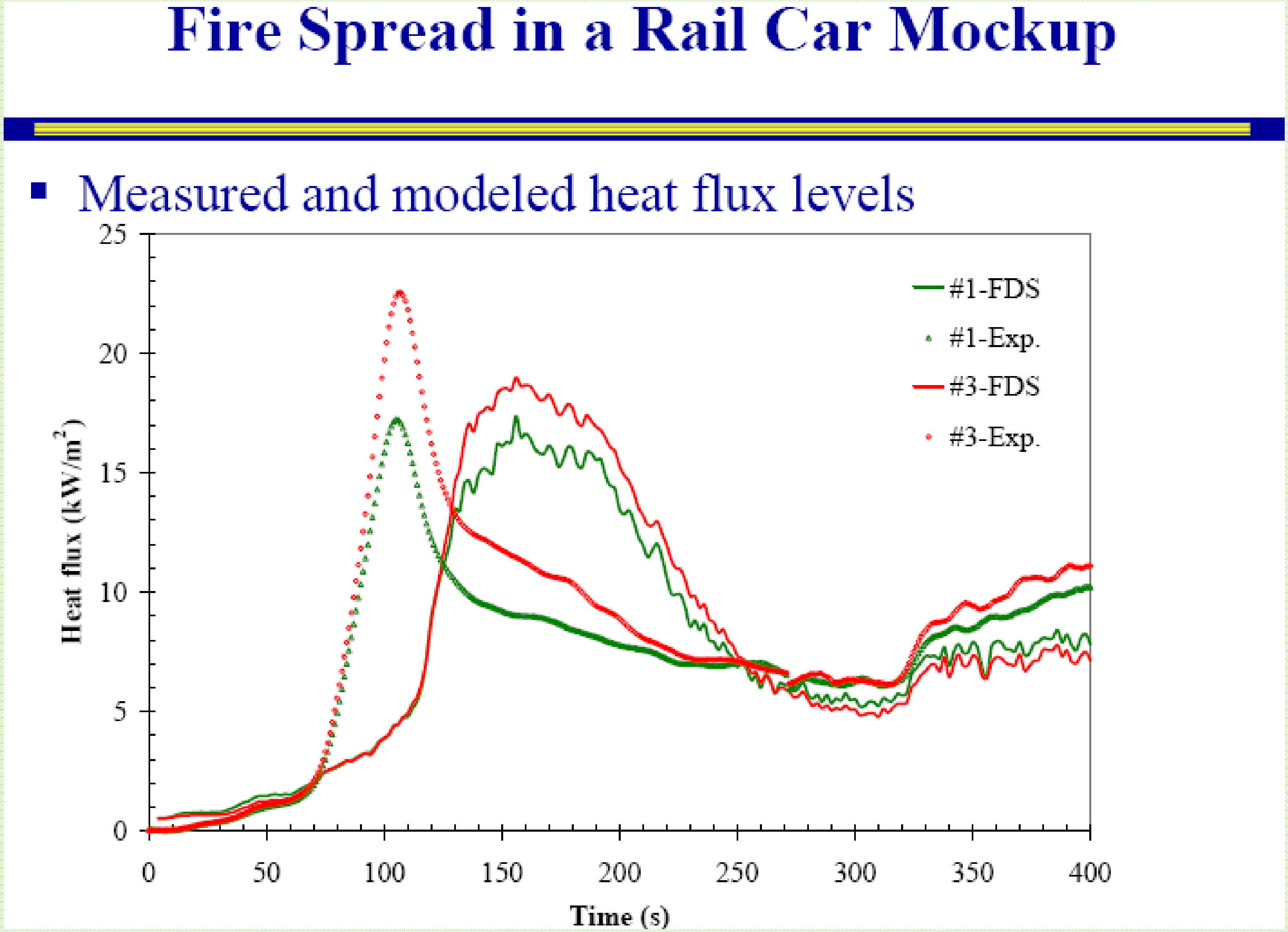
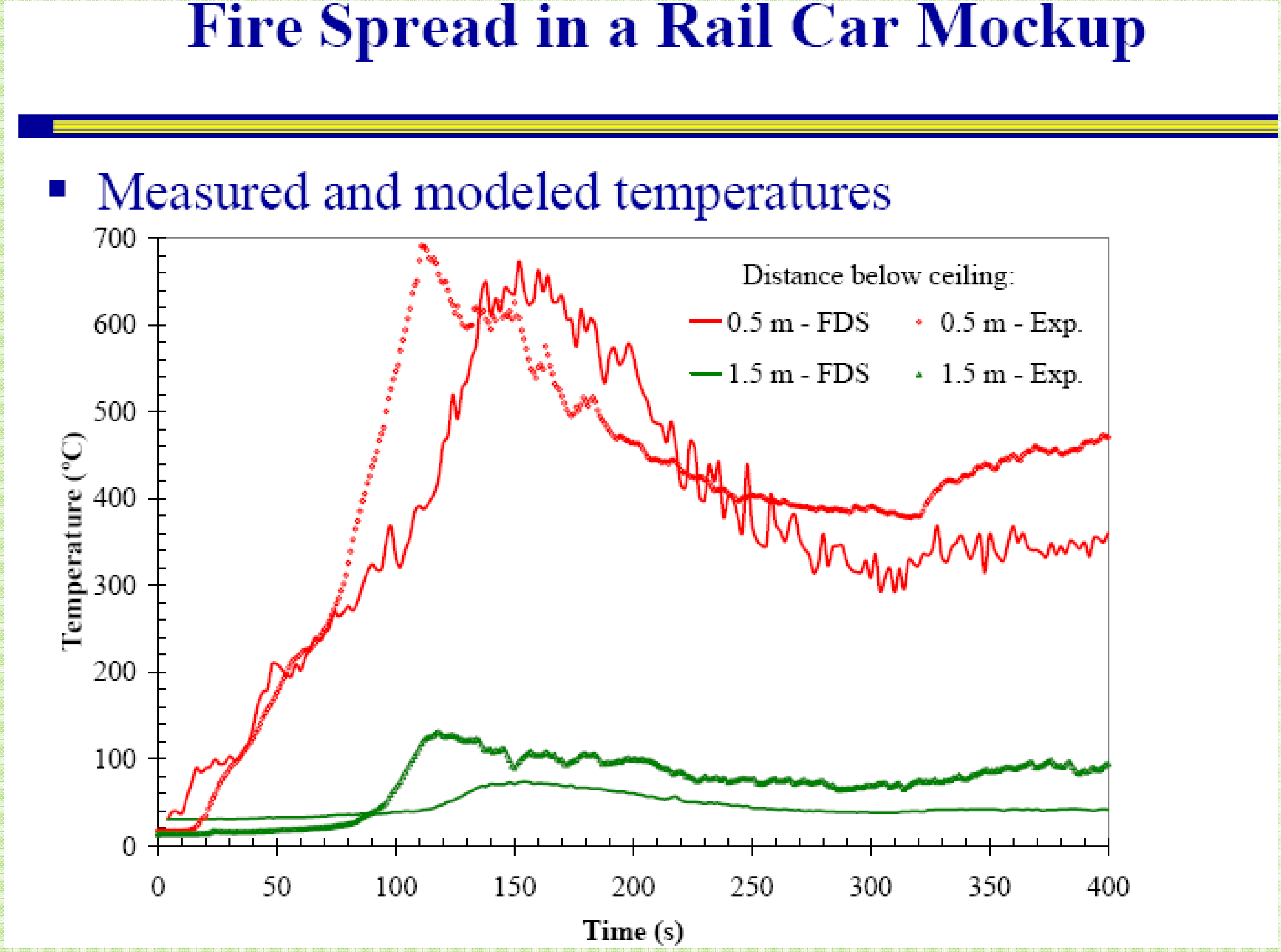


Fire Spread in a Rail Car Mockup

- Measured and modeled heat flux levels

From: October 2008 presentation by Lauterberger, Uni. California



Fire Spread in a Rail Car Mockup

- Measured and modeled temperatures

Radiation Emission on Coarse Grids in LES

- FDS makes the approximation:

$$\overline{\dot{q}_r'''} \approx \chi_r \overline{\dot{q}'''}$$

- But real physics (local radiant emission) are:

$$\dot{q}_r''' = 4\sigma\kappa T^4$$

- Difficult to calculate on coarse grid (SGS fluctuations)

$$\begin{aligned}\overline{\dot{q}_r'''} &= 4\sigma\int_0^1 \kappa(Z,T(Z),f_v)T^4(Z)P(Z)\mathrm{d}Z \\ &\approx 4\sigma\kappa\left(\overline{Z},T(\overline{Z}),\overline{f_v}\right)\int_0^1 T^4(Z)P(Z)\mathrm{d}Z\end{aligned}$$

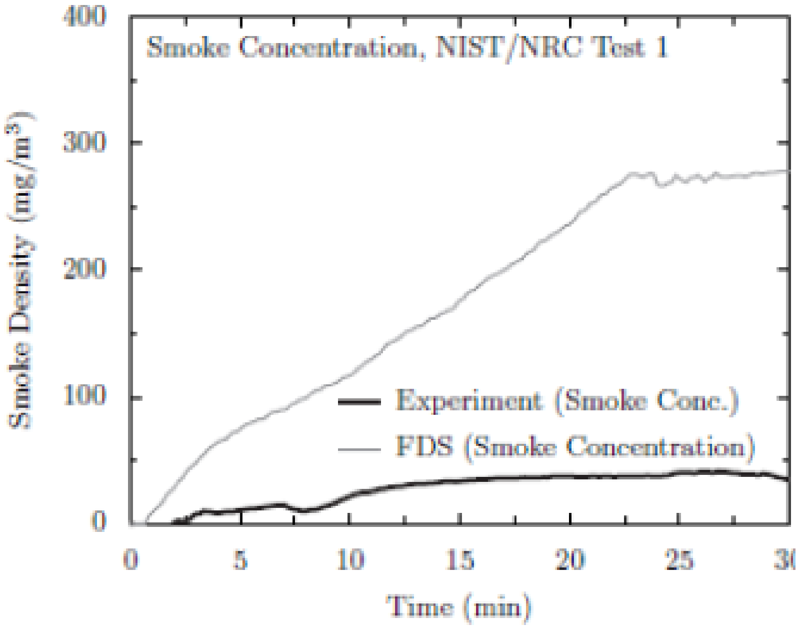
Radiation Blockage

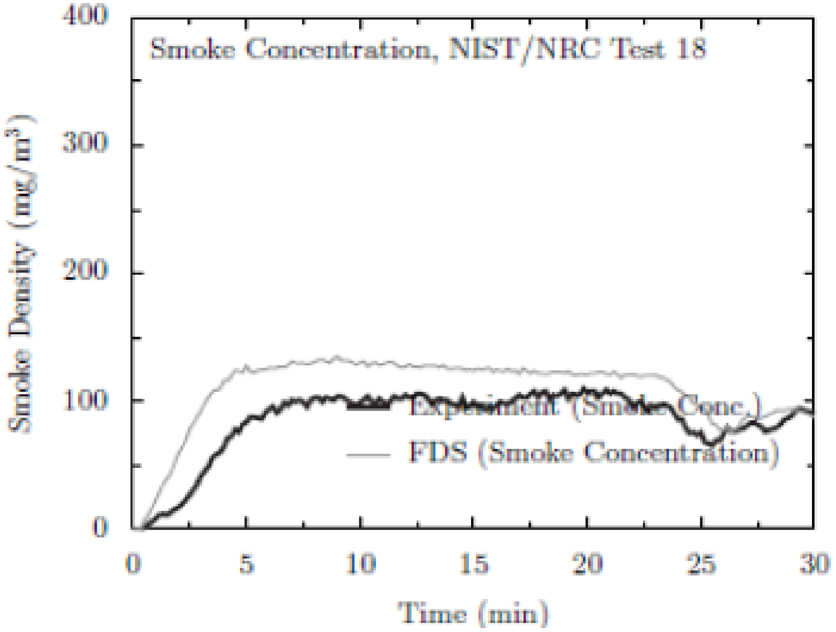
- Pyrolysate near condensed fuel absorbs radiation
  - Spectral
  - In FDS, all fuels have properties of methane (RADCAL)

From: October 2008 by Lauterberger Uni. California

Soot Concentration Measurements – Courtesy FDS Validation Guide

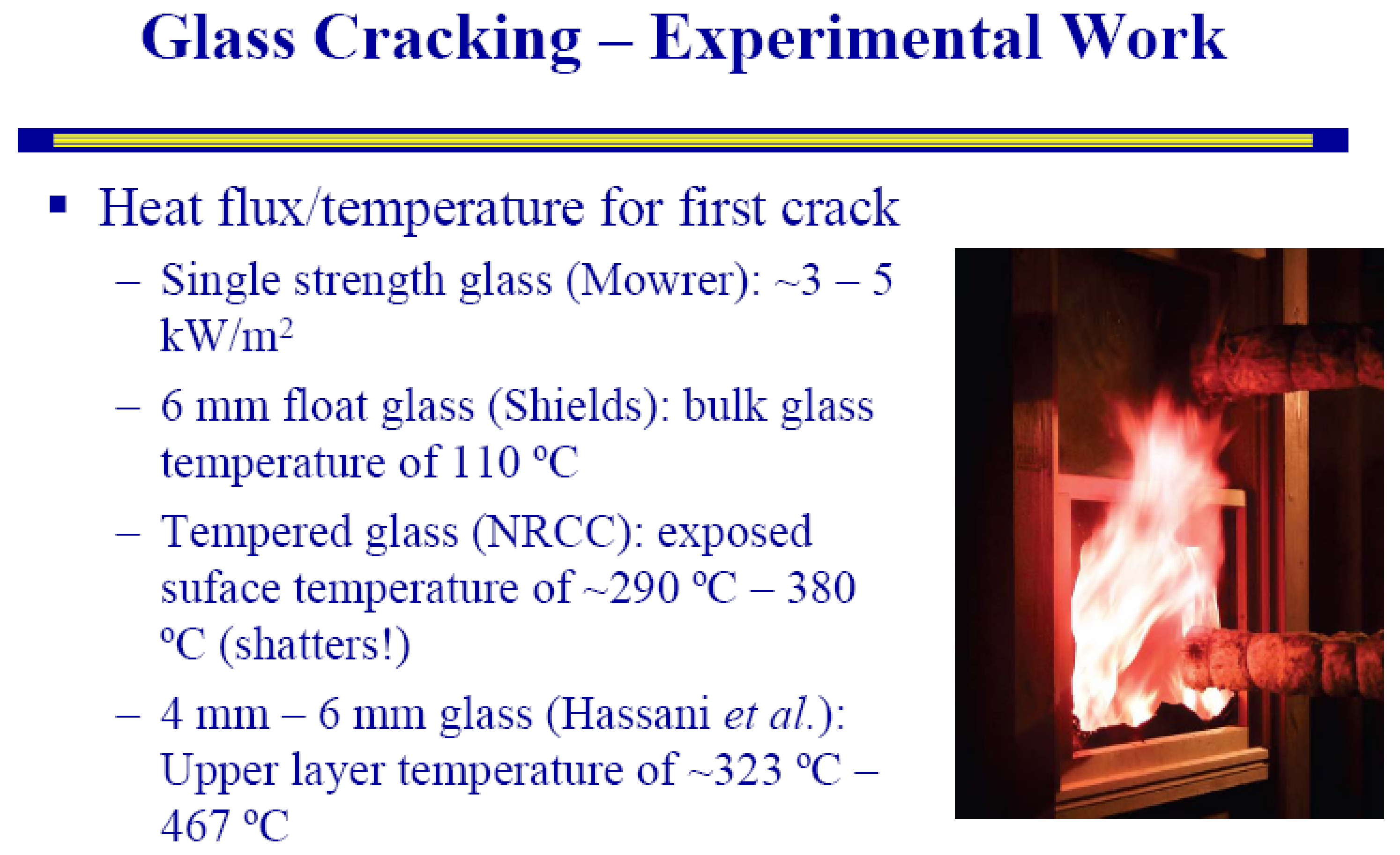
- FDS significantly over-estimates smoke concentrations





Glass Breakage/Fall Out and Its Effect on Fire Ventilation

If window glass does not break, flames do not escape; the dynamics of fire In upper levels of floors will be controlled better.

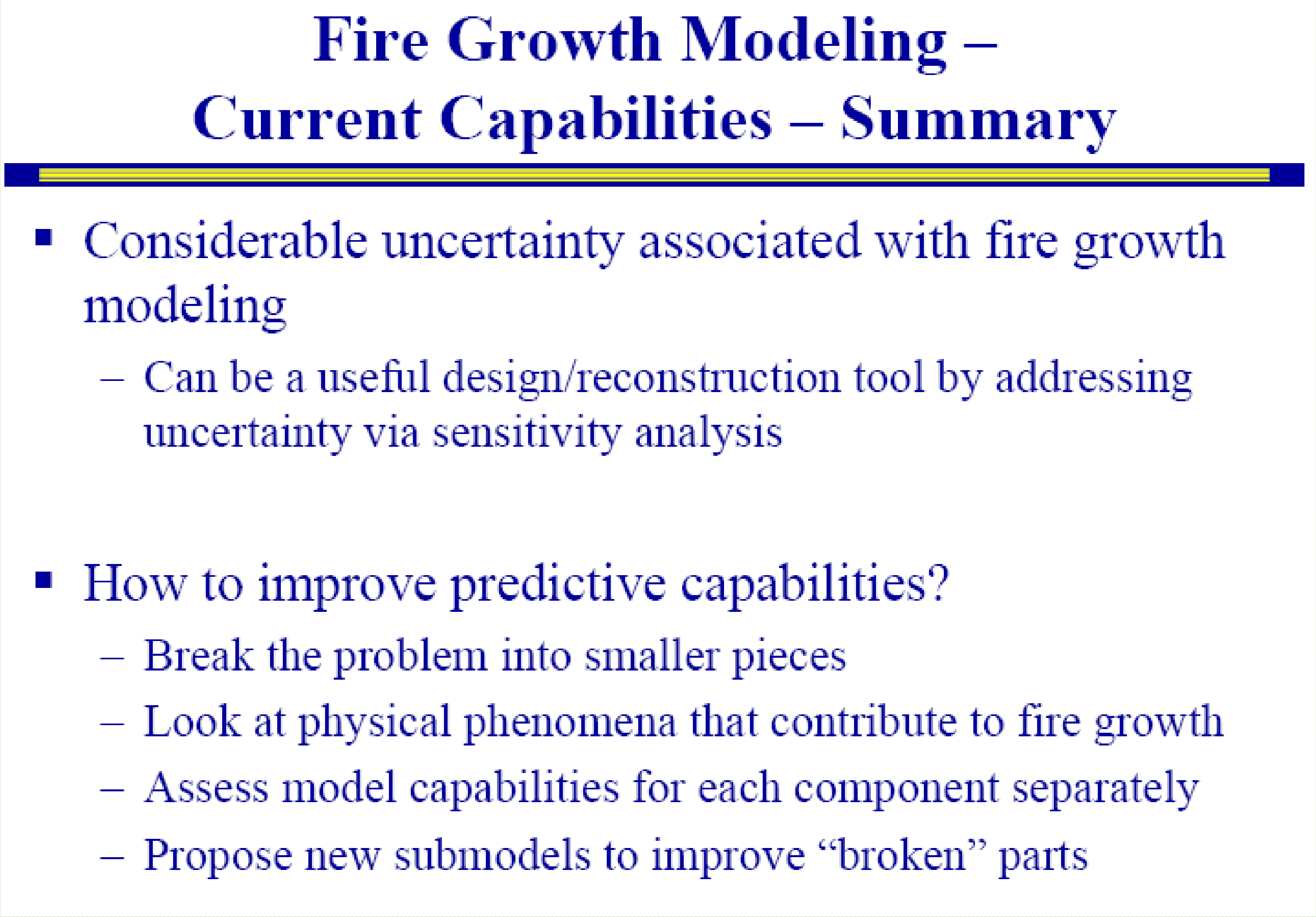


Glass Cracking – Experimental Work

- Heat flux/temperature for first crack
  - Single strength glass (Mowrer): ~3 – 5 kW/m^2
  - 6 mm float glass (Shields): bulk glass temperature of 110 ºC
  - Tempered glass (NRCC): exposed suface temperature of ~290 ºC – 380 ºC (shatters!)
  - 4 mm – 6 mm glass (Hassani *et al.*): Upper layer temperature of ~323 ºC – 467 ºC

Glass cracking behavior needs to be studies as well

From: October 2008 presentation by Lauterberger, Uni. California

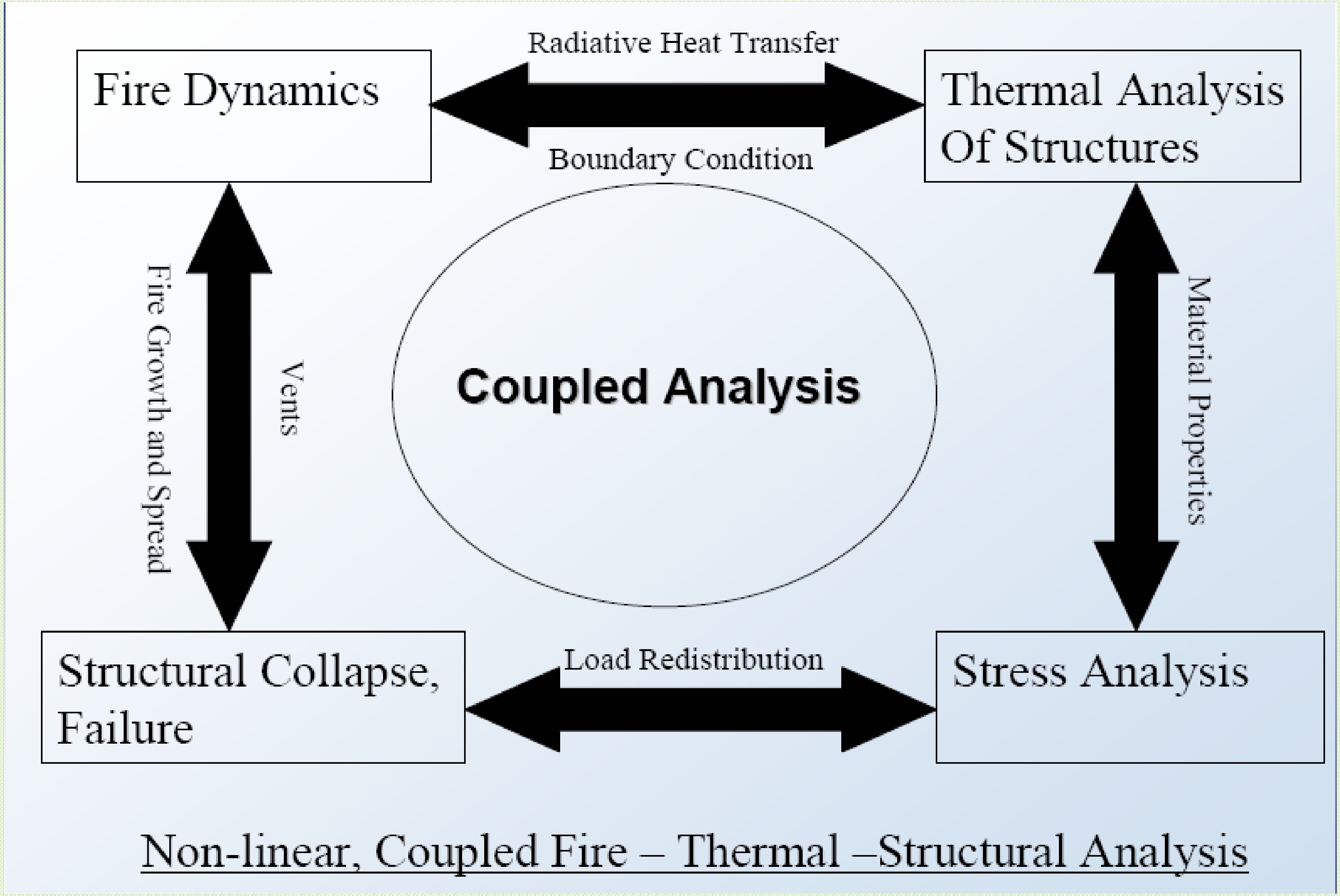


Fire Growth Modeling – Current Capabilities – Summary

- Considerable uncertainty associated with fire growth modeling
  - Can be a useful design/reconstruction tool by addressing uncertainty via sensitivity analysis

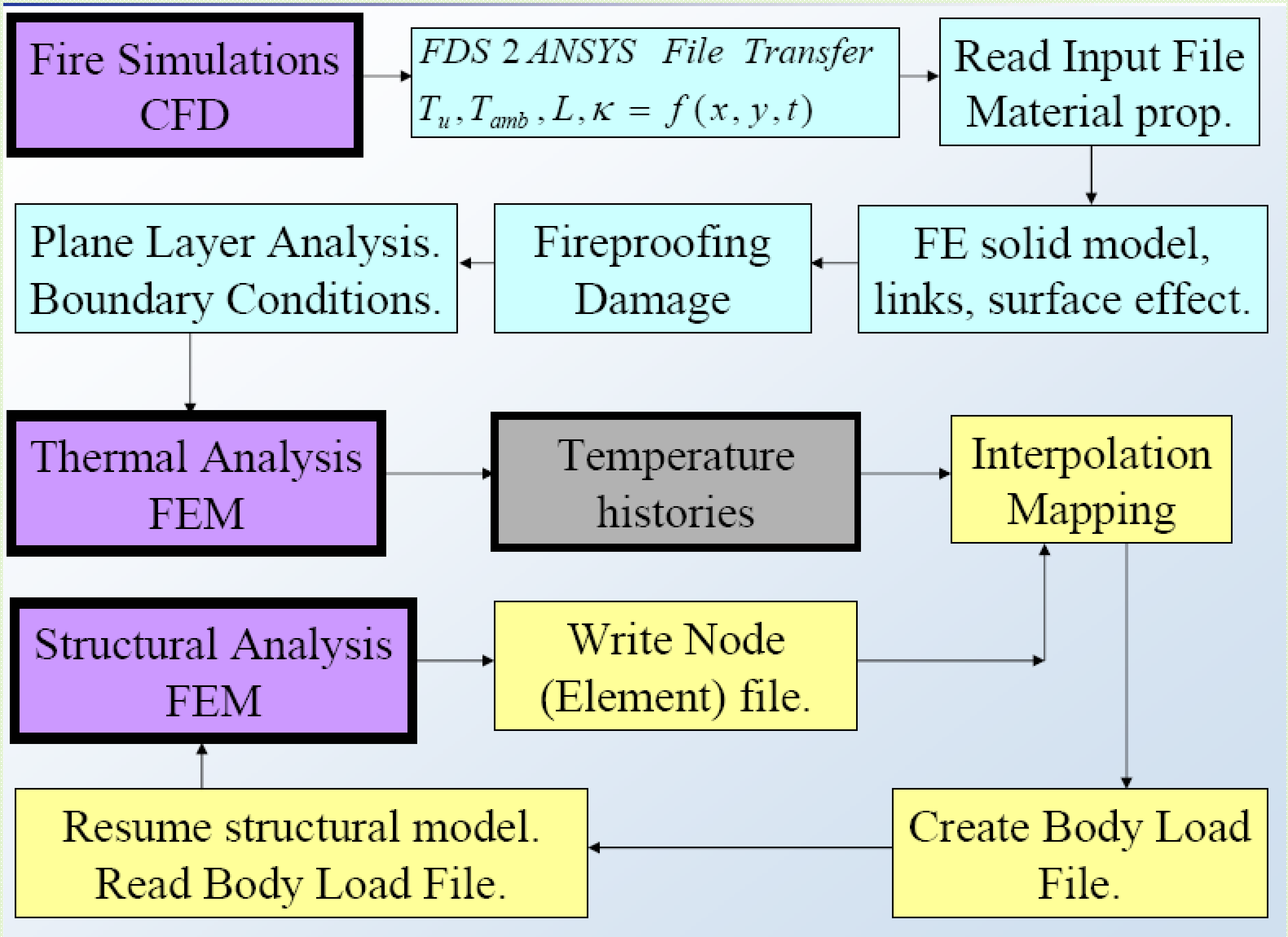
- How to improve predictive capabilities?
  - Break the problem into smaller pieces
  - Look at physical phenomena that contribute to fire growth
  - Assess model capabilities for each component separately
  - Propose new submodels to improve “broken” parts

…….Notice that this conclusion by them is in 2008



Non-linear, Coupled Fire – Thermal –Structural Analysis

From: Kuldip Prasad and Howard Baum (2004)
Building and Fire Research Lab, NIST, USA



Fire Simulations CFD

FDS 2 ANSYS File Transfer

$T_u, T_{amb}, L, \kappa = f(x, y, t)$

Read Input File Material prop.

FE solid model, links, surface effect.

Fireproofing Damage

Plane Layer Analysis. Boundary Conditions.

Thermal Analysis FEM

Temperature histories

Interpolation Mapping

Structural Analysis FEM

Write Node (Element) file.

Create Body Load File.

Resume structural model. Read Body Load File.

From: Kuldip Prasad and Howard Baum (2004)
Building and Fire Research Lab, NIST, USA

An Indian context for fire research

1. Indian researchers in combustion:fire = 100:5
2. High-rise buildings were far and few in 1990. They have increased due to increased land prices.
3. Corresponding fire related issues have enhanced (significantly?)
4. Most building clearances overseas require fire propagation studies
5. There is hardly any base for such work in India
6. It is important that this area is considered “important”

….Thanks, then