Fire research at CDM/JU

- Understand fire behavior of materials, also why?
- Provide support for performance based designs (as different from prescriptive approach)
- Provide inputs for modifications and develop fire resistant materials
- Insurance, courts and Fire dynamics simulator

H S Mukunda, IISc/CDM (JU)
hsm.cgpl@gmail.com

Why understand?

- There is a prescriptive building code to take care of fire issues. The general status is that even this is not quite followed. Why spend time to understand fire behavior?
- I wish to draw the example from the more concerned nation – the USA
- The building codes and the Life Safety Code have similar egress requirements and provide examples of prescriptive requirements. Some common means of egress limitations include:
- A 300-foot maximum travel distance in a fully sprinklered office building, per NFPA 101.
- Two required exits from an assembly occupancy with an occupant load of greater than 50 people, per the International Building Code (IBC) These prescriptive code can appear "dumb" some times. For instance……
- But then how will a performance based approach look like?

Why understand?....

"…The prescriptive requirements of NFPA 101, for example, simply state that a travel distance of 299 feet, 11 inches in an office building is acceptable, but 300 feet, 1 inch is not.

…Similarly, under the IBC, only one exit is needed in a conference room with an occupant load of 49, whereas when an extra person is added to the occupant load, two exits are required. The same line is drawn between 500 and 501 people in a floor exit scenario in NFPA 1. Prescriptive code requirements are meant to encompass the majority of occupancies and building situations, drawing upon past loss history and standard construction methods…"

But then how will a performance based approach look like?

…Performance codes?

The same requirements from a performance-based perspective might look something like this:

- Provide a maximum travel distance over which safe conditions for egress can be maintained for building occupants throughout the egress period. (These are defined as parameters that indicate the ability of building occupants to escape from a building during a fire. Examples of these parameters can include visibility, carbon monoxide levels and temperature.)
- Provide a sufficient number of exits from an area of generally high density occupant load to allow for safe egress, where the determination has been made that only a single means of egress presents an unacceptable risk.
- Provide a sufficient number of exits from a floor area where the large number of people need more than two exits from the area in the event of an evacuation.
- And also show that it performs.

Further..

Modifications are sought to be made into an existing building that could be even a heritage building. Prescription is preventive of these modifications. Can performance approach provide a solution that is “safe” and yet allow modifications?

And is the “safety” environment getting more responsive?

Karnataka high court orders Bangalore civic body to set fire safety rules

Published: Tuesday, Mar 29, 2011, 8:43 IST

The PIL filed by Beyond Carlton pleaded for passing necessary directions under Section 13 of the Karnataka Fire Force Act, 1964, enabling the director general of fire and emergency services or any other authorized person to inspect and ensure high-rise’s compliance with fire safety on a regular basis.

What is it that is meant by understanding fire behavior?

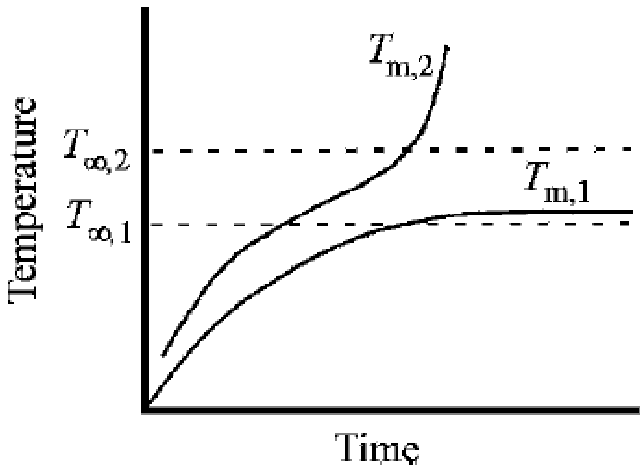
Examples from some typical situations (Indian as well).

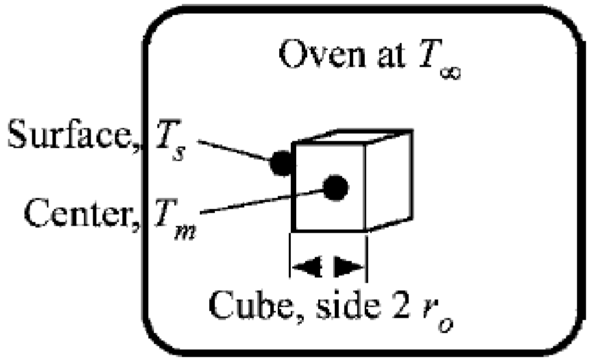
1. A half-smoked cigarette is left on a sofa unattended. – would this lead to the start of a fire? If so, can I add a fire retardant to the material of the sofa to delay the ignition? Can I prevent the emission of toxic compounds if ignition takes place at all.
2. The valve of a LPG cylinder is stuck in part-open position. It is noticed after the leakage is smelled after a while. Would this lead to a fire? an explosion?
3. A large pile of textiles is placed in a large room that has other heat generating processes going on with transfer of heat by convection and radiation to the pile. Would this lead to starting of a fire or is it safe? Is it possible to distinguish between a natural incident and arson?

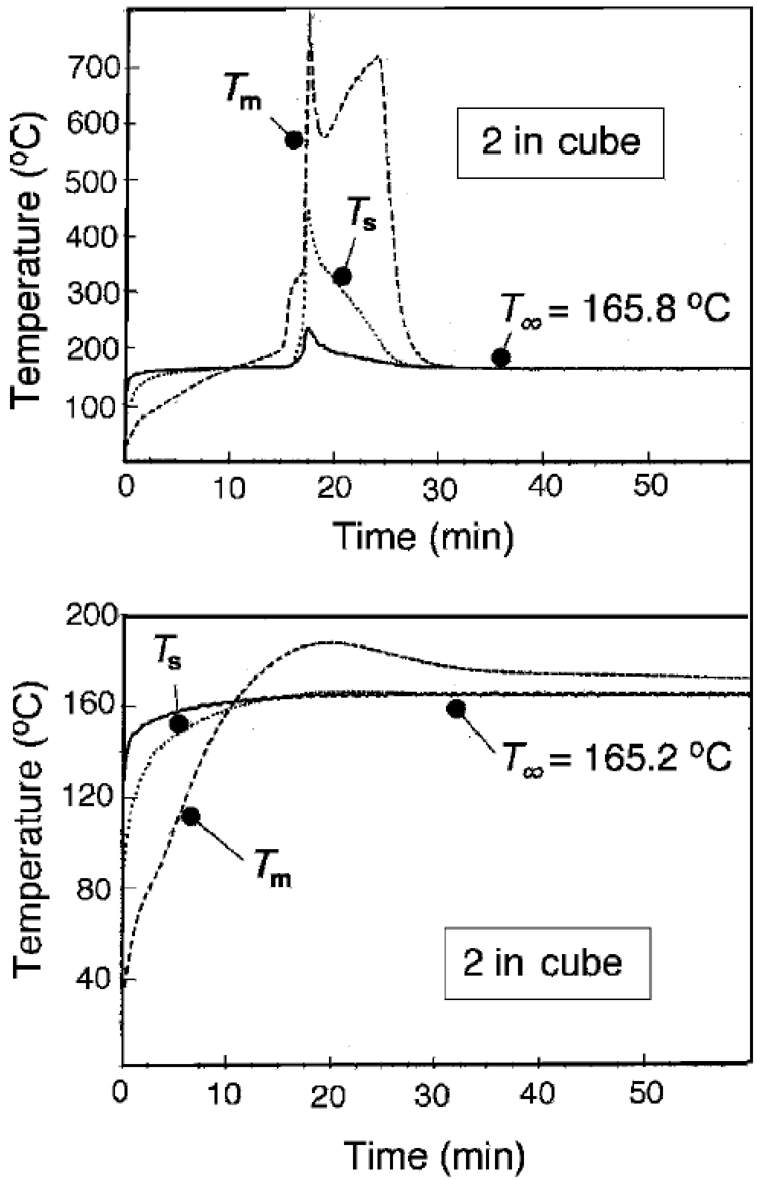
Examples….

A cubical stack of natural foam rubber pillows was stored in a basement near a furnace. That part of the basement could achieve 60 °C. A fire occurs in a furnace area and destroys the building. The night watchman is held for arson. However an enterprising investigator suspects spontaneous ignition – related to the size of the stored material, its properties and the ambient temperature.

This problem is classical in the area of spontaneous ignition of solids.







The material – compressed cotton block

Note that at 165.2°C, things are "cool"

At 165.8°C, things go overboard – there is ignition.

The cause of this sensitive dependence is The strong dependence on chemistry

$dT/dt \sim \exp(-E/RT)$

Results on critical ignition temperatures for blocks of Sawdust with and without oil

Case, $2r_0$ (mm)	Oil content %	Ignition temperature ^0C
25.4	0	212
25.4	11	208
910	0	109
910	11	65

Note that the ignition temperature is pretty low for large sizes ~ a meter

These aspects can be simply derived from theory. The size effect come through precisely.

More aspects…

- There are aspects like flame spread, fire plumes, smoke generation, toxic components in fire that affect fire safety issues.
- Experiments on reduced size models and mathematical modeling need to be developed on these aspects to get a better grip on fire problems of full scale buildings and structures.

The experimental and computational tools…

Tools of understanding and what they give

Characterization studies depend on whether one looks for gaseous, liquid or solid fuels.

The variety and complexity in solid fuels is larger – cellulosic materials like fabrics, plastics and combined products in wide spectrum of shapes and sizes.

- Equipment like TGA & DTA, Limiting Oxygen index, Cone calorimeter are commonly used
- Specifically designed "instrumented" fire tests reveal details – forensics in fire research.

Non-combustibility Apparatus

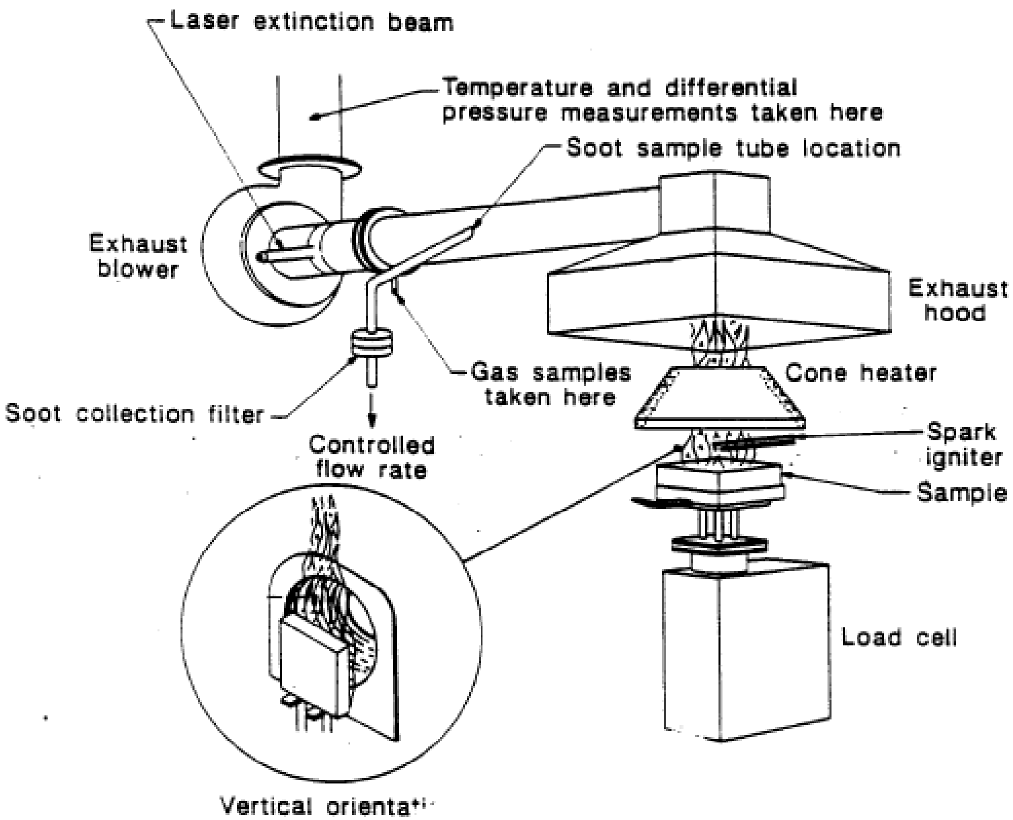
ISO 1182 / ASTM E 2652

- Checks specimen for combustibility
- Specimen (45 dia x 50 mm high) is immersed into furnace at 800 ^{0}C for 30 min
- Classified as non-combustible if temperature of specimen does not exceed 850 ^{0}C or mass loss less than 50% of initial mass

Limiting Oxygen Index Apparatus
ASTM D 2863

- Limiting Oxygen Index is the mole percentage of the oxygen in ambient air that supports a downward fire propagation rate of 20 mm/min for 3 min on a vertical dry specimen
- It establishes the relative flamability of specimen
- Lower the LOI higher will be the flamability

Cone Calorimeter



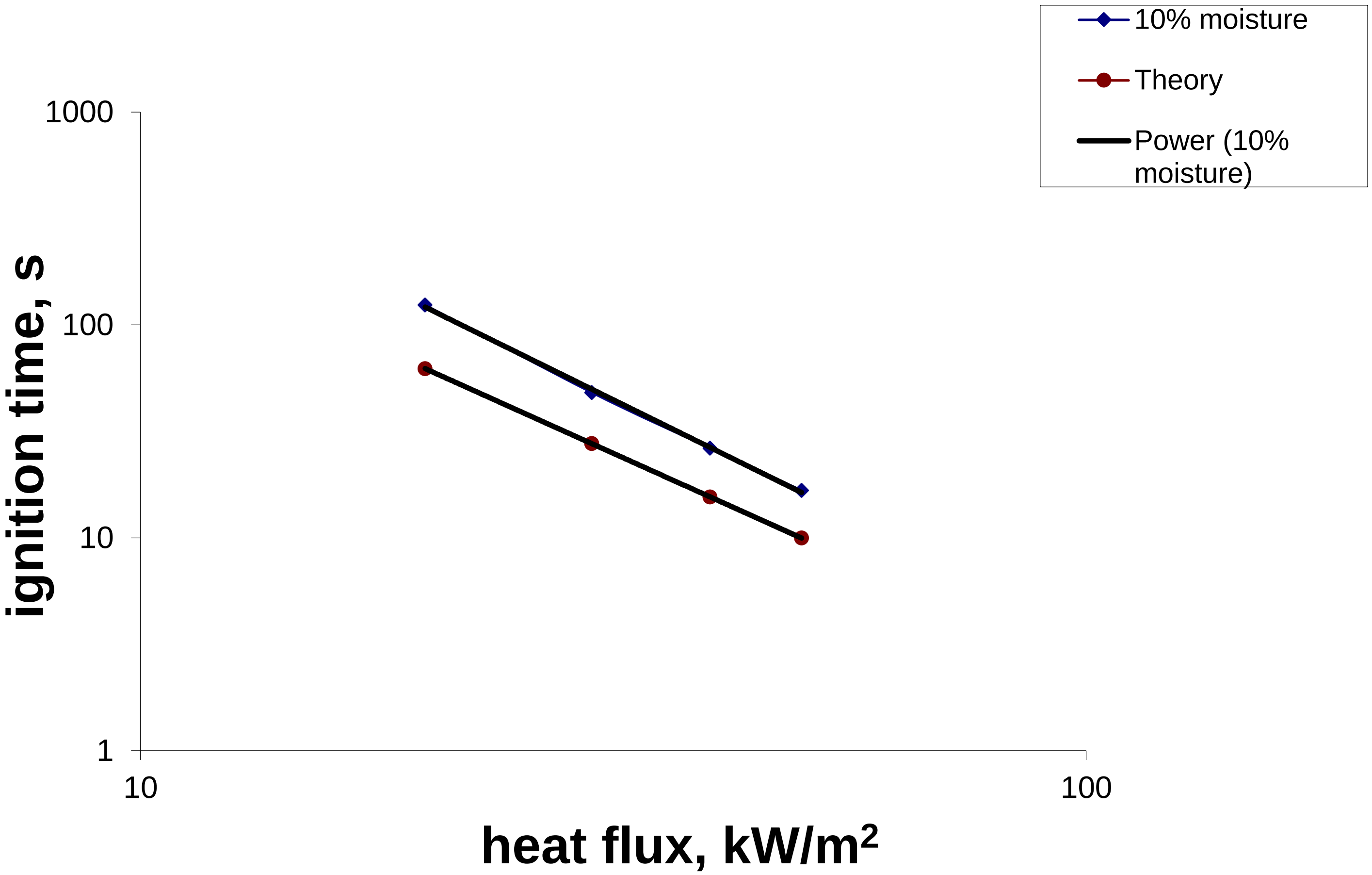
Sample 100 x 100 mm,
Up to 50 mm thick

5 kW Radiant Variable heater, up to 100 kW/m^2

Fire Dynamics Simulator (FDS)

- "The model simulates the growth and spread of a fire based on such factors as the furnishings, the walls, the floors and the ceilings".
- It is an openly available software tool that is currently the best for computing the flow field of fires in buildings and other situations (Fifth version released in 2007).
- It is yet a research tool that is acquiring greater and greater acceptability even with several uncertainties because it is improved by calibrating it against several well defined instrumented experimental fires.
- This is being adopted at CDM for understanding fires and helping development.

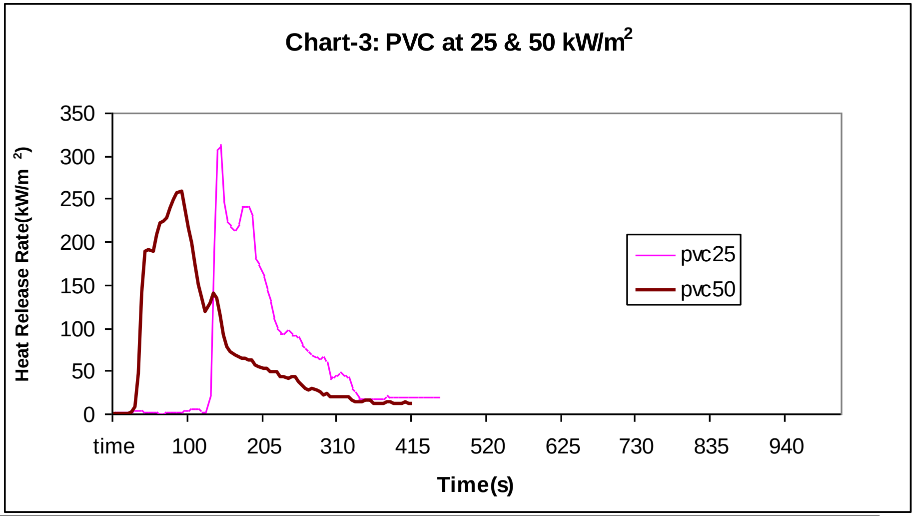
FDS at CDM on ignition of biomass

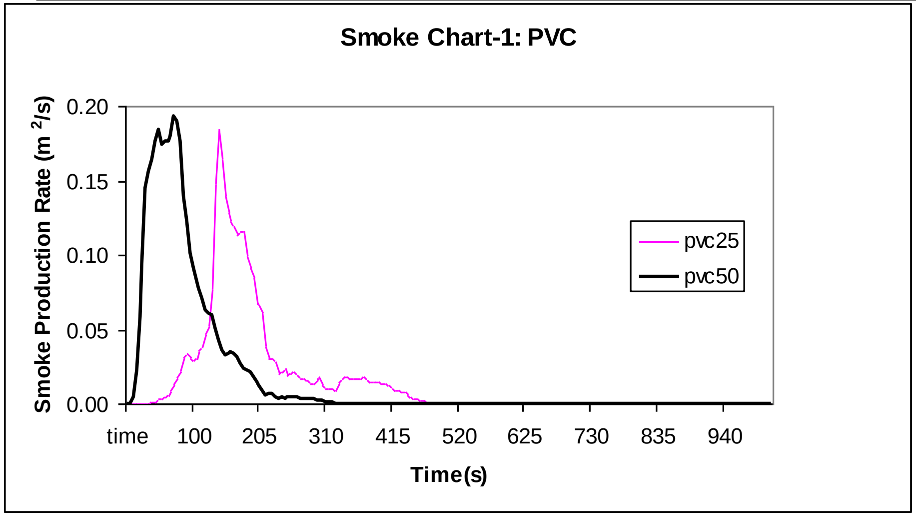


$$t_{ig} = \frac{2}{3}(k\rho c)\frac{(T_{ig} - T_0)^2}{(\dot{q}''_{net})^2}$$

Cone calorimeter data

PVC: Heat Release Rate, Smoke Production Rate - at 25 & 50 kW/m^2



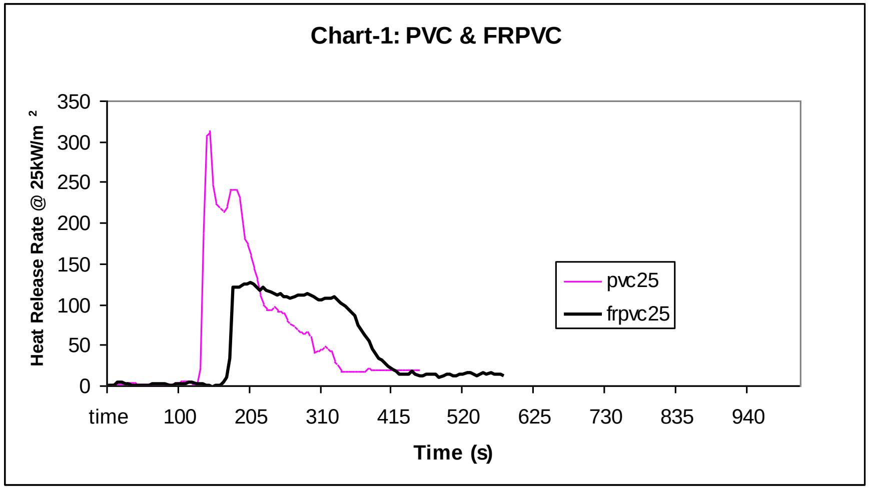


- Time to ignition is at 49s for 50kW/m^2 and129s for 25kW/m^2
- PVC begins to lose HCl at 250^{0}C
- This temperature is achieved by the surface in 16 s with 25kw/m^2 and in 10 s with 50kW/m^2 (calculated)

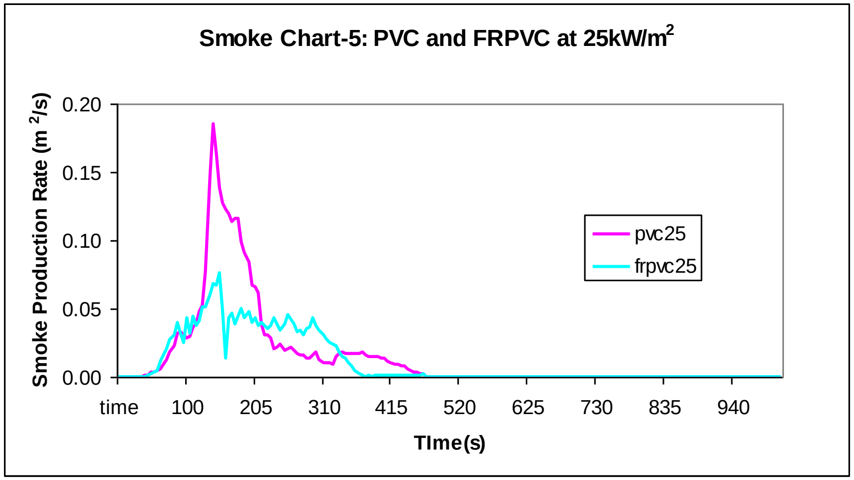
- Beginning of smoke indicates the decreasing concentration of HCl and burning of char residue
- With PVC in this case, it happens in 50s and20s with 25 & 50 kW/m^2 of irradiance respectively
- Again with 50 kW/m^2 there is a gradual increase in SPR which reaches up to 0.19 m^2/s at 100s and then drops gradually @0.05 m^2/s till 320s when all the residue burns completely.

Data from Nageshwar Rao et al, Fire and Materials Conf., 2009

PVC & FRPVC: HRR & SPR at 25kW/m^2

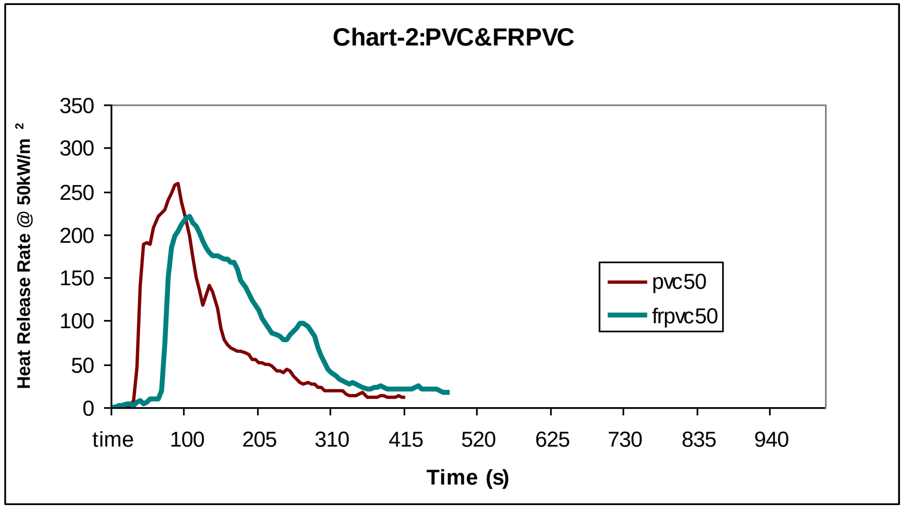


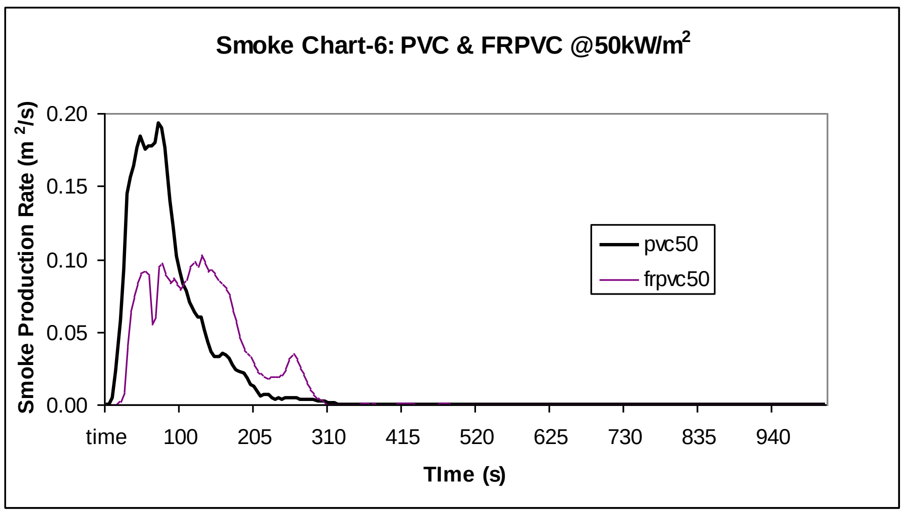
- There is a clear shift in ignition time in FRPVC with the addition of additives, while it has also extended the time of burning up to 450 s.
- There is also significant drop in peak heat release rate up to 60%



- There is significant drop in smoke production rate by about 50% with peak, but there is not much reduction in over all smoke quantity

PVC & FRPVC: HRR & SPR at 50kW/m^2





- With 50 kW/m^2, the differences between PVC and FRPVC seem marginal (~ 15 %)

- From the smoke chart it is evident that the smoke has been reduced marginally
- But the smoke is found to prevail equally long time
- The additives have helped only to slow down the reaction rate
- This indicates to the possibility of the performance of FR materials being misunderstood in various situations

FDS and fire-retardant features

1. Experiments on cone calorimeter also provide data on the complex pollutants – their composition and magnitude.
2. CO is one of the crucial pollutants causing death in fires (nearly 60 %).
3. Predicting the CO in fires is one of the aims of modeling.
4. Addition of fire retardants leads to changes in the pollutant emissions in fires.
5. Currently efforts are being made to predict the pollutant emissions.

Insurance, FDS and Courts

- Fire related insurance for dwellings and industries is a known business.
- FDS can be a better tool to set insurance premiums for complex situations that are difficult to evaluate otherwise.
- Attempt is made by insurance companies to defend insurance cases in courts, rather unsuccessfully…and successfully….

Judge Rejects Insurance Company's Bid to Use 'Fire Modeling' Results at trial (07, July 2010)

In an insurance dispute involving a 2006 residential fire, a Nassau County judge (USA) has barred the defendant insurance company from introducing the results of a computerized "fire modeling" program, which purportedly corroborate the company's claim that the fire was deliberately set.

State Farm Fire and Casualty Company sought to introduce the testimony of a University of NC (Charlotte) professor regarding the findings of a Fire Dynamics Simulator model of a fire at the Bethpage home of plaintiff.

The scientific standards for determining the origins and dynamics of fires became a national issue last year, following an article in *The New Yorker* magazine about the execution of a Texas man for a fatal fire he may not have caused.

http://www.law.com/jsp/article.jsp?id=1202463308765&slreturn=1&hbxlogin=1

NIST, FDS Software survives *Daubert challenge in Ohio*

In a recent decision, Turner v. Liberty Mutual Fire Insurance Co., 2007 WL 2713062 (N.D. Ohio)(September 14, 2007); a trial court held that the National Institute of Standards and Technology (NIST) Fire Dynamics Simulator (FDS)(Version 4.0) computer simulation proffered by the defendant's expert satisfied the Daubert reliability test governing expert testimony.

The underlying action arose from a breach of contract and bad faith action filed by the plaintiff against Liberty Mutual Fire Insurance Company for failing to pay insurance proceeds after a house fire. Liberty disclosed its liability expert, who wrote a report based on *computer software simulations* showing that the *fire was incendiary*. The plaintiff filed a Motion in Limine attacking Liberty's expert's methodologies.

Daubert Challenge?

A Daubert challenge is a hearing conducted before the judge where the validity and admissibility of expert testimony is challenged by opposing counsel. The expert is required to demonstrate that his/her methodology and reasoning are scientifically valid and can be applied to the facts of the case.

The term comes from the 1993 U.S. Supreme Court case, Daubert v. Merrell Dow Pharm, Inc., 509 U.S. 579 (1993), in which the Court set out criteria for the admissibility of scientific expert testimony.

Under *Daubert, the court provided several (non-exclusive) factors to consider in determining reliability: (1) whether the theory or technique "can be (and has been) "tested"; (2) whether it has been "subjected to peer review and publication"; (3) "the existence and maintenance of standards controlling the technique's operation"; (4) the theory or technique's "known or potential error rate"; and (5) its "general acceptance" in "a relevant scientific community."*

And further…

Court observed that

- First, the software was tested.
- FDS is described in NIST Special Publication 1018. The acknowledgments section of Publication 1018 lists various individuals who have "conducted a number of small and large scale experiments to validate FDS."
- Perhaps the best evidence of the software's acceptance is its use in three recent nationally-recognized fires: the World Trade Center collapse, the Rhode Island nightclub fire, and the South Carolina sofa store fire.

……And so, there is merit in developing skills in using computational tools for understanding fire behavior

Fires, dwellings
Experiments and FDS

Annual fire loss record for single family dwellings 1982 – 1996 (USA)

Item first ignited	Fires thousands	Deaths	Injuries	Damages, million USD
Rubbish/Trash	49.6	72	307	86
Cooking material	42.4	89	2011	126
Structural member	30.0	226	532	433
Electrical wiring	27.1	120	482	168
Matress/Bedding	20.1	390	1501	167
Unclassified material	18.8	72	377	102
Internal wall covering	16.05	199	480	215
Fuel	15.6	142	849	102
Exterior siding	12.2	17	102	103
Upholstered furniture	10.4	534	965	133

Though the combustible material per household in Indian houses will be smaller compared to USA on the average, perhaps the situation is no different in affluent multi-storey apartments; note that rubbish/trash and cooking zone lead to large number of fires.

Integrating experiments and modeling (NIST)

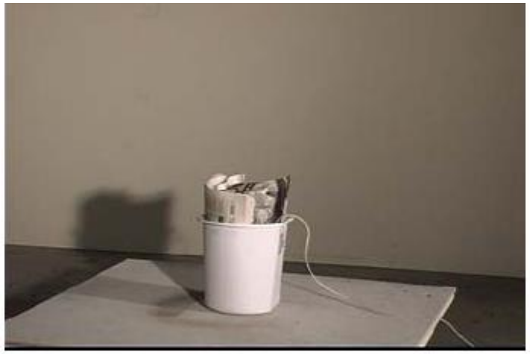


Figure 3.2-1. Trash container 1, ignition

Figure 3.2-2. Trash container 1, 100 s after ignition

Figure 3.2-3. Trash container 1, 200 s after ignition

Figure 3.2-4. Trash container 1, 300 s after ignition

Figure 3.2-5. Trash container 1, 400 s after ignition

Figure 3.2-6. Trash container 1, at peak heat release rate, 406 s after ignition

Figure 3.2-1. Trash container 1, ignition

Figure 3.2-2. Trash container 1, 100 s after ignition

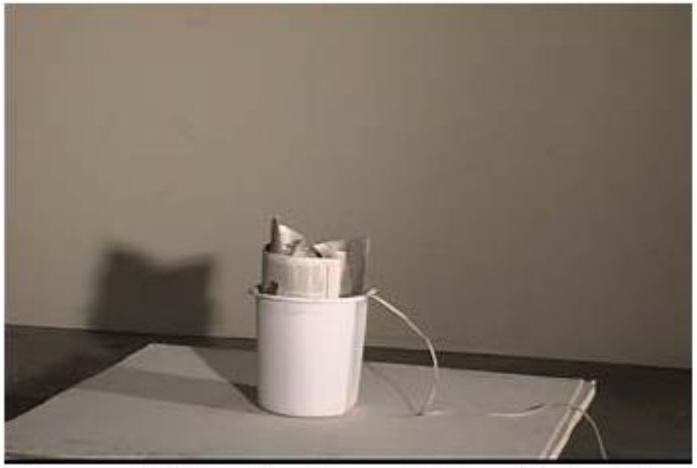
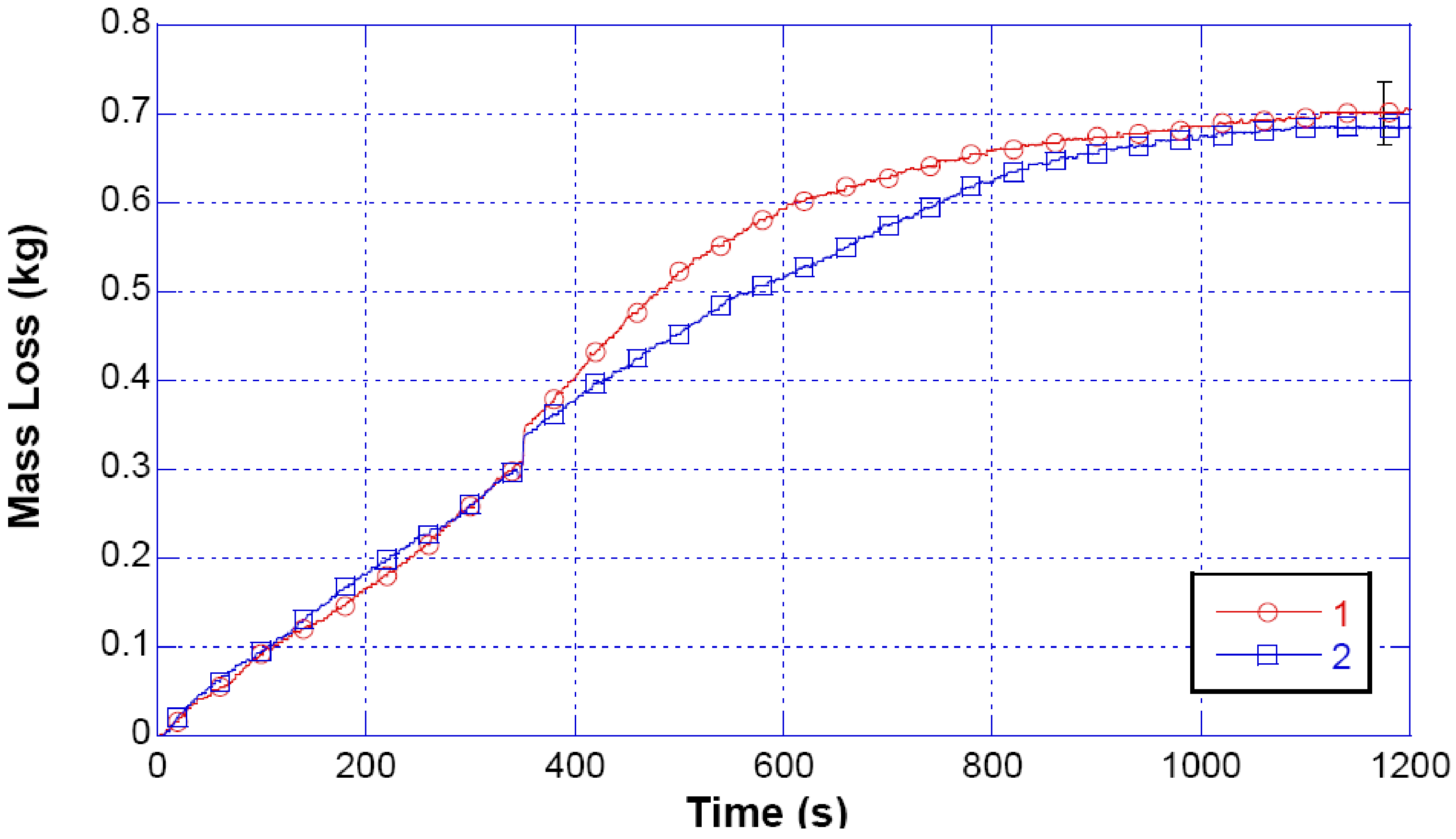


Figure 3.2-9. Trash container 2, ignition

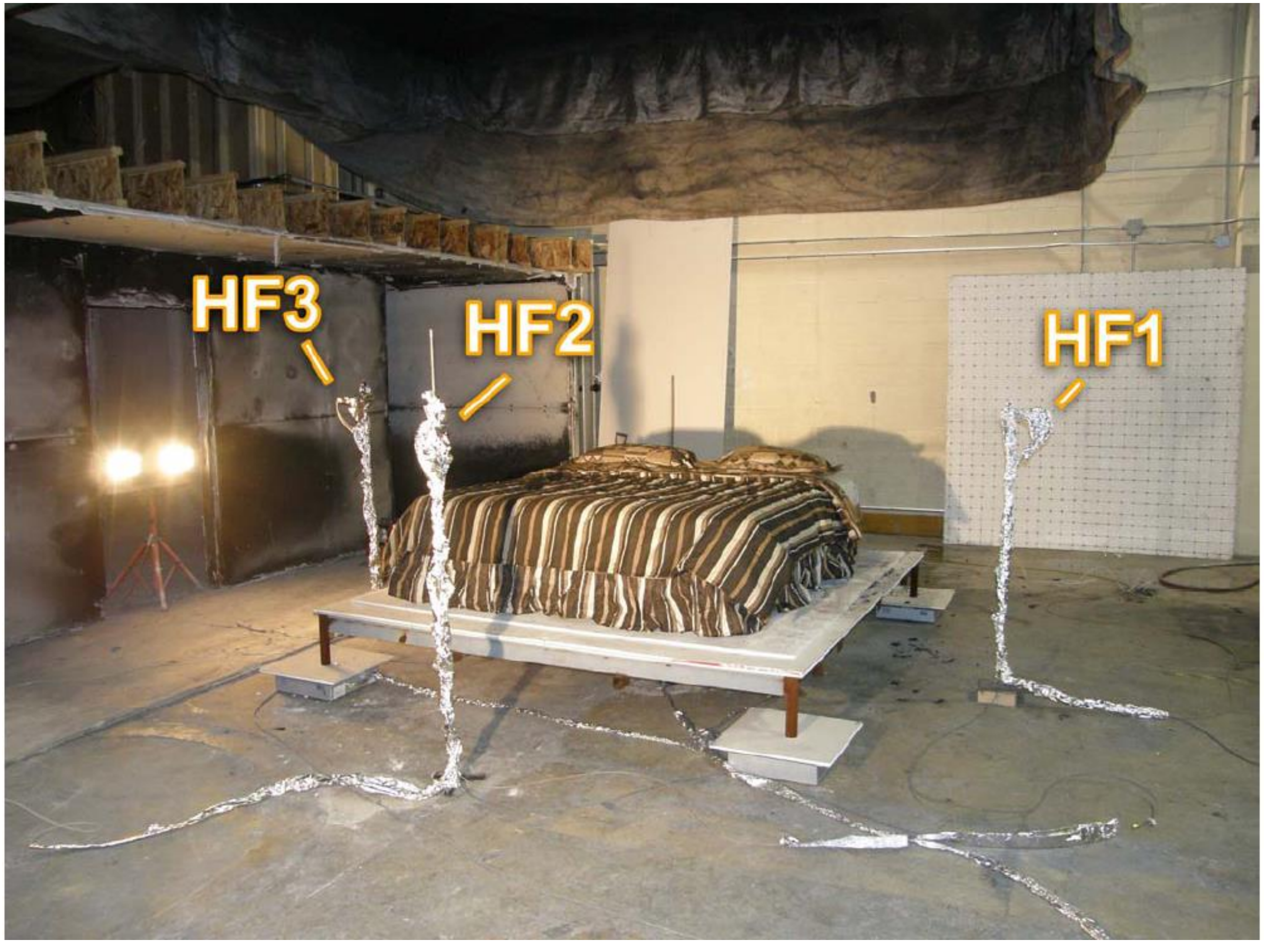
Figure 3.2-10. Trash container 2, 100 s after ignition

Comparison of two different arrangements of trash in the can



Mass loss vs. time for the two trash can experiments, other data like heat release rate and flux at a distance are also measured.

NIST experiments….



Typical heat release rate experimental arrangement, using the bed fuel package, with the heat flux positions labeled. This arrangement was used for all chair, bed, and sofa heat release rate experiments.

Figure 3.3.2-1. Bed 2, ignition

Figure 3.3.2-2. Bed 2, 100 s after ignition

Figure 3.3.2-3. Bed 2, 200 s after ignition

Figure 3.3.2-4. Bed 2, 300 s after ignition

Figure 3.3.2-5. Bed 2, at peak heat release rate, 380 s after ignition

Figure 3.3.2-6. Bed 2, 400 s after ignition

Figure 3.3.2-7. Bed 2, 500 s after ignition

Figure 3.3.2-8. Bed 2, 600 s after ignition

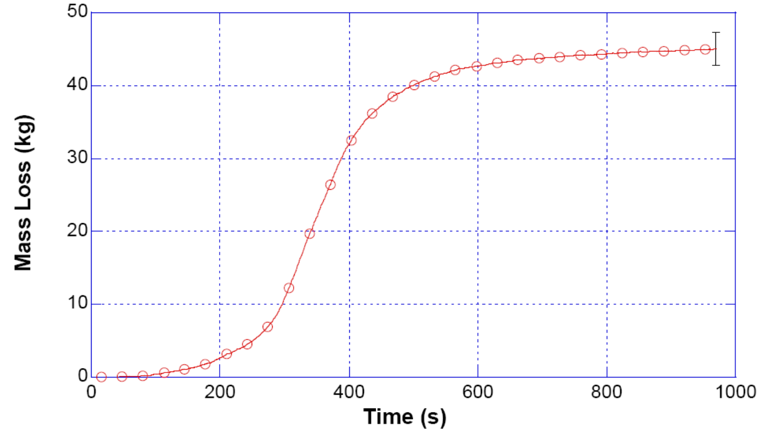


Figure 3.3.2-11. Mass loss versus time for bed fuel package 2.

Ignited by the trash can at an edge, the flame engulfs the bed in less than 4 mins after ignition and consumes it in less than 10 minutes! The mass loss rate, heat release rate and heat flux at a distance are measured

The question: Given the physical, chemical and thermodynamics properties, can we predict this mass loss? Yes (to be done, yet)

Figure 3.4.1-1. Chair 1, ignition

Figure 3.4.1-2. Chair 1, 100 s after ignition

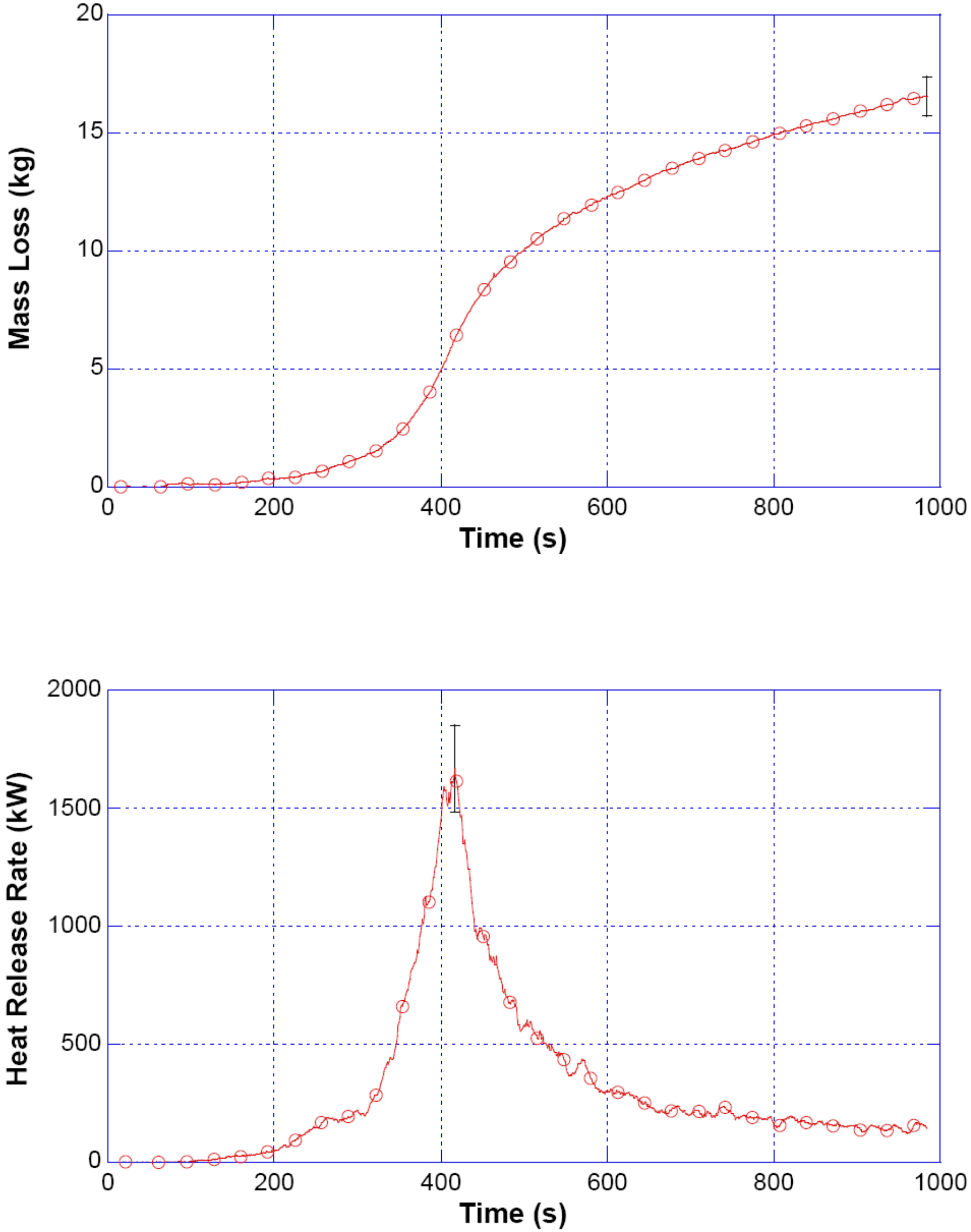
Figure 3.4.1-3. Chair 1, 200 s after ignition

Figure 3.4.1-4. Chair 1, 300 s after ignition

The combustion process is completed at ~ 10 mins.

Figure 3.4.1-5. Chair 1, 400 s after ignition

Figure 3.4.1-6. Chair 1, at peak heat release rate, 417 s after ignition



These data on realistic fire situations are the sub-elements of a complex fire situation. by modeling these phenomena using fire physics and realistic property data, it is hoped that the predictions will be realistic and practically relevant.

On other developments you have heard

- Mist and intumescent coatings have been the subject of earlier presentations.
- In each of these cases, there will always questions for which you would want an answer on the behavior apart from clearance or otherwise of a given product.
- Dealing with them needs examination of the fundamental behavior of the materials in a fire environment.
- Questions can come from UL on a given product behavior or other developers who have not succeeded in qualifying a product in a UL test, for instance – to see why things happened the way they have.
- These are also the focus of consideration at CDM (JGI). They will be jointly examined scientifically.

Summary

- Much suffering due to fires has led to greater scientific attention to and greater understanding on the subject in the USA and Europe.
- At present awareness is getting created about the subject in India. We have a long way to go.
- It appears that we cannot escape issues of insurance, litigation as in other countries.
- An important approach to help in these matters is to establish experimental and computational studies for practical benefit.
- The centre for disaster mitigation has researchers devoted to the subject of fire behavior using all fundamental tools.
- They will work in close cooperation with UL on several aspects.

……...and so invitation to you to benefit from these... Thank you