出國報告（出國類別：出席國際會議）

參加國際火災安全科學研究會議
（2014 國際防火研究領導人論壇會議）
報告

服務機關：內政部建築研究所
姓名職稱：王天志 研究員
派赴國家：美國
出國期間：103 年 9 月 21 日至 103 年 9 月 28 日
報告日期：103 年 12 月 17 日

摘　　　要

關鍵詞：防火安全、國際合作研究、熱裂解模型

為執行 103 年度內政部建築研究所預算派員出國計畫「03 參加國際火災安全科學研究會議-2B」，經簽奉由安全防災組王天志研究員代表出席在美國芝加哥諾斯布魯克舉行之「2014 國際防火研究領導人論壇會議（The International FORUM of Fire Research Directors Annual Meeting，簡稱 FORUM Meeting）」，會議期間為自 103 年 9 月 23 日起至 9 月 26 日，為期 4 天。

本年度 FORUM 會議係由位於美國芝加哥諾斯布魯克的保險商試驗所總部（Underwriter Laboratories Inc., UL）主辦，總計有 9 國 23 個組織或會員出席參加。會議內容主要包括「國際組織交流報告」、「區域會員報告」、「專題討論報告」、「會務報告及討論」等項，其中專題討論主題為熱裂解模型解析，共有 9 個合作單位報告分享，並與各代表進行意見交換與討論。會議期間同時參訪 UL 實驗設施，了解學習該實驗室試驗設備及量測儀具之建置、人員及儀器之操作模式、實驗室管理機制等實務經驗。

會議期間就各單位討論議題，適時與各會員分享交流研究成果，包括本所近幾年的研究成果如水系統保護之各種防火設備、與建築一體式太陽光電系統耐火性、利用聲光提升避難逃生標示導引等成果，以及即將進行的複合式災害之結構耐火行為等，均獲得相關會員熱烈討論。達成提升

國內研究能見度及建立與國外研究機構良好互動關係，並完成蒐集國際最新防火新知，明瞭其他國外防火研究單位目前相關研究動向，可供本所防火研究方向及未來國內研發相關技術、檢測標準、法規制度檢討之參考，亦可藉此參與國際研究合作並增加國際會議參與度。

目　　錄

第一章　目的

第一節　緣起

國際防火研究領導人論壇（International FORUM of Fire Research Directors，簡稱 FORUM)，為全球防火研究實驗機構負責人的非官方、非營利組織，設立宗旨為透過國際合作進行相關防火研究，以減少火災造成的危害。近年來，各種防火國際組織均積極邀請具代表性的單位成為會員，以擴大影響力及提升重要性，同時加速各會員間研究成果之合作與共享。本所雖為資深會員，但在各會員踴躍出席下，自應定期參加會議，藉以參與國際交流，同時將本所研究成果與各代表分享討論，促進各國對我國建築防火研究之了解。另外，也藉此機會充分吸收各國先進的研究方法、學習新式研究設備之建置、了解各國或標準組織之研究動態、建立後續研究交流之管道等，以供本所未來有關建築防火科技計劃之規劃參考。

第二節　依據及計畫內容

一、計畫依據

本所「建築防火科技發展計畫（4/4）-防火安全設計及工程技術精進研發」中程計畫

二、計畫內容

1. 參加於美國伊利諾州諾斯布魯克舉辦之「2014 國際防火研究領導人

論壇會議」。

2. 與世界各國主要防火研究機構之領導人、火災科學安全專家等進行研究心得、技術交流及相關法規、試驗標準修訂方向等討論。

3. 參訪主辦單位 UL 的實驗設施。

4. 多方蒐集國際最新防火新知，明瞭其他國外實驗室未來研究趨勢及需求,增加國際研究合作機會並增加國際會議參與度及研訂未來科技計畫課題。

第二章　會議過程

本章說明本次奉派赴美國參加FORUM年度會議成員、時間、行程及會議內容。

第一節　會議行程

一、代表人員名單

姓名	職稱	專長
王天志	約聘研究員	建築防火、結構分析及設計

二、出國期間

民國 103 年 9 月 21 日至 9 月 28 日。

三、會議行程

本次 FORUM 年度會議行程如下所示：

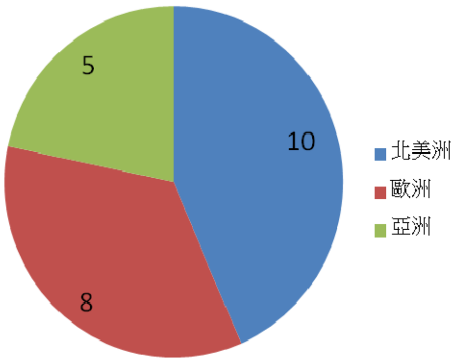
日　　期	上　　　　午	下　　　　午
9 月 21、22 日 (日、一)	路程 高雄－桃園－芝加哥	
9 月 23 日 (二)	報到、參加會議 ● 宣布開會、議程確認 ● 其他國際組織交流報告	參加會議 ● 區域會員報告 • UL • LCPP • EGOLF • ATF

9 月 24 日 (三)	參加會議 ● 區域會員報告 • ASTM E05 • ISO TC 92 • IAFSS • CIB W14 • FPRF • Brandforsk • ATF • FM globle • NIST • NRC • SNL • SwRI	● 參觀 UL 實驗設施 ● 芝加哥市區建築參觀 ● 晚宴
9 月 25 日 (四)	參加會議 ● 確認上年度（2013 年）會議紀錄及會議決議辦理情形 ● 財務報告 ● Sjölin Award 討論 ● 章程異動 ● Officers 提名及選舉	參加會議 ● 專題討論-材料熱裂解模型 • VTT • FM globle • LCPP • NIST • ASTM E1591 • LNE • SNL • FIRETOOLS • SP
9 月 26 日 (五)	參加會議 ● 未來（2015 年、2016 年）會議地點討論 ● Forum 網頁討論 ● 確認 2014 會議決議事項 ● 臨時動議	回程
9 月 27、 28 日 （六、日）	路程 芝加哥－桃園－高雄	

第二節　會議內容

一、出席會員名單

FORUM 是世界各地防火研究組織負責人連繫交流的一個組織，藉由每年定期舉辦論壇會議，了解各會員單位研究發展概況及趨勢，同時藉由不同區域輪流舉辦，可實地參訪不同區域研究單位實驗設施之種類及運作模式，對本所研究及實驗中心之運作有很大助益。本次總計 23 個單位組織參加會議，北美洲會員組織計有 10 個，包括美國之工廠互助保險全球集團（FM Global）、煙酒武器及爆裂物檢驗局（ATF）、國家防火協會（NFPA）、山迪亞國家實驗室（SNL）、西南研究所（SwRI）、國家標準技術研究院（NIST）、美國材料試驗協會（ASTM）、國際建築資訊聯盟（CIB W14）、防火研究基金會（FRPF）以及加拿大國家研究院火災實驗室（NRC-IRC）；歐洲會員組織計有 8 個，包括法國巴黎警察總局中央實驗室（LCPP）、法國國家度量衡測試實驗室（LNE）、法國營建科學技術中心（CSTB）、瑞典技術研究院（SP）、瑞典防火研究委員會（Brandforsk）、國際火災安全科學學會（IAFSS）、國際標準組織（ISO）以及芬蘭技術研究中心（VTT）；亞洲會員組織計有 5 個，包括我國內政部建築研究所（ABRI）、日本建築研究所（BRI）、日本國家消防研究中心（NRIFD）、韓國營建技術研究所（KICT）以及大陸之中國科學技術大學火災重點實驗室（SKLFS）。各區域出席統計如下：



各區域出席統計圖

二、會議簡要內容：

本次會議為期三天半，均在 UL 實驗室內的會議室進行，會議議程如附錄一，概將會議內容簡要整理如下：

（一）會務討論事項：

1. 主席 Marc Janssens 報告及調整會議議程。
2. 秘書 Franco Tamanini 報告經費帳戶更動及使用概況。
3. 請會員代表持續接洽各該區域內有代表性之防火研究組織參加或出席 FORUM 會議，例如 Yoshiyuki Matsubara (JFEII)、Ulrich Krause (Un. of Magdeburg?)、BAM 及 CFEES。
4. 本年度新增會員代表為 Ahmed Kashef（NRCC）、David Sheppard（ATF）、Stéphanie Vallerent (CSTB)、Tokiyoshi Yamada (NRIFD) ，申請中會員為 George Braga (FDFD-Brazil)，變更申請的有 Pierre Carlotti (CSTB → LCPP)。
5. 目前會員總數為 22 個，北美洲 7 個，Pravinray Gandhi (UL), Lou Gritzo (FMG), Anthony Hamins (NIST), Marc Janssens (SwRI),

Ahmed Kashef (NRCC), David Sheppard (ATF),Randall Watkins (SNL)；歐洲7個，Pierre Carlotti (LCPP), Eric Guillaume (LNE), Tuula Hakkarainen (VTT), Per-Erik Johansson (BF), Debbie Smith (BRE), Björn Sundström (SP), Stéphanie Vallerent (CSTB)；亞澳洲8個，Greg Baker (BRANZ), Ichiro Hagiwara (BRI), Ming-Chin Ho (ABRI), Naian Liu (SKLFS), Hyun-Joon Shin (KICT), Tokiyoshi Yamada (NRIFD),Shuitsu Yusa (TBTL), Qinglin Zhang (TFRI)。

6. 討論有關補助主辦 FORUM 年會經費及補助研究學生參加國際研討會事宜。
7. 請秘書單位收集彙整有關 FireToss 軟體應用可用性及目前研究概況，並提供給會員參考。
8. FORUM 網頁資料更新及相關網站連結訊息。
9. 下次會議主辦單位及地點事宜：配合第10屆亞澳火災科學技術國際研討會（10th Asia-Oceania Symposium on Fire Science and Technology)明年10月在日本筑波(Tsukuba, Japan)舉行，明(2015)年 FORUM 會議擬一併於該地點附近舉行，日本國家消防研究中心（NRIFD）為主辦單位，會議舉辦時間則再與各會員討論後決定。

（二）區域會員及國際組織交流報告：

此部份報告會員包括 UL、LCPP、KICT、NRIFD、NRCC、NIST、ASTM E05、ISO TC92、IAFSS、CIB W14、FPRF、BF、ATF、FM Global、NIST、SNL、 SwRI、NRIFD 及 ABRI。各單位分別就其單位歷史沿革、組織、研究人力經費、國際合作以及近年來所進行的研究項目與成果等介

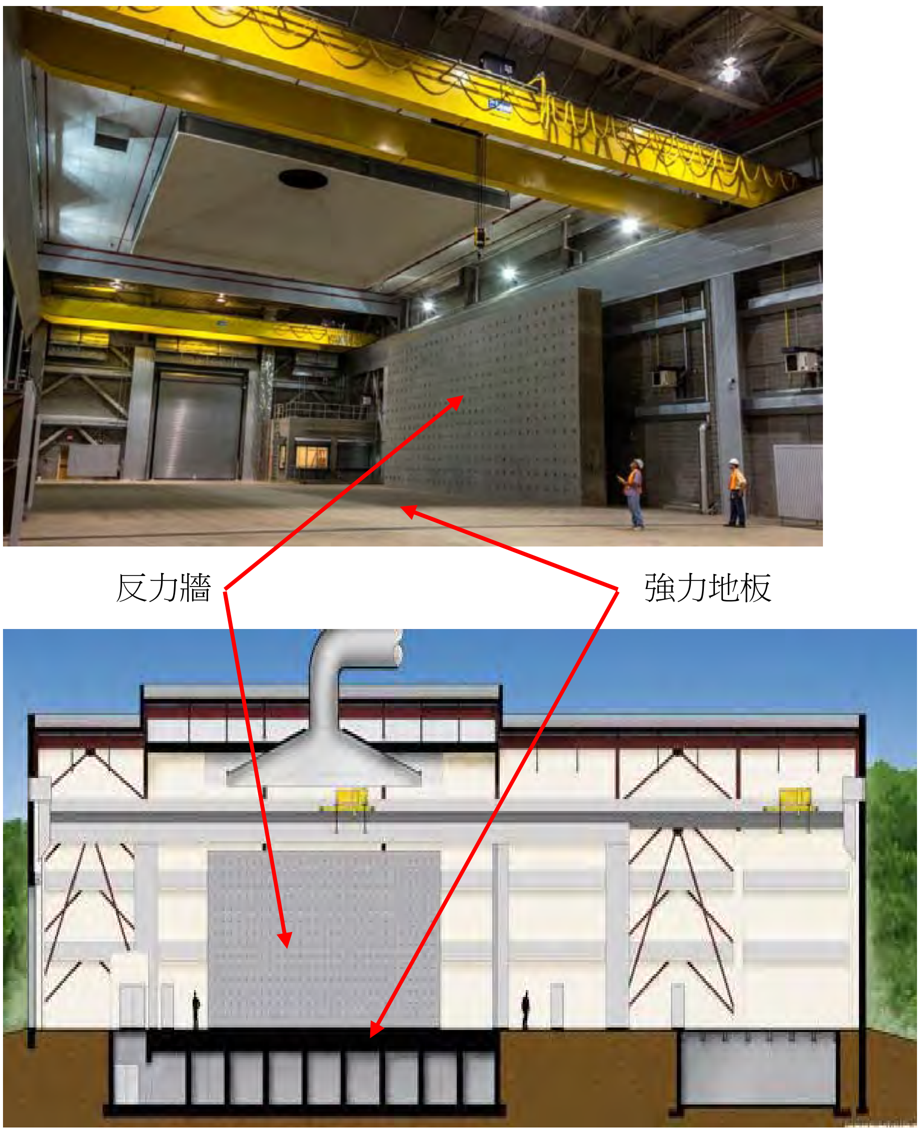
紹。因 FORUM 為國際防火研究領導人論壇，從這些單位的報告可吸收到各領域的防火研究對象與知識，包括交通工具（車輛、火車或捷運、飛機與船舶等）火災、鐵公路隧道火災、工業火災、軍武火災、森林火災、再生能源火災以及建築火災等。研究型態包括燃燒、火災、煙毒、爆炸、鑑定、避難逃生、主動式消防設備以及風險評估等。另外本所由王天志研究員介紹本所近年來之研究內容，主要包括內填充混凝土箱型鋼柱耐火性能、太陽光電板系統耐火性能、結合水系統隔熱之各種分隔構件設備耐火性能以及即將進行之大型實尺寸鋼構架複合式災害下耐火性能等。各單位簡報內容，詳如附錄二，僅摘錄部分本所業務有關之重要簡報內容如下：

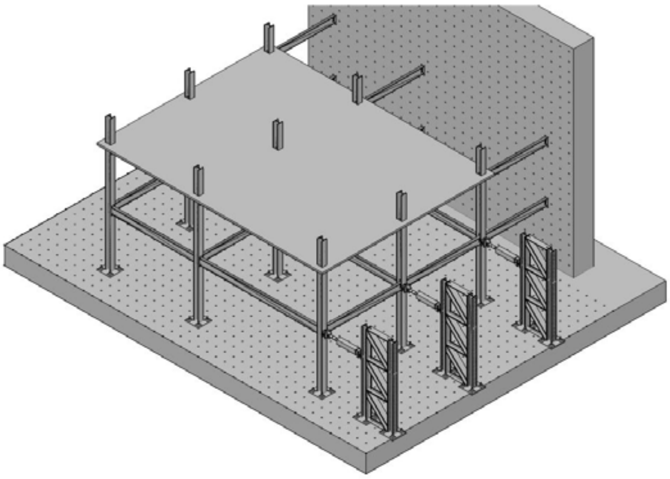
- NIST：其主要宗旨為藉由量測科學降低火災所造成的人命及社會成本，研究範圍包括材料、模擬、量測、調查鑑定以及標準化。在材料研究上特別針對創新的製作程序和材料（例如層狀噴塗、奈米管、奈米纖維和生物材料等）。在火災模擬上，預期在運用性能式設計下進行火場重建、避難逃生設計及結構耐火分析等用途。另外進行火災模擬時會結合氣候模擬軟體同時考慮建築外在氣象影響因子分析。

  自從美國 911 事件後，NIST 即致力於建築結構火害中及火害後行為研究，有鑒於世界部分研究單位已建立加熱中可同時加載的試驗設備，因此建置了可進行實尺寸、實場火災試驗設備，可更精確了解火災-結構之交互作用。該設備為將結構體構築於強力地板上，加載系統安裝於強力

地板及反力牆上，另於結構體內進行實際燃燒行為，可在加載下，同時觀察量測燃燒從起火、成長、旺盛期直至衰退期之結構行為。設備規格為反力牆 60 ft. x 90 ft. x 4 ft.，強力地板 60 ft. x 30 ft. x 4 ft.；油壓加載系統為 55-215 kip.，加載行程為 30 in.。

另外，該實驗室原有 1、3、10 MW 量熱裝置，新增 20 MW 量熱裝置，以量測更大規模的物體熱釋放率。





結構框架安裝於反力牆及強力地板示意圖

20 MW 大型量熱裝置

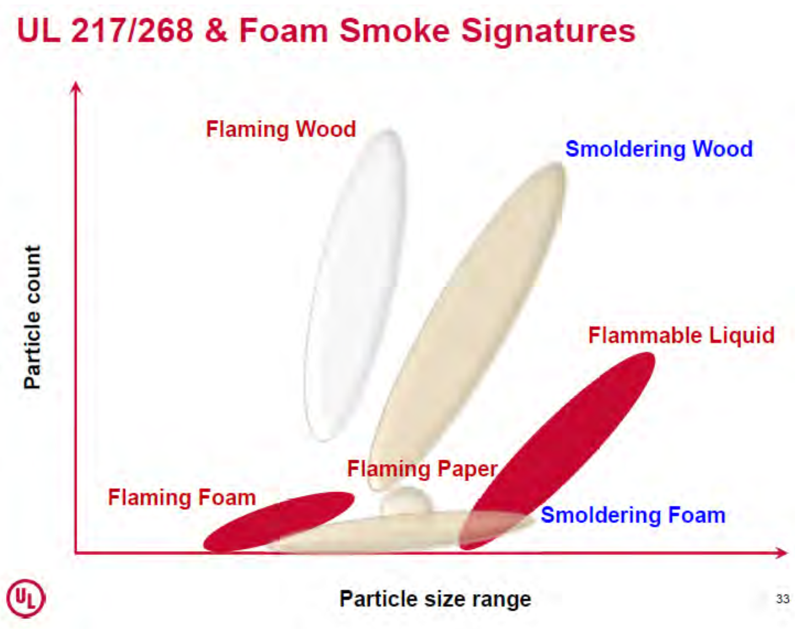
- UL：近年來研究項目包括地下室火災、消防員安全、光電板系統火災、垂直通風的影響、紐約總督島火災試驗、閣樓火災、正壓通風影響性等。目前研究重點為耐燃性試驗資料的解析

- 影響關鍵因子、複合材料的行為；認證後市場追蹤監控的適用性- 抽樣次數、實務統計控制限制；發展微燃燒量熱儀設備應用 MCC 替換 UL 94 試驗（目前著重在建築內部連接纜線及家電類材料的特性比較）驗證比對；建立用於預測模擬最終產品性能試驗的輸入資料庫。

發展微燃燒量熱儀設備應用，Micro-Combustion Calorimeter，MCC，ASTM D7309-13　用微燃烧量热仪测定塑料和其他固体材料的易燃特性，試樣僅需 2-5 mg 。

微燃燒量熱儀 Micro-Combustion Calorimeter，MCC

在煙的研究方面，持續針對不同材料所產生的煙粒子特性，包括煙的形成、偵煙器的反應、避難逃生安全以及標準或法規的建議修訂來進行，根據目前的研究成果（如下圖），提出偵煙器產品標準 UL 217/268 STP 的修訂，建議加大煙顆粒性質量測範圍，包括煙顆粒大小、數量、粒徑分布及顏色，以確保符合現代材料燃燒煙產物特性。



不同材料所產生的煙粒子特性

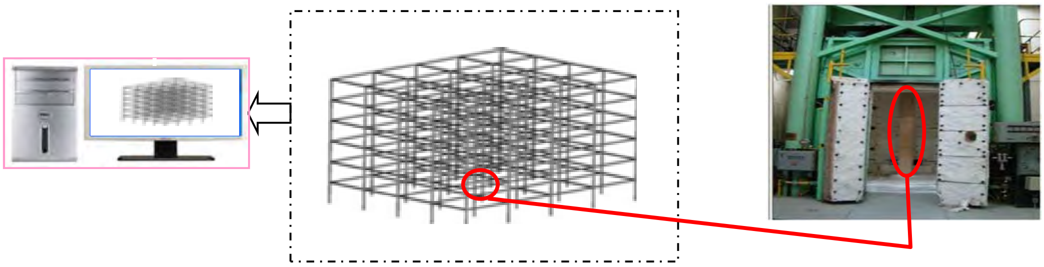
UL 近期也針對安裝太陽光電板系統對建築火災危害進行測試及探討，包括光電板系統對屋頂火災成長之影響、光電板系統耐火等級與屋頂防火之關係、光電板系統火災對消防員安全性以及相關建築法規之修正。

光電板系統安裝於屋頂

UL 790 光電板系統耐火測試

- NRCC：該單位在火災安全研究領域，包括被動式建築構造防火、主動式滅火系統、煙控、避難逃生、消防搶救安全以及風險管理等。

近期在建築構造防火方面，主要進行複合式火災試驗同時進行數值模擬評估結構耐火性能。利用 1 個 6 層樓建築，考量結構支撐的拘限以及荷重重分配的影響。



在避難逃生指示研究方面，為加強火場內避難逃生指示有效性，提升人員避難逃生指示，近期研究導入螢光材料於避難逃生指示，以供緊急電源失效時之避難導引。

螢光材料避難逃生標示

- 其它研究單位較具特色的研究項目綜整如下，FM Global的倉儲貨架工業火災以及搭配水系統滅火之行為、SwRI的核電廠開關室以及電力電纜火災、LCPP的隧道及地下車站的火災及煙控、FPRF的永續建築（綠建築）防火、BF的局部火災對梁構件的影響以及生物燃料之儲存安全，再生/替代能源之火災危險性（生質燃料、電動車電池及其停車空間安全性、光電板系統、風力發電機、平板電視火災）

等。

（三）熱裂解模擬工作會議報告：

熱裂解模擬及試驗研究合作始於2013年，目的為借由各會員代表之參與，建立並提供給實驗室材料熱裂解研究共同的參考準則。本次會議共有VTT、FM Global、LCPP、NIST、SwRI、LNE、SNL以及DBI等8個單位進行現狀成果收集報告。因各案報告主題相同，茲將報告綜整簡述如下，重要簡報資料詳附錄三：

- 燃燒行為研究為一連續性尺度過程，從材料特性、燃燒行為反應到系統耐火性。

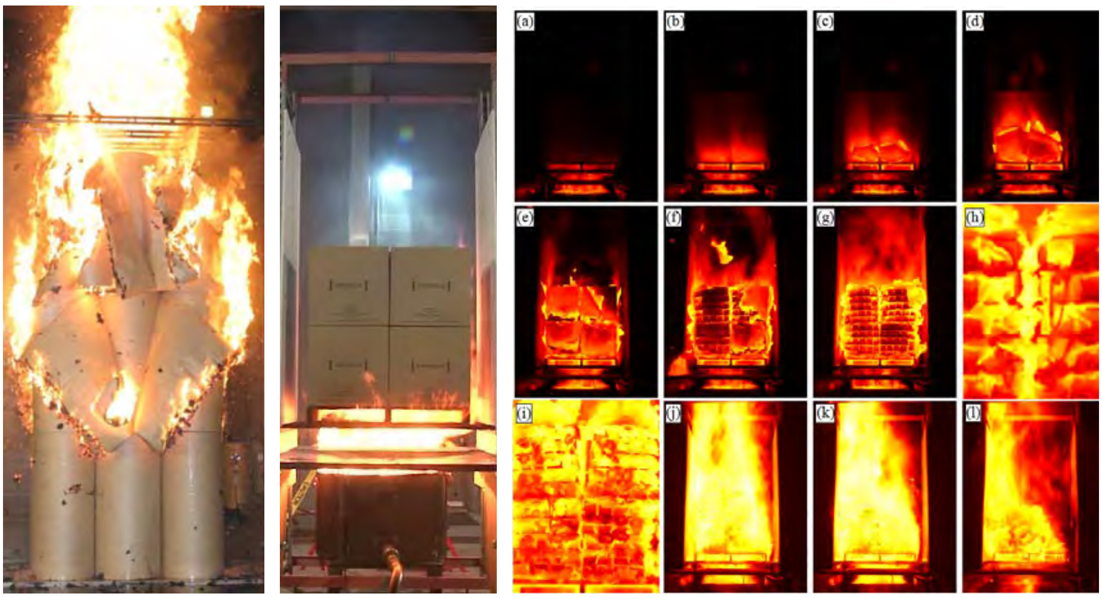
連續性尺度	微觀	材料	產品	系統
研究對象	原分子	板材/複合材	家具/裝潢/物品	完整單元

- 裂解模型研究的目的：以必要和充份的學理建構最簡單的模型，試驗室試驗的數據，以試驗和模型數據比對，最終轉換成模型和最佳化；探討的物理和化學現象包括能量轉換、質量轉換、化學反應、化學動力學、結構變化、碳化後空氣層、邊界條件變化。
- 近期探討研究應用包括交通運輸工具纜線燃燒、核電廠用電纜燃

燒、大型紙捲/紙箱倉儲貨架燃燒等。

- 熱裂解燃燒模型的未來探討重點，包括複合式/複合材燃料、奈米材料、材料幾何不規則、燃燒行為結合外在氣象條件等。

VTT的電纜熱裂解燃燒模擬



FM Global 的大型紙捲及紙箱貨架火災實驗

會員代表進行會議情形1

會員代表進行會議情形2

會員代表進行會議情形3

與美國ATF、韓國KICT及中國大陸SKLFS代表於晚宴中合影

第三章　UL 實驗設施參訪

有關該實驗室研究試驗設施設備介紹，如下所示。

UL院區外觀　　　　UL院區入口

UL防火安全實驗室1　　　　UL防火安全實驗室外觀2

參訪前工作人員講解及領取安全裝備（安全帽及護目鏡）

Evacuation Procedures

Emergency evacuation routes are posted throughout the building. All fire exits are marked with signs. In the event of an emergency, your escort will direct you to the appropriate exit and assembly location.

Exterior Evacuation:

- Continuous audible alarm with visual notification strobes will alert you.
- Immediately exit the building upon alarm notification and follow your escort to the nearest emergency assembly area.

Emergency Procedures

Tornado Alarm:

- Continuous verbal announcement will alert you.
- Stay away from windows and proceed with your escort to the nearest tornado shelter.

Medical Emergencies:

- For life threatening medical emergencies call 911 immediately and then contact loss prevention. (x42000 or 847.664.2000)
- For non-life threatening medical emergencies notify your escort and report to Health services.

Northbrook Visitor Safety Guidelines

333 Pfingsten Road, Northbrook, IL 60062-2096 USA

24 hour site Emergency Number: EXT. 42000 or 847.664.2000

General Information

- Upon arrival and prior to departure, all visitors must sign into iVisitor at the reception desk(s) or security office.
- All visitors are required to review this booklet.
- Access to laboratories and testing areas is limited to authorized personnel and their visitors. Visitors must be escorted at all times, and must remain in designated areas.
- Cameras and recording devices are prohibited, unless authorized in advance by UL in writing. You are being given access to relevant laboratories and testing areas in order to witness testing and other activities. However, this access cannot compromise the confidentiality of other clients.
- Do not examine product samples or access confidential information that does not belong to you. Do not use, disclose, or transfer any confidential information that you observe during your visit without UL's prior written consent. In addition, please do not touch or handle anything in the laboratory and testing areas, unless authorized.

Hazard Awareness

- There are a variety of hazards present in labs such as, but not limited to smoke, fire, chemicals, electricity, slips, trips, and falls, as well as forklift traffic. There are also overhead hazards, such as cranes and hoists.
- While you are in the lab, your escort will warn you about any immediate hazards that are present. Follow all of the instructions given by your escort. Your escort or UL staff will also instruct you when it is safe to be in laboratories and testing areas during set-up, testing, and post-testing.
- Floors are often marked with lines that identify safe aisle ways and viewing areas. Remain in areas designated by the marked floors or posted signs.

Emergency Telephone Numbers

Medical Emergencies: 911

Health Services: 42291

Loss Prevention: 42000

EHS: 42760

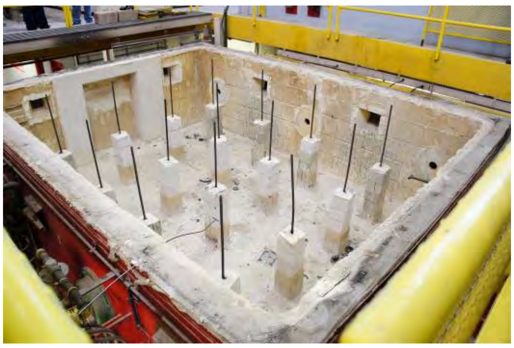
Personal Protection

- Personal Protective Equipment (PPE) is required in all laboratory and testing areas.
- Entrances are marked with signs indicating the minimum PPE required for entry. At the very least, this means safety glasses and shoes that have a closed-toe and closed-heel.
- In some laboratory areas, approved steel toe safety shoes are mandatory for entry. In addition, safety equipment such as hard hats and hearing protection must be worn in posted areas. If respiratory protection is required, you must follow your employer's respiratory protection program, and you must bring your own respirator.

UL 實驗室訪客安全指引

避難逃生路徑平面圖

高壓危險氣體存放



水平耐火試驗爐

垂直耐火試驗爐

承重牆試體框及其下方加載設備

非承重牆試體框及門試體

注水試驗設備及試體位置排水設備

貫穿部耐火試驗試體

樓板試體吊裝

大型圓錐量熱裝置

可動樓板加撒水設備

ASTM E84 試驗設備

NFPA 285 外牆延燒試驗設備及試體

第四章心得與建議

1. FORUM 組織為世界各地防火研究組織負責人所組成的國際性組織，會員遍佈全球各區域，研究領域也相當多元，因此在眾多會員與會及報告下，本所有必要持續參與此組織及會議，說明介紹本所的研究設備與能量，以提升本所甚至我國在全球防火領域地位，並藉由與其他先進研究單位交流或合作，對本所研究有極大助益。
2. 本次會議除各單位會員與會外，另有多個國際組織參與會議，例如 ISO、CIB、ASTM 等，經由各國際組織的報告，可發現各組織皆積極招攬會員，並注重各區域代表的均衡，以期其研究或規範標準能更容納各區域的研究成果，並於未來能主導或影響未來的發展；對於這類國際組織有些是標準的制定或是較為實際的技術規定，值得本所積極參與，以了解並掌握標準的動態及其制訂原由。
3. 借由區域會員及國際組織交流報告，可了解本所近年來科技計劃研究方向，除了因應我國國情及當下社會需求外，很多的研究項目均與國際研究動態相符，例如水系統隔熱、太陽光電耐火性以及實大尺寸結構複合式災害耐火性等研究，值得本所與其他研究單位進一步互相交流或合作。
4. 另外在會議報告中，可發現幾個與建築相關的研究課題，或可提供作為本所未來科技計劃研究規劃，包括（1）電動車停車空間的相關防火、（2）火災模擬結合氣候氣象風場模擬、（3）新型/複合材料或不規則形材料的基本燃燒性質測定、（4）再生/替代能源系統的防火性（包括

生質燃料、電池、光電系統、風力發電等)、(5)實大尺寸結構複合式災害耐火性以及(6)永續建築的防火性等。

5. 本次會議參訪 UL 實驗室，因該實驗室亦接受外部單位委託測試，因此除了部分設備正進行委託測試不便參觀外，其他設備均詳細解說，對於參訪者安全，除了常見的安全帽外，也提供了護目鏡，另外每位參訪者均發給 1 張訪客安全指引，告知安全需知及緊急狀況之處置。另外在垂直耐火試驗試驗框存放區，其上方的天車軌道可做不同區域的換軌連接，可以有效運用室內空間，值得參考。另外其外牆延燒試驗設備，其試體安裝、燃燒器噴嘴處理及設定，可提供本所相當多的實務操作經驗。。

在經歷 3 天半豐富又緊湊的開會後，會議圓滿成功，藉由參加此項會議，了解各單位會員研究近況、成果分享並可跨領域的共同討論各種研究的可能性，吸收全球各區域在防火研究裡的策略與方向，獲得許多寶貴的資料，可做為本所防火科技計畫未來研究發展的參考。

附錄

FORUM 會議相關資料

本頁空白

附錄一

2014 FORUM Meeting Agenda

The International FORUM of Fire Research Directors Annual Meeting

Tuesday, 23rd September, 2014 through Friday, 26th September, 2014
Host: Underwriters Laboratories (UL)
Venue: UL Headquarters, 333 Pfingsten Road, Northbrook, IL 60062, USA

<u>Tuesday, 23rd September</u>

09:30 Welcome (UL)

10:00 Announcements and review of the agenda (Marc Janssens)

10:30 Liaison reports:
- ASTM E05 (Marc Janssens)
- ISO TC92 (Patrick van Hees)
- IAFSS (Patrick van Hees)
- EGOLF (TBD)
- CIB W14 (George Hadjisophocleous)
- FPRF (Casey Grant)
- Brandforsk (Per-Erik Johansson)
- *Fire Safety Journal* (José Torero)

12:30 Lunch

13:30 Regional member presentations:
- ATF
- FM Global
- NIST
- NRCC
- SNL
- SwRI
- UL

17:00 Adjourn

18:00 TBD

Wednesday 24th September

09:00 Workshop

Possible Topics:

- Protecting Storage of Li-ion Batteries
- Aggregating Fire Safety Data Globally
- Pyrolysis Modeling

12:30 Lunch

13:30 Tour of UL facilities

17:00 Adjourn

18:00 TBD

Thursday 25th September

09:00 Regional member presentations (continued, if necessary)

10:00 Members-only session[1]

- Approval of the minutes from 2013 meeting (Franco Tamanini)
- Status of action items from 2013 meeting (Franco Tamanini)
- Finances, Membership (Franco Tamanini)
- Sjölin Award
- Bylaw Changes (Membership Eligibility)
- Nomination and Election of Officers

noon Lunch

13:00 Collaborations

17:30 Adjourn

18:00 TBD

[1] All sessions are open to visitors unless otherwise stated. No material presented can be distributed outside of the FORUM meeting without the express approval of the organization that is its source.

Friday, 26th September

09:00	Members-only session
	• Future meeting sites
	  - 2015, Asia/Oceania (TBD)
	  - 2016, Europe (TBD)
	• FORUM website
	• Review of action items (Franco Tamanini, members)
	• Other new business

noon	Lunch
13:00	Adjourn

附錄二

會員研究近況報告簡報資料（英文）

FORUM

September 23 – 36, 2014

UL LLC

Northbrook, IL 60062

Presentation Outline

- About UL
- UL R&D Structure
- Fire Research
- Q & A

UL Mission

TO PROMOTE SAFE LIVING AND WORKING ENVIRONMENTS FOR PEOPLE

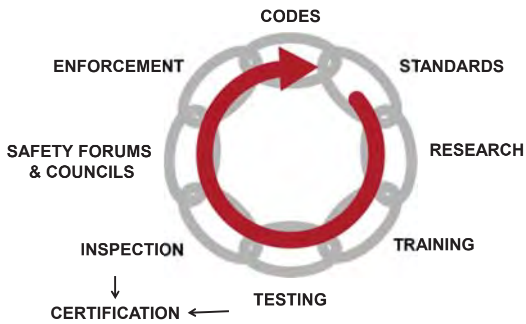
It all started with the Columbian Exposition (1893)

Electricity Building

William Henry Merrill's genius

- Recognized the need for developing standardized methods to test products for easier comparison of results. Started to publish the test methods as "test standards".
- First published "list" of approved electrical fittings and devices in 1897 and included items such as wire, conduit, rosette light sockets, and receptacles; resulting in "Listed" products we see now.
- Saw the need for regular monitoring (re-examination) for manufactured products. UL's Follow-Up Services was started in 1904.

UL and the US safety ecosystem



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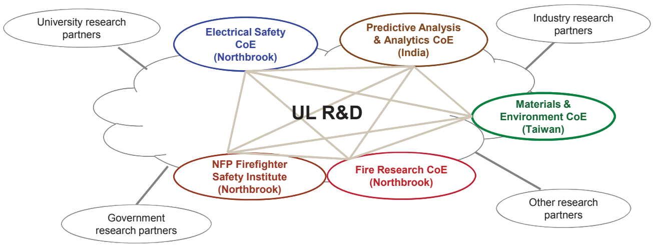
R&D Structure:
Global platform UL Safety Research



Center of Excellence (CoE) is a combination of expert staff, equipment and facilities in a strategic global location with a defined research focus. CoE's collaborate across geographic and technical boundaries creating a global platform for accelerated knowledge generation and discovery

R&D Supports UL Business and Mission

- UL Standards
- Safety Research
- Process Improvement
- New Services
- University Engagement

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Fire Research

Firefighter Safety Institute
create unique center to investigate Firefighter safety

Firefighter Safety Institute

- *Identify research to improve firefighter safety*
- *Platform for conducting research to improve firefighter safety*
- *Serves as focus point for knowledge transfer with the fire service*
- *Establishes eligibility for securing federal funding through grants such as AFG*-partially funded by NFP and external grants

www.ulfirefightersafety.com

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UL FF Projects to Date

2005 – Commercial Building Safety (Role of Codes and Standards)
2005 – Residential Fire Behavior
2005 – Review of Fire Modeling for the Fire Departments

2007 – Firefighter Exposure to Smoke Particulates

2006 – Performance of Special Extinguishment Agents for Firefighter Use

2008 – Impact of Horizontal Ventilation
2010 – Impact of Vertical Ventilation
2010 – FDNY Governors Island Testing
2012 – Use of Positive Pressure ventilation

2006 – Structural Stability of Engineered Lumber under Fire Conditions
2009 – Basement Fires
2009 – Firefighter Safety and Photovoltaic Systems
2011 – Attics Fires

Education and Training

Hazards

New technology

Tactics

New societal trends

11

House Experiments Overview

House Fires
- One-Story
- Two-Story

Fire Locations
Living Room
Bedroom
Kitchen

Fuel Load
Representative residential furnishings

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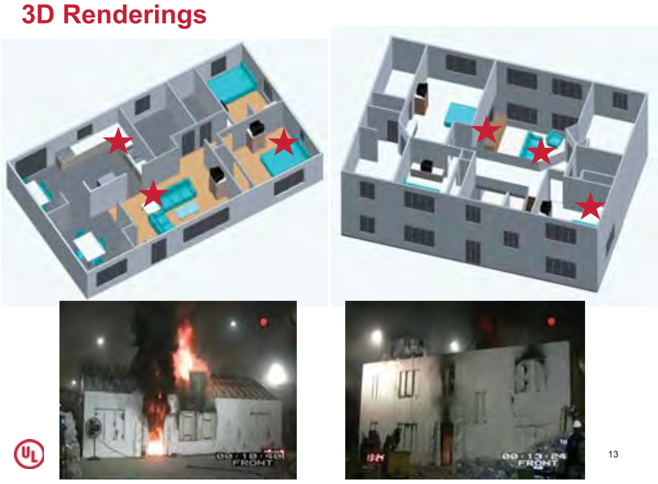
3D Renderings



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House Experiments – Fuel Load

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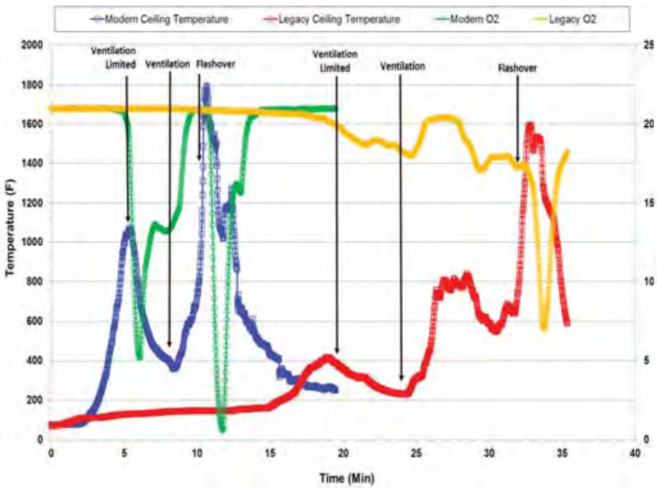

Developing Micro-Combustion Calorimeter for Post-Certification Monitoring of Materials

- Developed by Richard Lyon at FAA to investigate flammability characteristics of polymeric materials
- Uses 2-5mg sample heated in an ramped electrical furnace (0.5 – 1 K/s)
- Combustion environment may be varied depending upon application
- Heat release rate calculated using oxygen consumption technique (approximately 13.1 MJ energy release /kg of oxygen consumed)
- ASTM D 7309-13 Standard for test method

$$HRR(t) = \frac{E.V.\rho_{O2}}{m_o} \Delta O_2$$

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Focus in the Current Research

Interpretation of the flammability data

- Key flammability characteristics
- Interpretation of flammability behavior with respect to material composition

Suitability for UL's post-certificate surveillance

- Sensitivity with respect to variations in material composition
- Practical statistical control limits with limited number of test replicates per sample
- Substitute for UL 94 flame test for specific materials

Data input for predictive modeling of end-use product performance tests

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Fire Performance Level Tests

Application	Fire Performance Standard
Communications cables installed in air handling spaces	Plenum - NFPA 262
Communications Cables installed in riser shafts	Riser - UL 1666
Communications cables in other installations	Tray - UL 1685
Inter-connect cabling	UL 94 (VW-1)
Building wire	UL 94 (VW-1)
Appliance materials	UL 94 (V0, V1, V2, HB)

Current focus

UL Research – Materials [1]

Base Polymer	Structure or Grade	Application
PVC NM cable-1	Plasticized w/ DTDP*	Building wiring insulation
PVC NM cable-2	Plasticized w/ TOTM**	Building wiring insulation
PVC	With red colorant	Riser cable jacket
PVC	With blue colorant	Riser cable jacket
LSPVC	Low smoke flame retardant polyvinyl chloride	Plenum cable jacket
PVDF-HFP (2)	Polyvinylidene Fluoride	Plenum Cable jacket
FEP	Fluorinated ethylene propylene	Plenum Cable insulation/jacket
ETFE	Ethylene tetrafluoroethylene	Plenum Cable jacket
ECTFE	Ethylene chlorotrifluoroethylene	Plenum Cable jacket
PP	Polypropylene	Cable insulation
PET Elastomer	Polyester Elastomer	Non cable application
PBT	Polybutylene Terephthalate	Non cable application

Plasticized PVC

Jacket Color

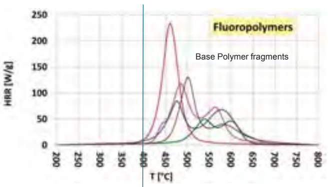
Jacket compounds

Polyolefin

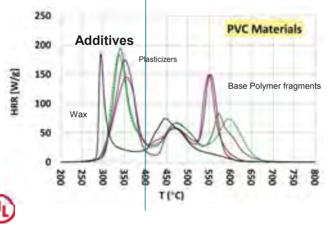
Polyesters

[1] Results presented at International Wire and Cable Symposium, 2013

MCC Flammability Results



ETFE (red line)
PVDF-HFP (pink)
ECTFE (blue)
PVDF (brown)
FEP (green)

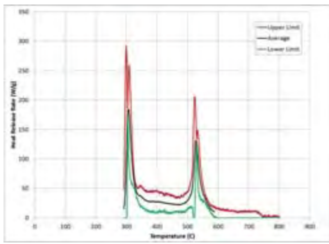


PVC NM cable-1 w/DTDP (solid green)
PVC NM cable-2 w/TOTM (dotted green)
PVC-red (Red)
PVC-blue (Blue)
LSPVC (Black)

Suitability for Post-Certificate (In-progress)

Key issues under consideration

- Test standard deviation
- Sensitivity of test to colorants, FR and additive loading
- Develop control limits based upon number of test replicates and defined confidence level
- Substitute test for UL 94 for post-certificate monitoring



Upholstered Furniture Flammability

Phase I — Phase II

material-level — mock-up — furniture — living room flashover

Research to demonstrate efficacy of barrier materials in upholstered furniture

- UL research was a multi-phase approach
- CPSC is performing significant research on the efficacy of fire barrier technology

New issue: Long-term chemical exposure safety from FRs used in UF

- UL led workshop series with CDC/NIOSH & USFA for industry discussions and identification of solutions to improve fire safety **and** mitigate chemical exposure effects.
- UL research on transport and transmission of chemicals from fire retarded PU foams

UL Smoke Research Program Overview

What is "Smoke"?

Smoke Build-Up

Alarm Response

Egress Time & Responder Safety

Codes & Standards, Outreach

Smoke Characterization Research

- Background and motivation
- Smoke detection and measurement
- Smoke characterization study
- Converting research into practice
- Q&A

Background and Motivation

- Indiana Dunes research study in 1970s on smoke profiles in homes led to UL 217 and UL 268 standards.
- Changes in our lifestyle has replaced natural materials (wood, cotton, wool) with synthetics (plastics)
- Research needed to review UL test methods for smoke alarms to ensure performance address current threats

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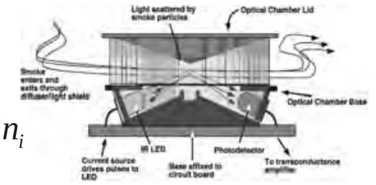
Prevalant Smoke Detection Technologies

Photo-electric

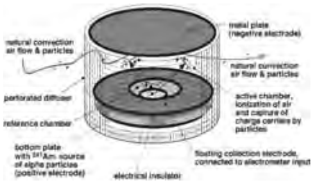
- Forward scattering

$$\Delta V_1 \propto f(\sigma_s).\sum d_i^{\,2} n_i$$



Ionization

$$\Delta V_2 \propto \sum d_i n_i$$



Smoke Research

- Understand the influence of contemporary materials in our homes on the responsiveness of smoke alarms
  - Materials (Natural, synthetics, liquids, UL 217 standard references)
    - Smoke propensity (extinction cross section area)
    - Particle size distribution and count
  - Burning condition
    - Flaming
    - Smoldering
  - Scale
    - Small-scale (materials characterization)
    - UL 217 standard fire test

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Research Materials

More than 20 materials tested in the study

- Small-scale (Cone Calorimeter)
  - Measured ignition time. heat and smoke release rates, heat and smoke propensity
  - Particle size distribution and number density
  - Gas effluents
- UL fire test room
  - Measuring ionization chamber signal, white light smoke obscuration
  - Responsiveness of smoke alarms
  - Particle size distribution and number density
  - Gas effluents

Tests conducted in flaming mode and smoldering mode

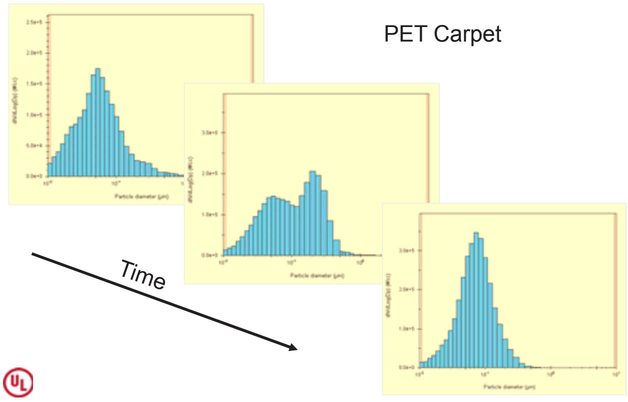
Measurement Equipment

Particle size and distribution measurement

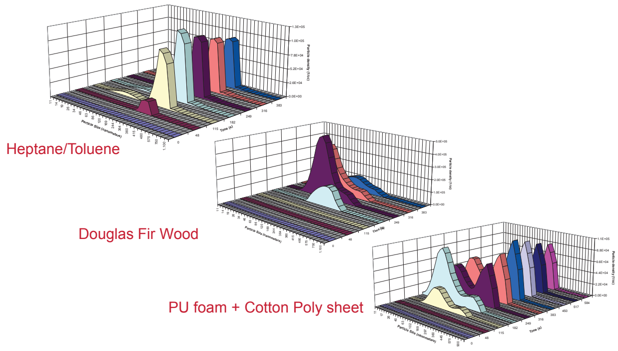
- Combination DMA and light scattering
- 0.01 – 10 µm size range
  - 0.01 – 0.5 µm (DMA)
  - 0.35 – 10 µm (LPS)
  - Calibration using NIST traceable PS latex spheres
- Dynamic sampling and analysis
  - 48 size ranges

Human hair ~ 50 microns

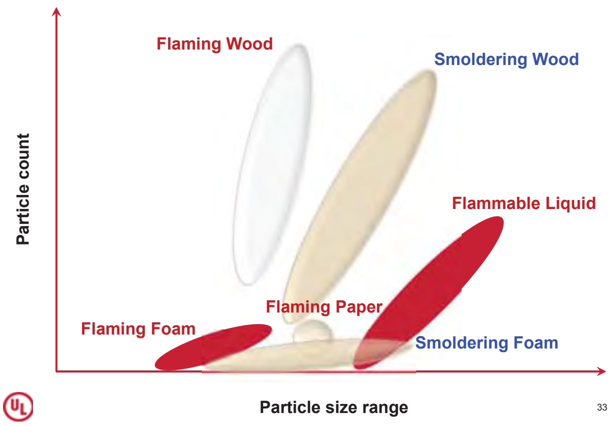
Smoke Particle Analyzer



Particle Size Distribution



UL 217/268 & Foam Smoke Signatures



33

Converting Research into Practice

- Proposal to UL 217 STP to introduce new test materials to broaden the range of smoke particulates (size, distribution, color) for testing smoke alarms
  - Flaming PU foam (lower count, smaller particles, dark)
  - Smoldering PU foam (lower count, larger particles)

34

Fire hazards to building from installed PV system

Background

- Fire service and building code concerned of adverse impact of PV installation on roofs to fire rating of roof covering materials
- UL partnered with SolarABCs to develop a research program

Objectives

- Determine how PV panels impact fire growth on roofs
- Develop data on the correlation between PV fire ratings and its impact on fire rating of roof materials
- Share research with building codes for revising code practice

Reports

http://www.solarabcs.org/current-issues/fire_class_rating.html

http://www.solarabcs.org/about/publications/reports/flammability-testing/pdfs/SolarABCs-36-2013-1.pdf

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Fire Research at FM Global

Sergey Dorofeev

Introduction to FM Global

FM Global: A Unique Company

Commercial and Industrial Property Insurance
- A Specialty Company

“Majority of Loss is Preventable” - Through Research/Engineering

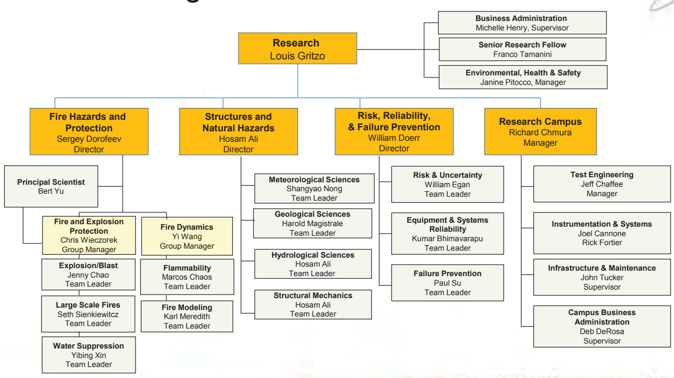
Mutual Ownership

179 Year

FM Global - Numbers

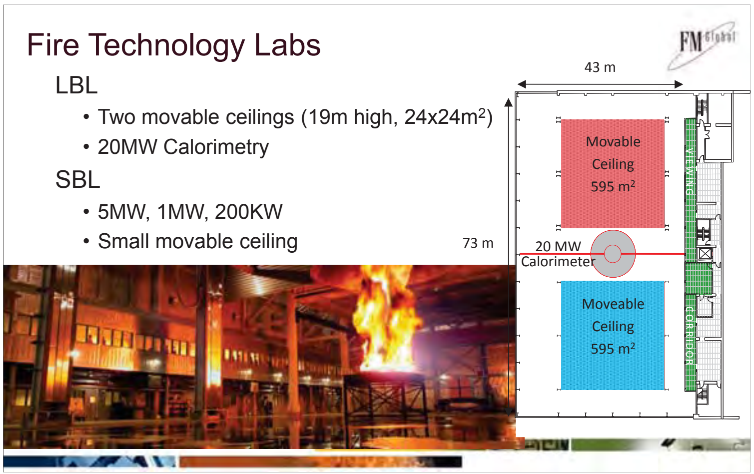
- Fortune 541
- > 5,000 employees
- 1,800 engineers
- 39 offices worldwide
- Research: > 110 scientists and engineers (>50 Ph.D.)

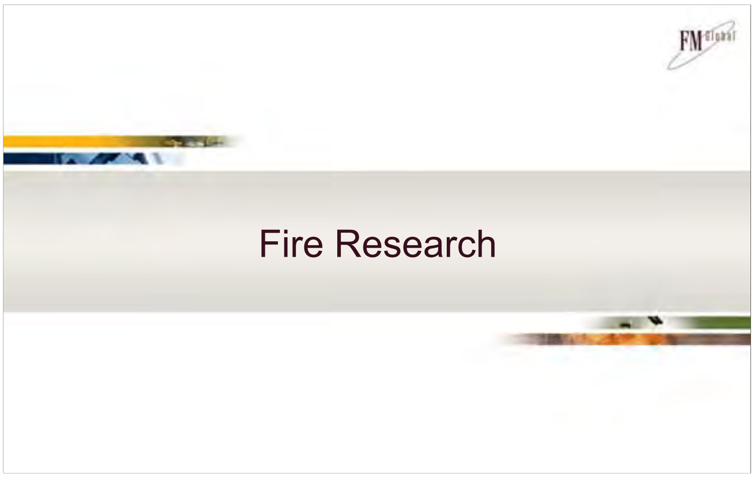
Research Organization




Center for Property Risk Solutions
FM Global
Center for Property Risk Solutions

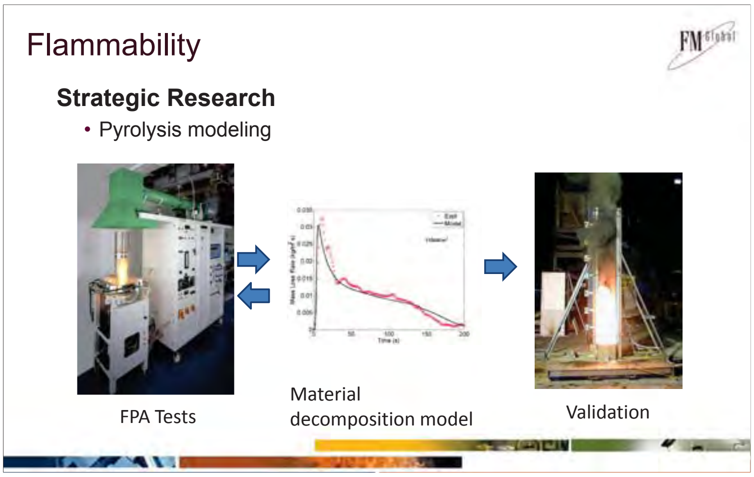

FM Global Research Campus
Natural Hazards
Research
Certification Testing
Education
Hydraulics
Electrical
Fire Technology
Explosions

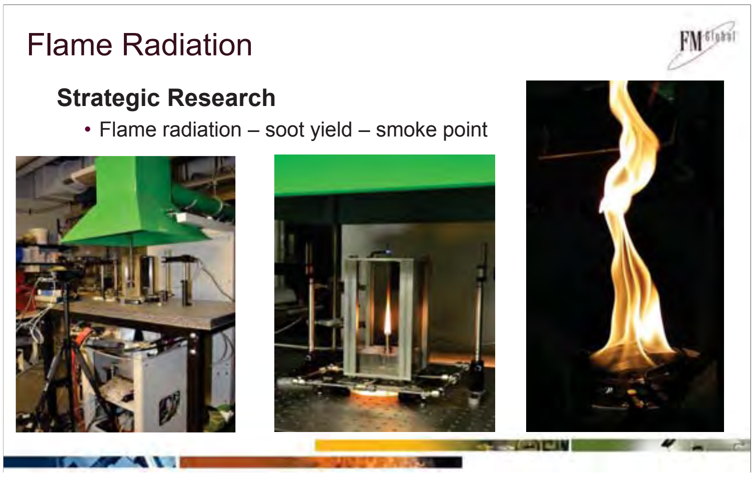

Fire Technology Labs
LBL
• Two movable ceilings (19m high, 24x24m²)
• 20MW Calorimetry
SBL
• 5MW, 1MW, 200KW
• Small movable ceiling
43 m
73 m
Movable Ceiling 595 m²
20 MW Calorimeter
Moveable Ceiling 595 m²
VIEWING
CORRIDOR

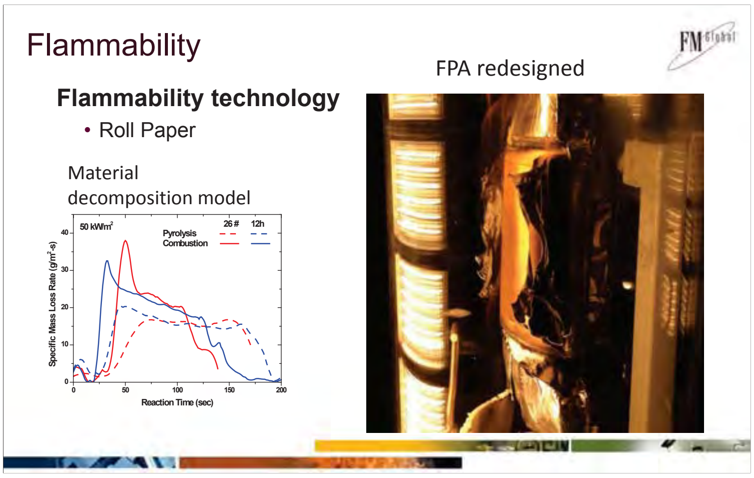

Fire Research

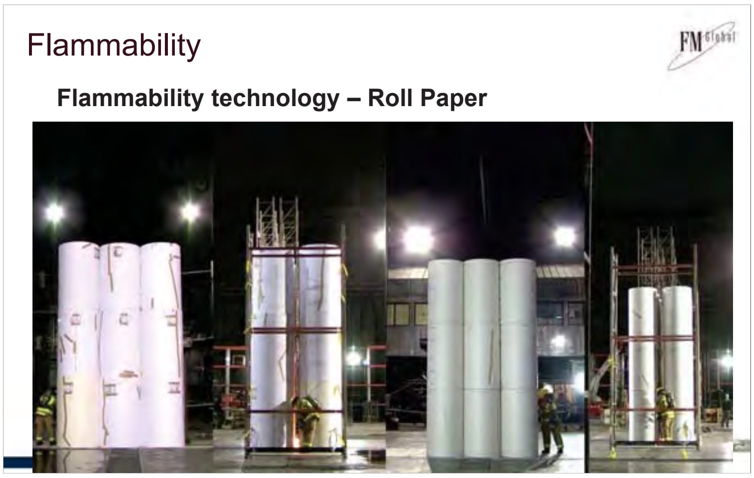

Fire Research
Flammability
Water Suppression
Fire Modeling
Large scale fire testing
Explosions

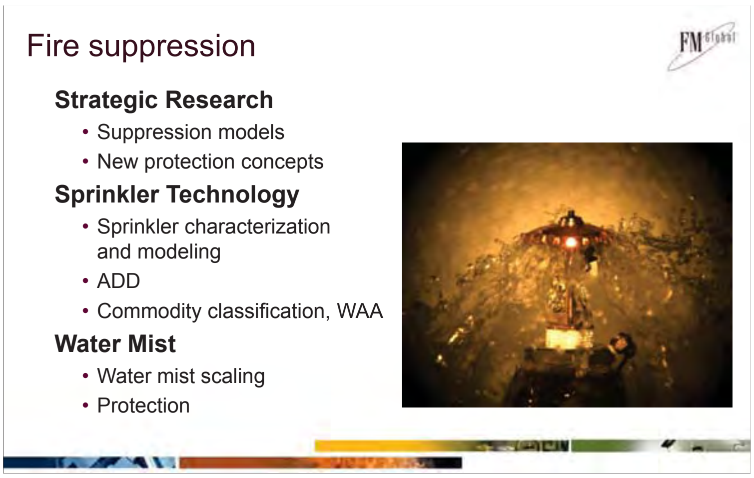

Flammability
Strategic Research
• Pyrolysis modeling
• Flame radiation
Flammability Technology
• FPA
• New materials (roll paper…)
• New test design
Material testing
• Test quality support
• Risk service and Certification

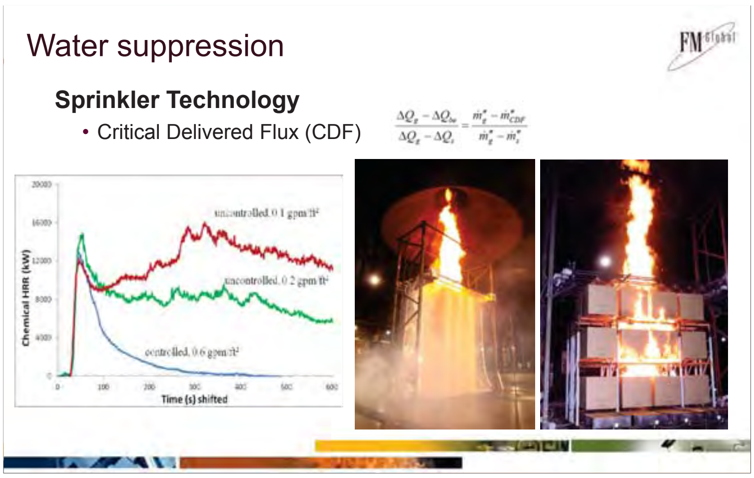

Flammability
Strategic Research
• Pyrolysis modeling
FPA Tests
Material decomposition model
Validation


Flame Radiation
Strategic Research
• Flame radiation – soot yield – smoke point


Flammability
Flammability technology
• Roll Paper
Material decomposition model
FPA redesigned
50 kW/m²
Pyrolysis
Combustion
Specific Mass Loss Rate (g/m²-s)
Reaction Time (sec)


Flammability
Flammability technology – Roll Paper


Fire suppression
Strategic Research
• Suppression models
• New protection concepts
Sprinkler Technology
• Sprinkler characterization and modeling
• ADD
• Commodity classification, WAA
Water Mist
• Water mist scaling
• Protection


Water suppression
Sprinkler Technology
• Critical Delivered Flux (CDF)
uncontrolled, 0.1 gpm/ft²
uncontrolled, 0.2 gpm/ft²
controlled, 0.6 gpm/ft²
Chemical HRR (kW)
Time (s) shifted

Fire modeling

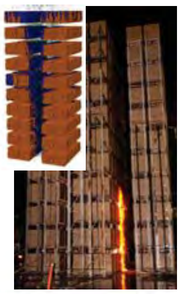
Aimed at fire protection solutions / test reduction

Strategic FireFOAM development

- New physics
- New materials
- Modeling quality

Applications

- Test support
- In-racks
- Roll paper
- Complex Fuels
- Water mist

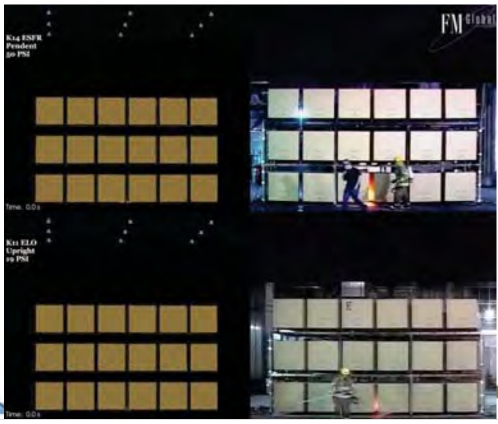


Fire modeling – recent history

FireFOAM 2008 | 8' Parallel Panel Test 2009 | 2x4x3 rack Free burn 2010 | 2x4x3 rack Water application 2011 | Rack storage sprinkler suppression 2012

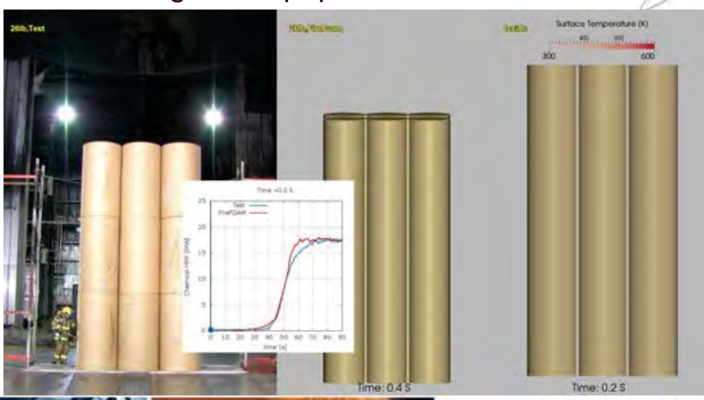
2012 Modeling simple protection

Model



Test

Fire modeling – Roll paper



Large Scale Testing

Test Quality

- Test material control
- Test condition control
- Test design guidance

New Storage / Materials

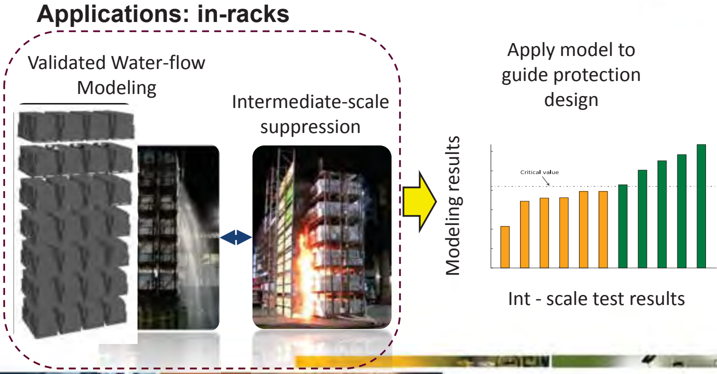
- Automatic storage and retrieval
- Li-ion batteries

New Protection Solutions

- Water cannons
- In-racks

Testing / Fire modeling

Applications: in-racks



Testing / Fire modeling

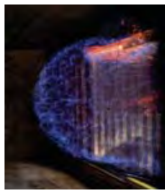
Applications: in-racks

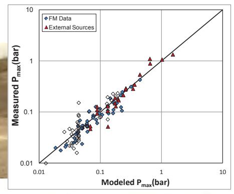
- Single large scale validation test
- Three commodity types studied
  - UUP, CUP, UEP
- Increased vertical separation

Explosion Research

Strategic Research
- Mechanisms of Flame Acceleration
- Explosion modeling

Explosion Protection
- Vapor Cloud Explosion
- Explosion Venting
- Explosion Suppression
- Silanes

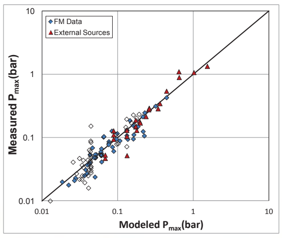




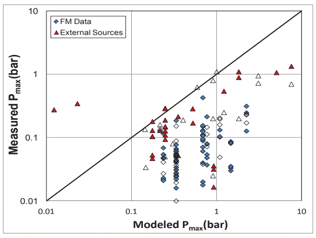
Explosion Research

Explosion Protection
- Explosion Venting

FM Global Vent Sizing Model vs NFPA68



FM Model



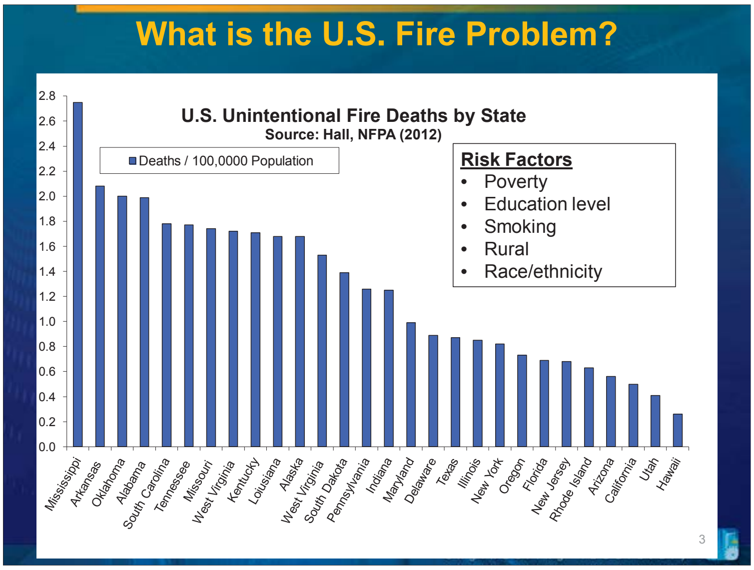
NFPA 68

Explosion Research

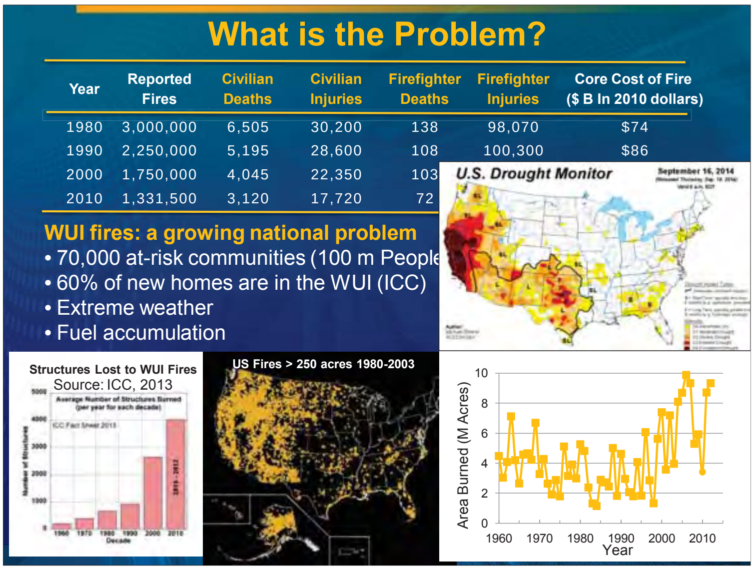
Explosion Protection
- Silanes
- New technologies
- Hydrogen

Fire Research Collaboration

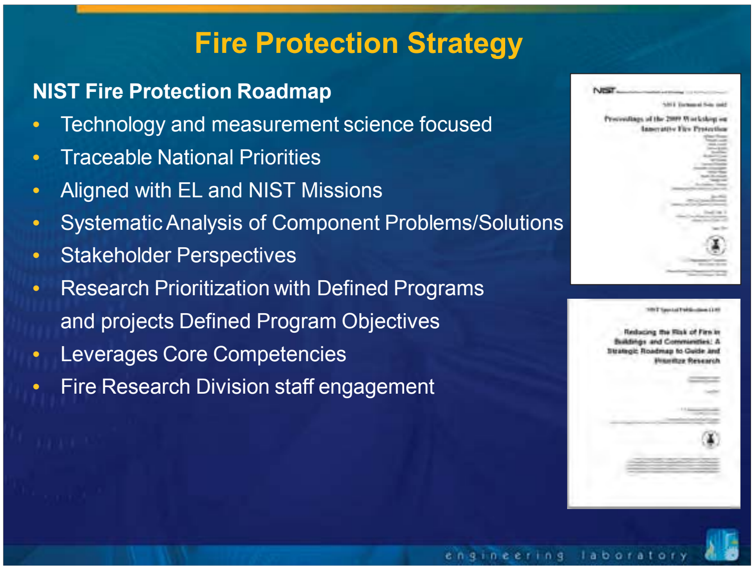
Questions



Incident	Date	Adjusted loss (2012 dollars)
1. World Trade Center, New York	2001	$43 billion
2. Earthquake and Fire, San Francisco	1906	$8.9 billion
3. Great Chicago Fire	1871	$3.2 billion
4. Oakland Hills Fire, CA	1991	$2.5 billion
5. So. California Firestorm, San Diego County	2007	$2.0 billion
6. Great Boston Fire, Boston	1872	$1.4 billion
7. Polyolefin Plant, Pasadena, TX	1989	$1.4 billion
8. Cerro Grande Wildland Fire, Los Alamos	2000	$1.3 billion
9. Cedar Wildland Fire, Julian, CA	2003	$1.3 billion
10. Baltimore Conflagration, Baltimore, MD	1989	$1.3 billion
11. "Old" Wildland Fire, San Bernardino, CA	2003	$1 .2billion
12. Los Angeles Civil Disturbance	1992	$0.9 billion
13. Power Plant, Dearborn, MI	2000	$0.9 billion
14. Southern California Wildfires	2008	$0.9 billion
15. Laguna Beach Wildland Fire, CA	1993	$0.8 billion



Year	Reported Fires	Civilian Deaths	Civilian Injuries	Firefighter Deaths	Firefighter Injuries	Core Cost of Fire ($ B In 2010 dollars)
1980	3,000,000	6,505	30,200	138	98,070	$74
1990	2,250,000	5,195	28,600	108	100,300	$86
2000	1,750,000	4,045	22,350	103		
2010	1,331,500	3,120	17,720	72		



NIST Fire Protection Vision & Goal

Long-term vision:

Remove unwanted fire as a limitation to life safety & economic prosperity in the United States.

- Save people's lives from fires,
- Help firefighters do their jobs better and more safely,
- Reduce the economic impact of fire,
- Help save people's homes from structural fires and wildfires,
- Promote U.S. exports by furthering sound international fire safety standards,
- Advance U.S. commerce by developing & bringing fire safe products to market.

Goal:

To enable the reduction of the preventable fire burden in the United States by one-third within a generation by providing appropriate measurement science.

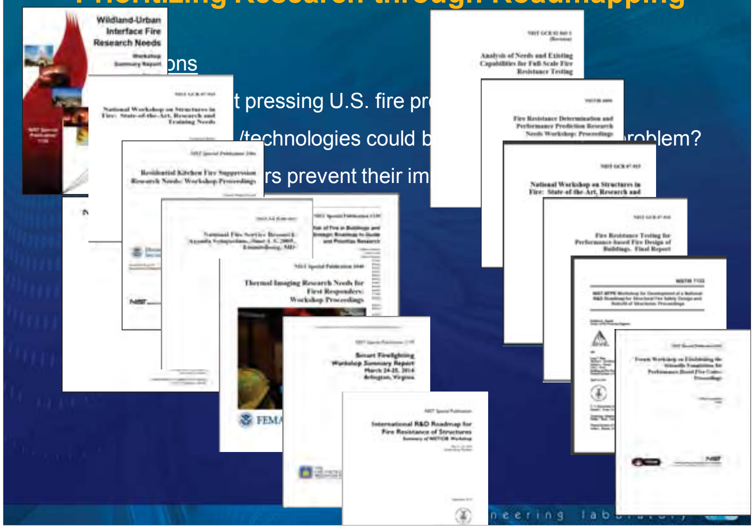
Prioritizing Research through Roadmapping

...ons

...t pressing U.S. fire pr...

.../technologies could b... ...roblem?

...rs prevent their im...



Program Objectives

Fire Risk Reduction in Communities (9 projects): To improve the resilience of communities and structures to unwanted fires through innovative fire protection and response technologies and tactics

Fire Risk Reduction in Buildings (8 projects): To increase the safety of building occupants and the performance of structures and their contents by enabling innovative, cost-effective fire protection technologies

4 thrust areas/ 17 projects:

Fire Service | Wildland-Urban Interface Fires | Residential Safety | Performance-Based Design

Fire Risk Reduction in Communities: WUI Fires

Enable standards, codes, and technologies to increase the fire resistance of WUI communities

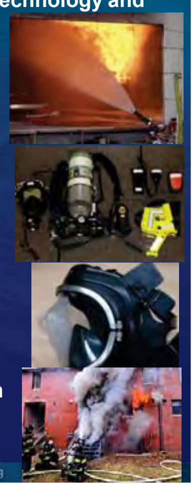
- **Develop standardized post-fire data collection methods, and a hazard scale to quantify the threat posed by WUI fires (including effects of thermal radiation, embers, wind, moisture, terrain)**
  Outcomes: A hazard scale, exposure maps, and mitigation strategies will provide guidance to homeowners, community planners, fire fighters, and standards and code committees.

- **Develop science based tools and test methods to evaluate the fire resistance of materials, building components, structures, parcels, & communities during WUI fires**
  Outcome: improved building codes & standards for the WUI.
- **Enable cost-effective WUI fire mitigation technologies (fire resistant vegetation, coatings, wraps, foams, gels, etc.).**
  Outcome: Enhanced best practices guidance, standards and codes to improve the resilience of communities.

Fire Risk Reduction in Communities: Fire Service

Enable the development & implementation of critical technology and tactics to improve Fire Service safety & effectiveness

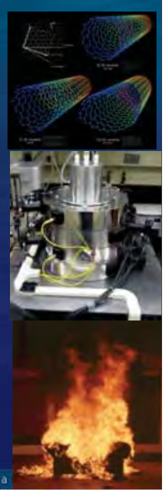
- **Develop performance metrics and best practices for critical fire fighting tactics (hose stream, positive pressure ventilation, wind-driven fires…)**
  Outcome: Improved fire fighter effectiveness.
- **Develop performance metrics for advanced personal protective equipment technologies (PASS, respirators, lens, face mask, turnout gear, thermal imagers, fire fighter locator …)**
  Outcome: Improved fire fighter safety.
- **Develop performance standards for cyber-physical systems including fire fighter SCBA air supply, hose line water flow and fire alarm device activation**
  Outcome: Improved fire fighter situational awareness and effectiveness.

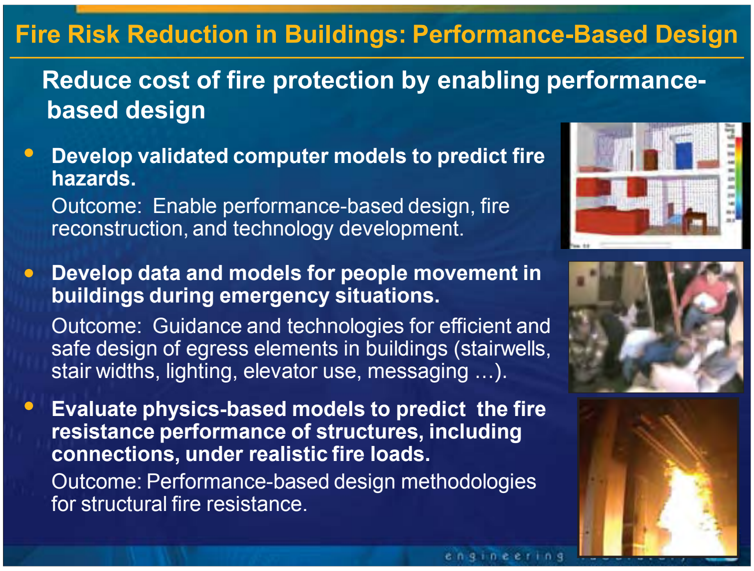


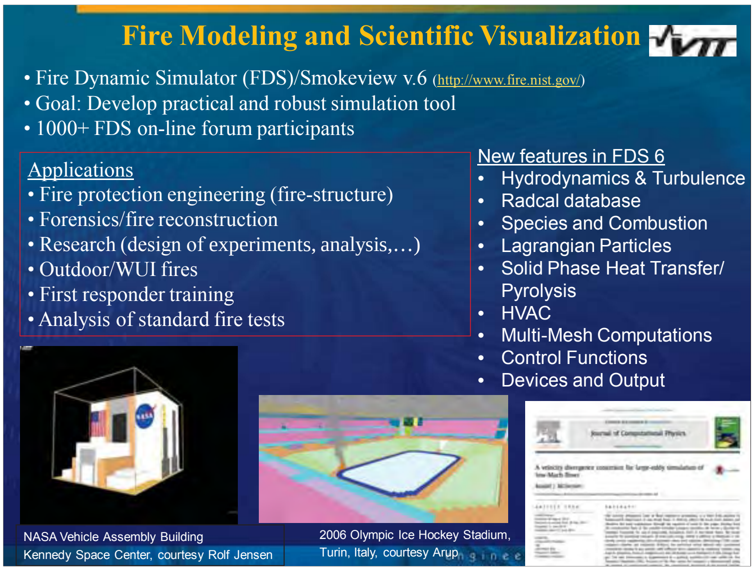
Fire Risk Reduction in Buildings: Residential Safety

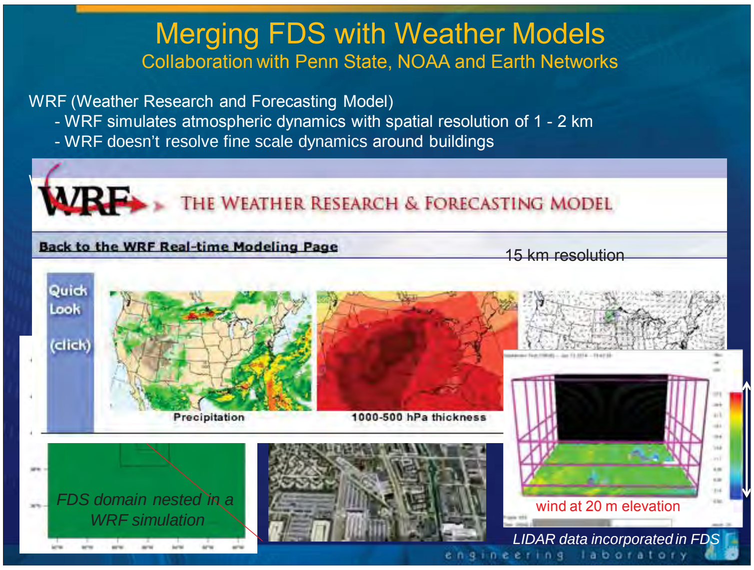
Reduction of deaths, injuries, and property loss through application of measurement science

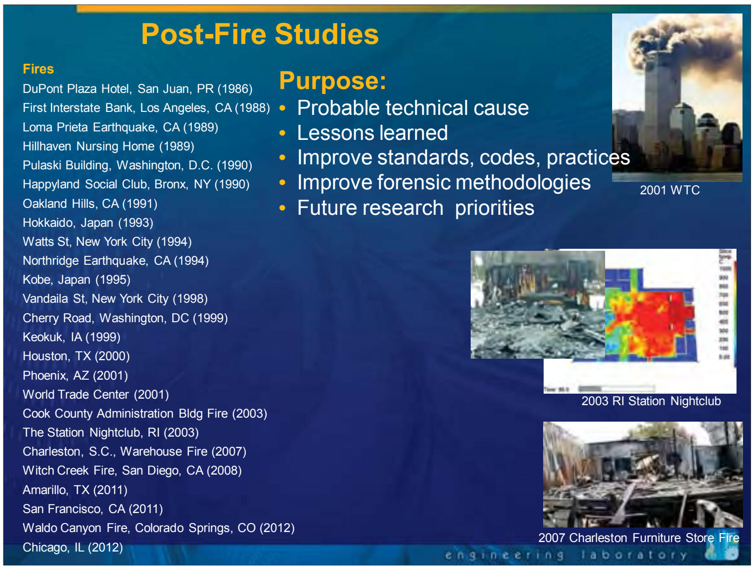
- **Evaluate innovative processes, technologies, and materials (Layer by layer coatings, nano-clays, -tubes and -fibers, bio-derived materials, etc…) to significantly improve the fire performance of materials and products**
  Outcome: Less costly development of superior fire resistant materials (plastics, fabrics, fibers, foam, etc…) for use in common products.
- **From measurements of particle light scattering, gas species, and thermal signatures, provide knowledge to discriminate smoke and nuisance sources.**
  Outcome: Enables development of detection systems that have a rapid response time and are nuisance-free
- **Develop guidelines on the relationship between fire performance of furniture components and assemblies including barrier materials, cover fabrics,…**
  Outcome: Enable innovation to reduce furniture fire hazard



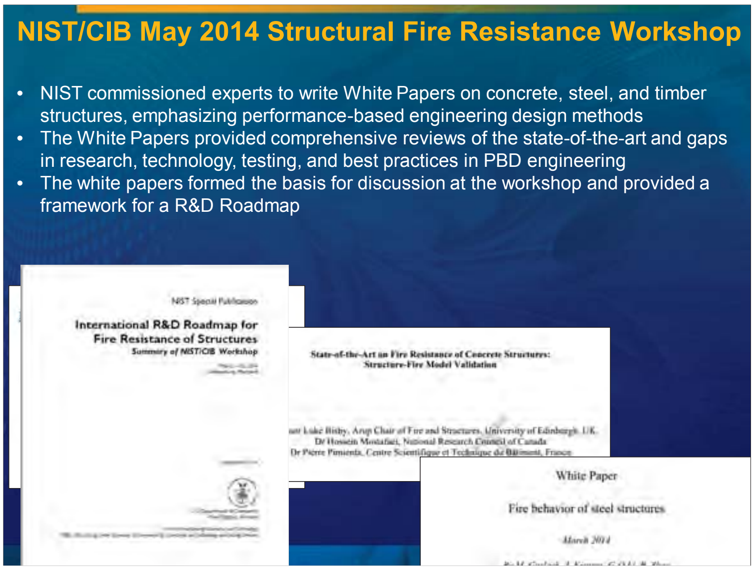

Fire Risk Reduction in Buildings: Performance-Based Design
Reduce cost of fire protection by enabling performance-based design
Develop validated computer models to predict fire hazards.
Outcome: Enable performance-based design, fire reconstruction, and technology development.
Develop data and models for people movement in buildings during emergency situations.
Outcome: Guidance and technologies for efficient and safe design of egress elements in buildings (stairwells, stair widths, lighting, elevator use, messaging …).
Evaluate physics-based models to predict the fire resistance performance of structures, including connections, under realistic fire loads.
Outcome: Performance-based design methodologies for structural fire resistance.
engineering laboratory


Fire Modeling and Scientific Visualization
• Fire Dynamic Simulator (FDS)/Smokeview v.6 (http://www.fire.nist.gov/)
• Goal: Develop practical and robust simulation tool
• 1000+ FDS on-line forum participants
Applications
• Fire protection engineering (fire-structure)
• Forensics/fire reconstruction
• Research (design of experiments, analysis,…)
• Outdoor/WUI fires
• First responder training
• Analysis of standard fire tests
New features in FDS 6
• Hydrodynamics & Turbulence
• Radcal database
• Species and Combustion
• Lagrangian Particles
• Solid Phase Heat Transfer/ Pyrolysis
• HVAC
• Multi-Mesh Computations
• Control Functions
• Devices and Output
NASA Vehicle Assembly Building
Kennedy Space Center, courtesy Rolf Jensen
2006 Olympic Ice Hockey Stadium,
Turin, Italy, courtesy Arup
Journal of Computational Physics


Merging FDS with Weather Models
Collaboration with Penn State, NOAA and Earth Networks
WRF (Weather Research and Forecasting Model)
- WRF simulates atmospheric dynamics with spatial resolution of 1 - 2 km
- WRF doesn't resolve fine scale dynamics around buildings
WRF
THE WEATHER RESEARCH & FORECASTING MODEL
Back to the WRF Real-time Modeling Page
15 km resolution
Quick Look (click)
Precipitation
1000-500 hPa thickness
FDS domain nested in a WRF simulation
wind at 20 m elevation
LIDAR data incorporated in FDS
engineering laboratory


Post-Fire Studies
Fires
DuPont Plaza Hotel, San Juan, PR (1986)
First Interstate Bank, Los Angeles, CA (1988)
Loma Prieta Earthquake, CA (1989)
Hillhaven Nursing Home (1989)
Pulaski Building, Washington, D.C. (1990)
Happyland Social Club, Bronx, NY (1990)
Oakland Hills, CA (1991)
Hokkaido, Japan (1993)
Watts St, New York City (1994)
Northridge Earthquake, CA (1994)
Kobe, Japan (1995)
Vandalia St, New York City (1998)
Cherry Road, Washington, DC (1999)
Keokuk, IA (1999)
Houston, TX (2000)
Phoenix, AZ (2001)
World Trade Center (2001)
Cook County Administration Bldg Fire (2003)
The Station Nightclub, RI (2003)
Charleston, S.C., Warehouse Fire (2007)
Witch Creek Fire, San Diego, CA (2008)
Amarillo, TX (2011)
San Francisco, CA (2011)
Waldo Canyon Fire, Colorado Springs, CO (2012)
Chicago, IL (2012)
Purpose:
• Probable technical cause
• Lessons learned
• Improve standards, codes, practices
• Improve forensic methodologies
• Future research priorities
2001 WTC
2003 RI Station Nightclub
2007 Charleston Furniture Store Fire
engineering laboratory


CIB/NIST May 2014 Workshop Objectives
• Identify research and development needs for large-scale experiments on fire resistance of structures (steel, concrete, and timber) to support performance-based engineering and structure-fire model validation;
• Prioritize those needs in order of importance to performance-based engineering;
• Phase the needed research in terms of a timeline, i.e. near term (less than 3 years), medium term (3 to 6 years) and long term;
• Identify the most appropriate international laboratory facilities available to address each need;
• Identify the potential collaborators and sponsors for each need;
• Identify the primary means to transfer the results from each series of tests to industry through specific national and international standards, predictive tools for use in practice, and comprehensive research reports; and
• Identify the means for the coalition of international partners to review progress and exchange information on a regular basis.
engineering laboratory


NIST/CIB May 2014 Structural Fire Resistance Workshop
• NIST commissioned experts to write White Papers on concrete, steel, and timber structures, emphasizing performance-based engineering design methods
• The White Papers provided comprehensive reviews of the state-of-the-art and gaps in research, technology, testing, and best practices in PBD engineering
• The white papers formed the basis for discussion at the workshop and provided a framework for a R&D Roadmap
NIST Special Publication
International R&D Roadmap for Fire Resistance of Structures
Summary of NIST/CIB Workshop
State-of-the-Art on Fire Resistance of Concrete Structures: Structure-Fire Model Validation
White Paper
Fire behavior of steel structures
March 2014

CIB/NIST May 2014 Workshop

Participant List (~50 people from industry, academia and government)

- **Adam Barowry** *Underwriters Laboratories (USA)*
- **Birgit Ostman** *SP Wood Technology (Sweden)*
- **Nicolas Pinoteau** *CSTB (Scientific and Technical Center for Building) (France)*
- **Tuula Hakkarainen** *VTT Technical Research Centre of Finland* (Finland)
- **Farid Alfawakhiri** American Iron and Steel Institute (USA)
- **Hosam Ali** *FM Global (USA)*
- **Joel Kruppa** *Centre Technique Industriel de la Construction Métallique (France)*
- **Robert Solomon** *National Fire Protection Agency (USA)*
- **Morgan Hurley** *Society of Fire Protection Engineers (USA)*
- **Kuma Samathipala** *American Wood Council*
- **Stephen Szoke** *Portland Cement Association (USA)*
- **Mike Moore** *Georgia Pacific (USA)*
- **Keith Poerschke** *National Gypsum Co. (USA)*
- **Darlene Rini** *ARUP (USA)*
- **Vincent Roux** *Efectis Group*
- **John Danko** *Isolatek International (USA)*
- **Graeme Flint** *ARUP (UK)*
- **Junichi Suzuki** *NILIM (Japan)*
- **Guo-Qiang Li** *Tongji University (China)*
- **Luke Bisby** *University of Edinburgh (UK)*
- **Andy Buchanan** *University of Canterbury (UK)*
- **Ian Burgess** *University of Sheffield (UK)*
- **John Gales** *Carleton University (CANADA)*
- **Ann Jeffers** *University of Michigan (USA)*
- **Venkatesh Kodur** *Michigan State University (USA)*
- **James Sullivan** *Alexandria Fire Department (USA)*

engineering laboratory

NIST/CIB Fire Resistance Structures Workshop: Workshop Summary Report

Conceptual Framework

Based on the discussion, recommendations on what should be addressed in the Roadmap are in Table 1.

TABLE 1: ELEMENTS TO BE ADDRESSED IN ROADMAP FOR PBD

Planning and Consensus Building

- Identify external demand for PBD/outcome-based design
- Identify drivers for scope and responsibilities for PBD
- Determine how PBD improves design and construction, facilitating construction job thoroughness and enabling builders/engineers to perform their jobs better
- Plan for implementation, outreach, and education
- Identify methods to educate authorities having jurisdiction (AHJs) to be able to evaluate alternative PBDs
- Identify incentives for material manufacturers to provide material properties, considering cost and use of information for net reduction in the need for fireproofing
- Include cost in the conceptual framework
- Convey that PBD will ensure more uniform risks, more efficient uses of resources, but losses still possible

Technical

- Determine a methodology to characterize building fires
- Consider combustible load instead of fire
- Identify fire scenarios under which different materials are susceptible to fire
- Define a structural hazard fire, including mean temperature and temperature gradient
- Determine the applicability of PBD in concrete, considering spalling phenomena
- Enable the use of material property data as input to methods
- Develop new materials, especially to resist against non-standard fires
- Conduct material modeling for finite element analysis, e.g., erosion strains tests for bolts in shear
- Develop high-temperature strain measurements methodology
- Develop a probabilistic approach to determine uncertainties
- Reach agreement on clearly defined goals and objectives for any large-scale test
- Use component testing first to determine whether large-scale testing is needed
- Elucidate advantages and disadvantages of hybrid testing
- Perform and validate multi-physics simulations
- Determine building response to thermal loading, effects on performance of "certified" products, and methods to address these issues in current studies
- Determine effects of fire suppression on structures (e.g., hose stream)
- Determine integrity of egress routes in steel structures (e.g., stairs, elevators)

Design Considerations

- Ensure that design basis for fire threat is applicable to all building structures, including bridges and tunnels
- Consider that fire brigades act as drivers and constraints in PBD in that they attack fires but are often not aware of

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NIST/CIB Fire Resistance Structures Workshop: Workshop Summary Report

R & D Agenda

The strategy to be used to generate the R&D agenda was discussed by the Workshop participants. The needs that garnered the greatest support by the participants are listed in priority order in Table 4.

TABLE 4: PROPOSED PBD R&D PRIORITIES

- Fire as a load case
- High temperature strain and deflection measurement methods
- Stakeholder education and code development
- Multi-scale simulation – including heat transfer modeling in specific scenarios
- External demand for property protection vs. life safety – societal awareness of fire "problem"
- Conduct 3D full-scale tests on structural systems
- Determine material properties for steel construction
- Identify and describe applicable fire scenarios
- Develop connection models, including fracture for simulation of 3D building structures under fire scenarios
- Predict the reliability of fire compartmentation
- Define acceptable performance criteria for a variety of timber structures
- Develop structural models for fire resistance of timber structures
- Calculate the strength of structural timber exposed to fire
- Perform compartment burn-out encapsulation studies (full/partial)
- Conduct reliability-based analysis of fire testing, especially standard testing

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A worldwide effort is required to address the research agenda. Workshop participants identified various capabilities that support the international R&D agenda including science and technology development areas, required sequences of development, priorities for research, international cooperation within the research community, and cooperation between research and practice as seen in Table 5.

TABLE 5: WORLDWIDE CAPABILITIES THAT SUPPORT RESEARCH AGENDA

- Build physical infrastructure to support small and large research needs
- Unify procedures, processes methods, and goals
- Develop multi-scale simulations tools
- Define performance levels
- Review literature and consolidate resources from CIB, the American Society for Testing and Materials (ASTM), the International Organization for Standardization (ISO), the Institution of Fire Engineers (IFE), the National Fire Protection Association (NFPA), and the Society of Fire Protection Engineers (SFPE)
- Conduct forensic studies to repurpose the National Construction Safety Team to look at smaller fire events
- Increase student involvement in courses and research
- Disseminate simulations and SOA papers more widely
- Design engineer-identify areas of practical application where PBD research can/should focus
- Develop technical basis for building codes and standards
- Characterize reliability and strategies to improve it
- Large-scale testing of systems - coordination needs to determine ROI to help with this exercise
- Acquire access to existing models
- Develop a suite of building information modeling programs, starting with drawing and ending at structural properties (e.g., integration of all of these models)
- Create a blue ribbon panel to assess existing models
- Standardize tests methods and equipment across materials and assemblies
- Develop standard testing for assembly/system level
- Conduct medium-scale testing, including compartments specific to decay and fire resistance
- Perform reliability-based analysis of fire testing
- Investigate compartment burnout (e.g., encapsulation, self-extinguishing flame spread)
- Convene testing experts for ideas, experiences, thoughts
- Define the properties wanted in the databases
- Collect all background data for inputs into models
- Find a legal way to aggregate and provide testing data
- Establish design objectives
- Collaborate with concrete, steel, and timber to find low-hanging fruit
- Define acceptable performance criteria, including use-specific
- Define PBD on an international level
- Determine the influence of sprinklers compared to passive prevention, especially in reliability
- Relate fire design with other pre-fire events such as floods and earthquakes

---

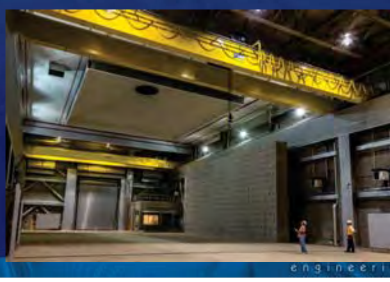
National Fire Research Laboratory

- Advance real-scale fire metrology
- Develop metrics for performance-based standards and codes
- Enable model validation
- Support post-incident disaster and failure studies
- Advance understanding of the fire-structure interaction

engineering laboratory

NFRL Expansion Design Objectives

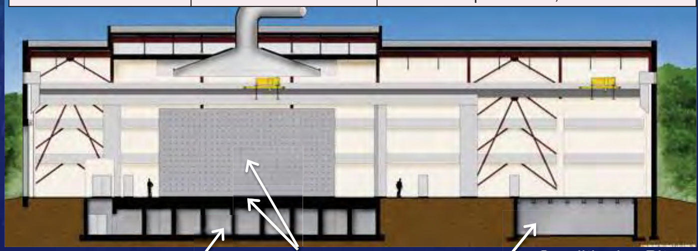
- Conduct tests on real-scale structural systems and components
- Create realistic fires that grow, spread and decay
- Apply controlled loads to the test structure to simulate true service conditions
- Measure response of structural system and components to incipient collapse
- Characterize the fires (measure heat release rate) in real time



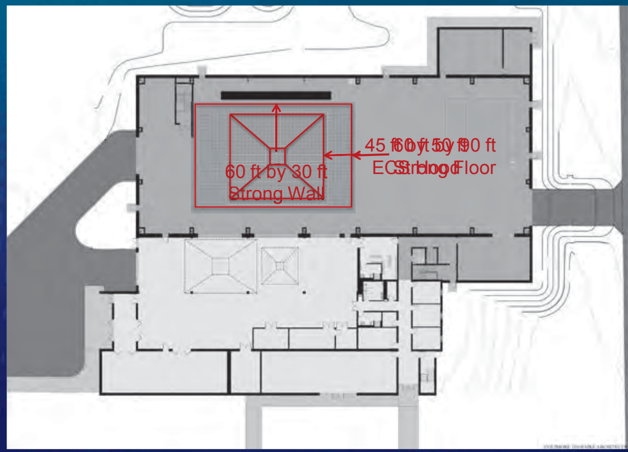
engineering laboratory

Expanded NFRL Capabilities

Specification	Existing Laboratory	New Expansion
Total Floor Area	10,800 sq. ft.	21,400 sq. ft.
Fire Capacity	1 MW (small hood) 3 MW (medium hood) 10 MW (large hood)	20 MW
Strong Floor/Strong Wall	None	60 ft. x 90 ft. x 4 ft. thick strong floor and 60 ft. x 30 ft. x 4 ft. thick strong wall.
Structural Loading	None	Reconfigurable hydraulic loading system, 55-215 kip actuators; 30 inch stroke



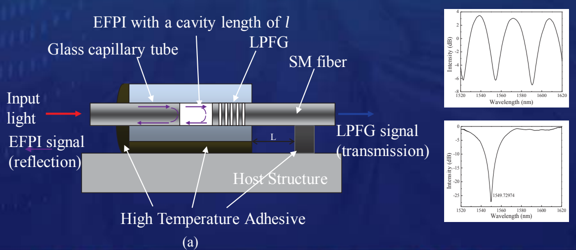
NFRL Expansion Features



DISTRIBUTED OPTICAL FIBER SENSOR NETWORK

Genda Chen and Robert W. Abbett

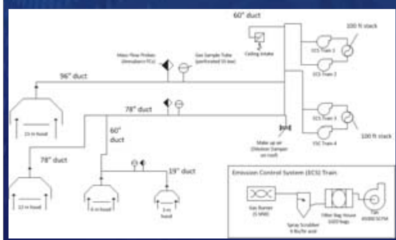
- Develop, calibrate, and validate distributed optical fiber sensors for simultaneous measurement of both large strain and high temperature under fire conditions



Large Fire Calorimetry

Measurement Challenges
- Smoke Capture
- Pollution Control
- Measurement Uncertainty
  - Flow profile in exhaust duct
  - Combustion efficiency
  - Gas sampling and conditioning

Measurement section inside 20 MW 8' duct



Schematic of Fire Hood Exhaust and Emission Control System

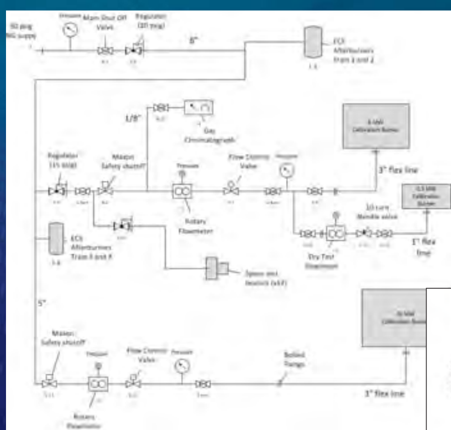
Measurement section outside 20 MW 8' duct

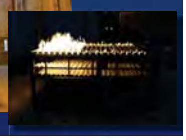
Natural Gas Burner Uncertainty

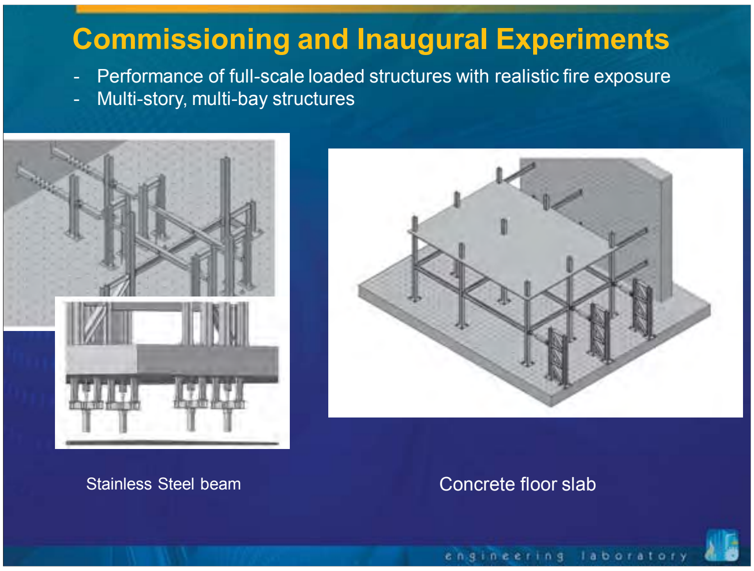
Table 1. Standard uncertainty budget for CO_2 emissions from a 2 MW natural gas fire.

Measurement Component (x_i)	Units	Value x_i	Std. Unc. $u_c(x_i)$	Rel. Std. Unc. $u_c(x_i)/x_i$
Gas Volume Flow Rate ($\dot{V}_{ng}$)	m^3/s	0.0298	0.000057	0.19 %
Gas Pressure (P_{ng})	Pa	197719	319	0.16 %
Gas Temperature (T_{ng})	K	290.65	0.507	0.17 %
Gas Compressibility (Z_{ng})	--	0.9958	0.0005	0.050 %
Gas Carbon Fraction ($X_{C,ng}$)	mol/mol	1.04	0.00213	0.20 %
Molar Mass of CO_2 (MW_{CO2})	g/mol	44.0095	0.0001	0.0002 %
Ideal Gas Constant (R)	J/mol/K	8.314472	0.000015	0.0002 %
Burner Conversion Efficiency (η_b)	--	1.00	0.015	0.15 %
Burner CO_2 Emission Rate ($\dot{m}_{CO_2}$)	g/s	112.4	0.45	**0.40 %**

Large Fire Metrology – Natural Gas Calibration






Commissioning and Inaugural Experiments
- Performance of full-scale loaded structures with realistic fire exposure
- Multi-story, multi-bay structures
Stainless Steel beam
Concrete floor slab
engineering laboratory


NFRL Commissioning Plan
Combined Fire and Structural Loading
• Simple Structure (e.g., loaded SS beam)
• Construct specimen and mounts (supports and loading)
• Instrument test specimen (for both thermal insult and structural response)
• Construct "fire loading" system (e.g., natural gas burner)
• Test to failure (by structural loading only)
• Test to failure (by structural loading and fire)
• Develop SOP for testing of structures in fire


Structural Fire Resistance Research in the NFRL
• Test the performance of real-scale structures under realistic fire and structural loading under controlled laboratory conditions.
• Develop an experimental database on the performance of large-scale structural connections, components, subassemblies and systems under realistic fire and loading.
• Evaluate physics-based models to predict fire resistance performance of structures.
• Provide the technical basis for performance-based standards for fire resistance design of structures and foster innovation in the building design and construction industry.


Collaboration: Example Research Partnerships
CPSC
Performance test methods
FEMA, USFA, NFPA
Fire fighting tactics
CALFire, TX FS, DHS
WUI fires
NIOSH
Charleston fire study
DHS, NFPA
Fire fighter technology
NRC, USFS
Validated fire models
engineering laboratory


Collaboration: Firefighting Tactics Research
• Fire Departments
– Austin, TX
– Baltimore, MD
– Chicago and Bensenville IL
– Delaware County, PA
– Dover, Ellendale, & Georgetown, DE
– Fairfax Co., and Prince William Co., VA
– Fayetteville, AR
– Gilbert and Mesa, AZ
– Houston, TX
– Kinston, NC
– Mobile, AL
– Montgomery Co., MD
– Myrtle Beach, SC
– New York City, NY (FDNY)
– Phoenix, AZ & Regional Fire and Rescue
– Prince George's Co., MD
– Santa Ana & Seaside, CA
– San Francisco, CA
– Spartanburg, SC
– Toledo, OH
– Washington, D.C.
• Private Laboratories
– Underwriters Laboratories
• Universities
– U of Arkansas
– Eastern Kentucky University
– Gaston College, NC
– Harvey Mudd - CA
– U of Illinois, ISFI
– U of Maryland, MFRI
– U of Michigan
– New York University, Polytechnic Institute
– North Carolina State University
– Polytechnic University, NYC
– U of Texas, Austin, TX
– Worcester Polytechnic Institute, MA
mechanical engineering
Taking the Measure of Hell


Recent Strategic Standards Participation
National Fire Protection Association
• Technical Correlating Committee, Protective Clothing and Equipment
• NFPA Research Section
• NFPA-2 Hydrogen Technologies.
• NFPA-13D Residential Sprinklers
• NFPA-72 Fire Alarm Systems
• NFPA-101 Life Safety Code
• NFPA-262 Fire Tests
• NFPA-295 Forest and Rural Fire Protection
• NFPA-921 Guide for Fire and Explosion Investigation
• NFPA 1403 Standard on Live Fire Training Evolutions
• NFPA 1404 Standard for Fire Service Respiratory Protection Training
• NFPA 1408 Standard on Thermal Imaging Training
• NFPA 1410 Standard on Training for Initial Emergency Scene Operations
• NFPA 1001 Standard for Fire Fighter Professional Qualifications
• NFPA-1800 Electronic Safety Equipment
• NFPA-5000 Building and Construction Code
American Institute of Steel Construction
• AISC 360-10 2010 Specification for Structural Steel Buildings
American Society of Civil Engineers
• ASCE 7 Design Loads for Structures
American Society for Testing and Materials
• ASTM Fire Standards Committee E
• ASTM Protective Clothing Committee F23
International Code Council
• ICC Performance Building Code Committee
• ICC Performance Fire Code
International Council for Research and Innovation in Building and Construction
• CIB W14 on Fire
• CIB TG37 Performance-Based Buildings
International Standards Organization (ISO)
• ISO TC92 Fire Safety Technical Program Management Group
• ISO TC92 SC3 Fire Threat to People and the Environment
Underwriter's Laboratories (UL)
• UL 217 Smoke Alarms
• UL 858 Electric Stove
engineering laboratory

Measuring Success

Long term: traceable, third-party fire statistics that verify improved life safety and reduced costs

Short term: enable development of key outputs and impacts

- improved national codes & standards and their adoption
- standard reference materials and their sale
- new or improved technologies and their use
- patents and their license
- software downloads and their reference
- research publications and their citation
- End-use of best practices, standard operating procedures, specifications

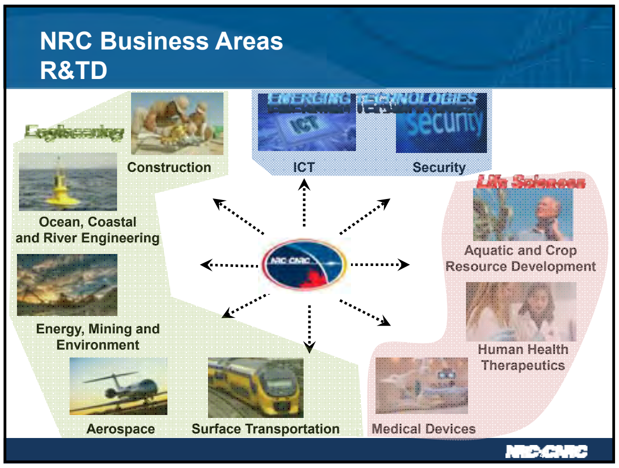
materials **models** **measurements** **investigations** **standards**

Questions?


NRC-CNRC
NRC update
International Forum of Fire Research Directors
Dr. Ahmed Kashef
Director, R&D, Fire Safety
September 22, 2014
Canada


IRAP
Research facilities
About NRC
• Over 4,000 employees and 650 volunteer and independent visitors
• Wide variety of disciplines and broad array of services and support to industry
2
NRC-CNRC


NRC is changing…
To become Canada's engine for industrial innovation
• Improved productivity and competitiveness for Canadian industry and SMEs
• Increased value from federal investment in R&D
• Future prosperity, higher standard of living
3
NRC-CNRC


NRC Business Areas R&TD
Engineering
Construction
Emerging Technologies
ICT
Security
Life Sciences
Ocean, Coastal and River Engineering
Aquatic and Crop Resource Development
Energy, Mining and Environment
Human Health Therapeutics
Aerospace
Surface Transportation
Medical Devices
NRC-CNRC


NRC Construction R&D
Building Regulations for Market Access
Critical Concrete Infrastructure
Mid-Rise Wood Buildings
High Performance Buildings
5
NRC-CNRC


NRC Construction Competencies
Building Envelope and Materials
Civil Engineering and Infrastructure
Intelligent Building Operations
Fire Safety
Building Regulations
Technical Services
6
NRC-CNRC

Fire Safety Mandate

- Develop/maintain R&D capacity to support model codes
- Respond to industry and stakeholder needs
- Enable development/evaluation of innovative fire protection systems
- Comprehensive testing of fire properties
- Guidance through standard approval process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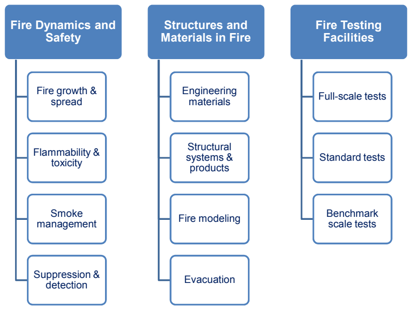
Fire Safety Competencies



8

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Fire Safety Testing Facilities

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Fire Safety Testing Facilities

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Emerging Fire Safety Issues

- **Construction**
  new materials, combustible construction, spatial separation, green buildings, engineered building assemblies, building exterior fires, alternative energy systems, shift to performance-based codes, products evaluation
- **Fire Protection**
  detection, suppression, compartmentation, changing fire loads, smoke management, fire fighter safety
- **Human Behaviour**
  changing demographics, evacuation, fire risk assessment
- **Aerospace and Transportation sectors**
  Electrical vehicles, FAA certification tests

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Emerging Fire Safety Issues

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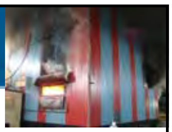
Fire Performance of Houses – Issues



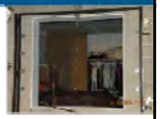
Fire Performance of innovative new products and systems with view to their impact on life safety

Outcome

- Untenable conditions reached before structural failure
- Structural fire performance of engineered floor assemblies
- Measures to maintain tenable conditions
- Phase II

  fire performance of conventional/innovative load-bearing foundation and above-grade wall systems

Fires in Low-rise Residential Dwellings (Design Fires)

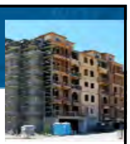


To characterize residential fires and typical fire loads in order to develop realistic design fires and computational methods

Outcome

- Web-based Database of residential fire loads
- Next steps
  - other occupancies (e.g. high-rise apartments)
  - sprinklered fires

Mid-Rise Wood

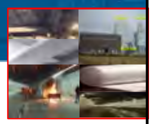


To permit midrise wood buildings, to facilitate code changes and to develop alternative solutions

Outcome

- Innovative approach to meet prescriptive requirements for noncombustible construction
- Wood-based assemblies/systems developed to meet code objectives for fire safety, acoustics, and building envelope performance
- Next phase: develop technical data for
  - maximum heights and areas
  - combustible/noncombustible construction types
  - performance-based requirements

Resilience of Critical Infrastructures in Extreme Fires



- Identify available fire protection materials & technologies
- Develop tool for rating resilience of CIs in extreme fires

Outcome

- Protection methods of CIs against extreme fires
- Test method for vulnerability assessment of CIs against extreme fires
- Upgraded testing facility to conduct vulnerability assessment for CIs against extreme fires

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Fire Safety of Military Buildings

Investigate fire impacts on soft-sided military shelters

Outcome

- Methods to delay fire spread
- Identified time available for evacuation

Forensic analysis and re-construction of fire incident in military heritage site

Outcome

- Timeline of key events during fire incident
- Identified possible causes of fire

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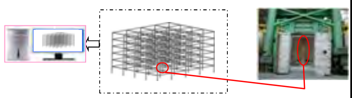
Hybrid Fire Testing

Combine experimental and numerical techniques to assess fire resistance of structures in real time

Outcome

- Developed/commissioned technique using 6-storey building
- Future: used to quantify system effects during fire safety design of buildings
  - supports restraints
  - load redistributions



Emerging Fire Safety Issues

- Construction
  new materials, combustible construction, spatial separation, green buildings, engineered building assemblies, building exterior fires, alternative energy systems, shift to performance-based codes, products evaluation
- **Fire Protection**
  detection, suppression, compartmentation, changing fire loads, smoke management, fire fighter safety
- Human Behaviour
  changing demographics, evacuation, fire risk assessment
- Aerospace and Transportation sectors
  Electrical vehicles, FAA certification tests

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Performance of Stairwells smoke control Systems Ongoing

- Investigate effectiveness of strairwell smoke control systems with open doors.
- Determine if pressure compensation systems required for sprinklered buildings.

Experimental 10-storey Tower

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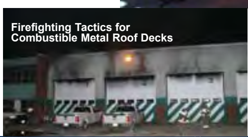
Firefighting – Issues

- Fire fighters balance effectiveness, efficiency and safety
- New suppression systems: evaluate effectiveness and identify possible concerns
- Compartment fire tests

Outcomes

- Identified possible safety issues
- Identified training issues



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Emerging Fire Safety Issues

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Photoluminescent Materials Issues

Use of PLM system for evacuation in fire emergencies under power failure

Outcomes

- Developed guidelines for PLM installation
- Proposal for code change submitted to NBCC Standing Committee for Fire Protection

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Emerging Fire Safety Issues

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  Electrical vehicles, FAA certification tests

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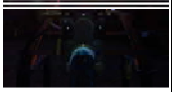
Aerospace Fire Test Cell

Ongoing

- Developing a fire test cell to conduct FAA Flammability tests for aerospace certification
- Calibrated to specific 2-D temperature fields and heat flux requirements in a highly repeatable fashion

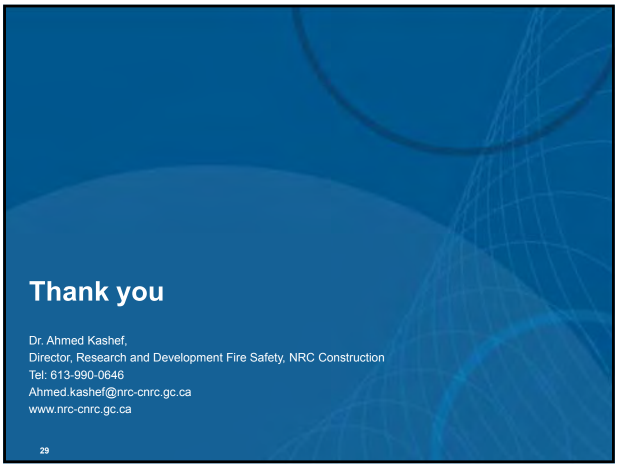


Electrical Vehicles Safety

Ongoing

To evaluate fire safety aspects of electrical vehicles including tenability

- Test set up for complete burn of electrical battery packs (UL)
- Testing full electrical vehicles including internal combustion



Future Fire Research: Model Codes Development

- Demographic impact (age, mobility)
- Spatial separation (external wall fires)
- Sprinklers (residential)
- Fire Performance of Houses Phase 2 (walls)
- Tall wood buildings (10+ storeys)
- Performance-based fire resistance

Future Fire Research: Other Areas

- Alternative energy systems (fuels, batteries, PV)
- Fire spread (exterior walls, internal vertical)
- Design fires in other occupancies
- Firefighting (tactics, technologies, safety)
- New wall systems
- Fire resistance of new materials
- Technical services/standard testing for product evaluation

Thank you

Dr. Ahmed Kashef,
Director, Research and Development Fire Safety, NRC Construction
Tel: 613-990-0646
Ahmed.kashef@nrc-cnrc.gc.ca
www.nrc-cnrc.gc.ca

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Recent Fire Research at ABRI

Dr. T.C. Wang
Research Officer, Fire Research Program
For
Dr. Ming-Chin HO
Director General, ABRI

1

Our Objects

Technology innovation
- Green environment
- Intelligent living space
- Urban and building disaster prevention
- Fire safety
- Building engineering quality enhancement
- Universal design

Regulations
Proposal of policy, law, regulation, technical code and standards

Promotion
- Conference
- Publicaiton
- Certification
- Technology transfer

2

Fire Research Program

- *2011-2014 Plan on Upgrading Fire Safety Design and Engineering Technology*
- *2011-2014 Plan on Fire Resistant Design of Steel Reinforced Concrete (SRC)*
- *2015-2018 Plan on Technology Innovation and Application of Building Fire Safety Engineering*
- *2015-2018 Plan on Fire Resistance Technical Research of Steel Structure under compound disaster*

3

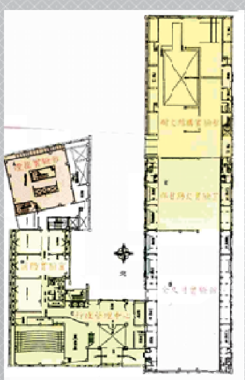



Science and technology development plan
- International communication
- Fire strategy and risk evaluation
- Integration: sustainable architecture/fire safety
- Fire safety for weakness evacuation
- Compartment Assembly & Structural Fire Resistance

4

Fire experiment Center



5

Fire Testing

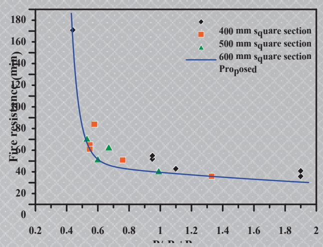
- For research
- For industries
  - Standard test
    - CNS, ISO, EN, JIS



6

Fire Testing

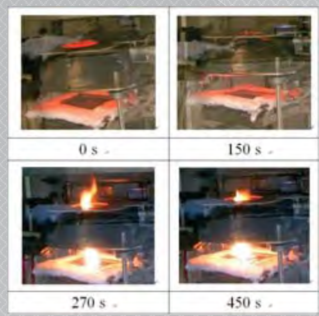
- Fire resistance – **CFBC**
- Factor- cross section size, f_c', t, load ratio, longitudinal steel
- Tested specimen: > 30



7

Fire Testing

- Fire test
  - Photovoltaic panels – BAPV, BIPV



Cone test

fire test

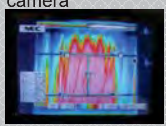
8

Fire Testing

- Fire resistance test with water protection system

Cloth product

Image from IR camera



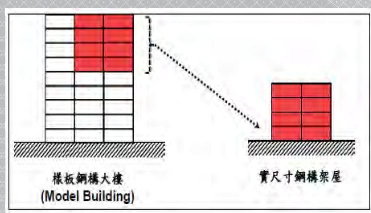
Window shade

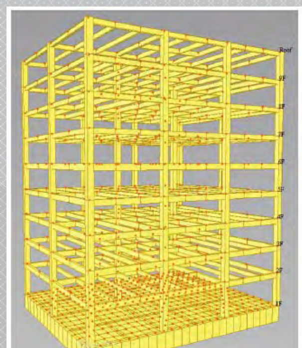
Rolling shutter

9

Fire Tests - large-scale real steel-framed structures

- **Compound disaster -**
  - **earthquake, fire**





3 D model

10

11

~Thanks for your attention~

Website ：www.abri.gov.tw
E-mail ：tcwang@abri.gov.tw

附錄三

熱裂解模擬工作會議報告簡報資料（英文）

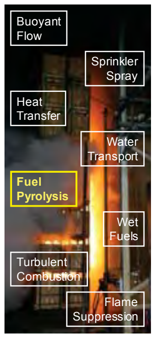
Pyrolysis Modeling at FM Global

Marcos Chaos

The International FORUM of Fire Research Directors
Workshop on Pyrolysis Modeling
9/24/2014

Interest in Fire Modeling

- Large-scale fires: challenging, limited, costly
- Physically-based fire simulations
  - Insights, inter/extrapolation of test results
  - Test design and interpretation
  - Reduce number of large-scale tests
  - Own set of challenges
  - FireFOAM (fmglobal.com/modeling) (github.com/firefoam-dev)

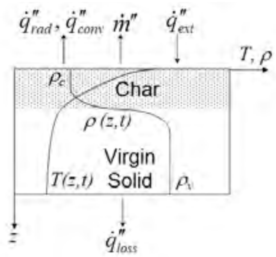


Pyrolysis Modeling Philosophy and Approach

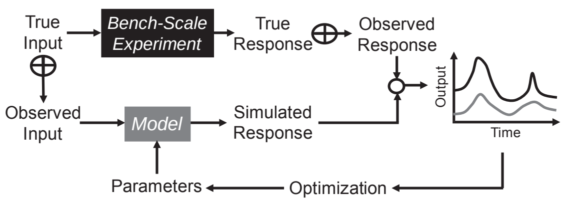
- Simplest model with necessary/sufficient physics
- Realistic outputs (e.g., fuel supply, surface phenomena: temperature, O_2 consumption, emissivity)
- Material properties
  - Model-effective over range of relevant conditions
  - Inverse modeling/optimization – Bench-scale data
  - Importance of BCs – Transferable properties

Pyrolysis Model

- 1-D, CV approach
- Homogeneous material
- Constant properties
- One-step Arrhenius reaction
- Thermal equilibrium
- No pressure build-up
- No gas migration
- Char oxidation



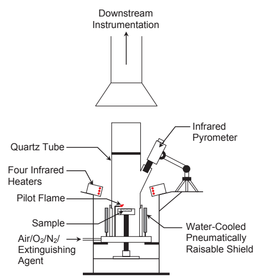
Optimization/Material Properties



Shuffled Complex Evolution

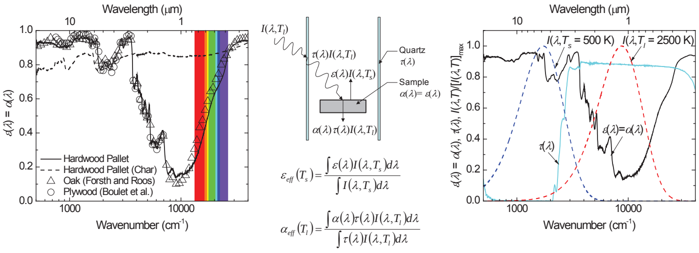
Bench-Scale Data

- Fire Propagation Apparatus (FPA)
- Environment control
  - Anaerobic and oxidative tests
  - RH (hygroscopic)
- 20 – 120 kW/m^2
- IR pyrometry
- Insulated sample holder
- Targets: ML, MLR, T_s



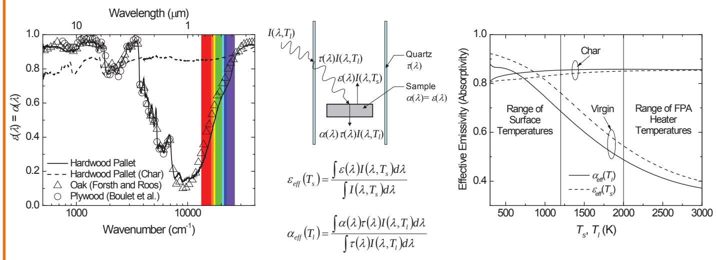
FM Global

BCs – Spectral Properties



FM Global

BCs – Spectral Properties



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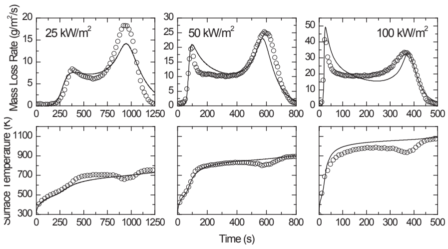
Sample Results – Hardwood



	Property	Value
Virgin	Thermal Conductivity (W/m²/K)	0.26
	Density (kg/m³)	***660***
	Heat Capacity (J/kg/K)	2533
	Emissivity/Absorptivity	Varies
Char	Thermal Conductivity (W/m²/K)	0.36
	Density (kg/m³)	100
	Heat Capacity (J/kg/K)	***1450***
	Emissivity/Absorptivity	***0.85***
Reaction	Pre-exponential Factor (s^{-1})	5.1×10^{14}
	Activation Energy (J/mol)	1.63×10^{5}
	Heat of Pyrolysis (J/kg)	-6.8
	Reaction Order	6.02

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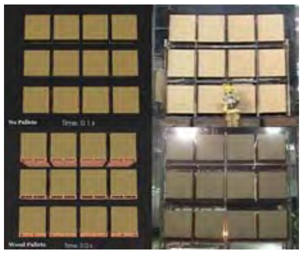
Recent Applications

Parallel panel

Rack storage
(Class 2 commodity)



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Future Directions/Challenges

- “Complex” fuels
  - Geometric
  - Multicomponent
- Challenge: Capture multidimensional phenomena in 1-D model

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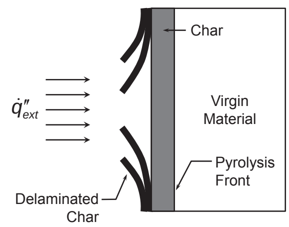
Roll Paper

- Delamination
- Radiation blockage
- Thermal thickness
- Influence of char
- New FPA tests for optimization target data



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Roll Paper

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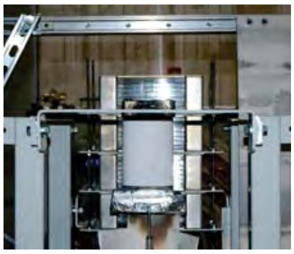

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Roll Paper

- Delamination
- Radiation blockage
- Thermal thickness
- Influence of char
- New FPA tests for optimization target data

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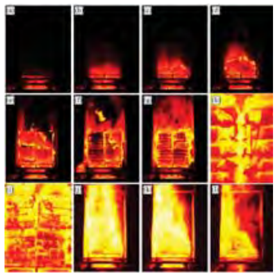
Cartoned Commodities

- Corrugated cardboard drives initial fire growth
- First-cut CV lumped-mass model for interior
- “Single-cell” FPA tests
- Characteristic Fuel Unit intermediate-scale tests
- Melting, dripping, collapse

FM Global

Cartoned Commodities

- Corrugated cardboard drives initial fire growth
- First-cut CV lumped-mass model for interior
- “Single-cell” FPA tests
- Characteristic Fuel Unit intermediate-scale tests
- Melting, dripping, collapse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Summary

- Pyrolysis: Integral submodel for CFD fire simulations
- Approach
  - Bench-scale: Model development and parametrization
  - Intermediate and large-scale: Validation of fully-coupled CFD model
  - Proven methodology for selected commodities
- Ongoing extension to more complex fuels
  - May need further considerations (e.g., 2-D)

Acknowledgments

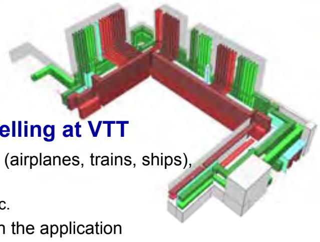
- FM Global Strategic Research Program on Fire Modeling
- RMT (L. Gritzo, S. Dorofeev, F. Tamanini, Y. Wang, C. Wieczorek)
- Research Campus
- Flammability Team (M. Chaos)
  - G. Agarwal
  - L. Crudup
  - S. Ogden
  - D. Zeng
- Fire Modeling Team (K. Meredith)
  - P. Chatterjee
  - A. Gupta
  - N. Ren
- Water Suppression Team (Y. Xin)
  - J. de Vries
  - S. Thumuluru
  - X. Zhou

FM Global

Thank You

Pyrolysis modelling at VTT

FORUM, Workshop on Pyrolysis Modelling
24.9.2014
Anna Matala
VTT Technical Research Centre of Finland

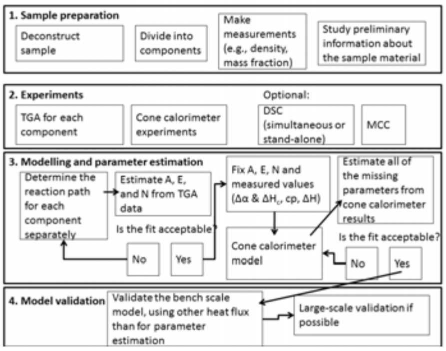


Pyrolysis modelling at VTT

- NPPs, means of transportation (airplanes, trains, ships), facades, etc.
  - Cables, composites, wood, etc.
- Level of complexity depends on the application
  - Detailed pyrolysis whenever reasonable and possible.
  - Different ways to do pyrolysis modelling too.
- Method development mainly in EU funded projects and national nuclear research programme
  - Applications in small assignments.

Pyrolysis modelling at VTT

- Pyrolysis parameters: Mainly GA (own Matlab code)
  - Also analytical methods, expert estimation
  - Chemical kinetics from TGA
  - Other parameters from cone calorimeter
- Other possible experimental methods
  - MCC
  - DSC
  - Measurements of thermal conductivity, specific heat, etc.
- Simulations using FDS
  - Also model development & improvement.
  - Large scale validation.

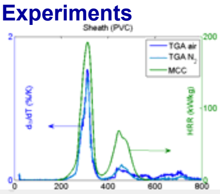


Step 1. Sample preparation

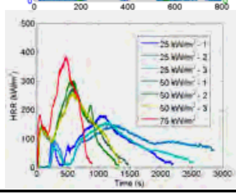
- Christifire cable #701
- GENERAL CABLE® BICC® BRAND SUBSTATION CONTROL CABLE 7/C #12AWG 600V (2006)
  - Sheath PVC, insulation PE, conductor Copper
- Study thermal degradation of PVC and PE
- Plan for experimental work

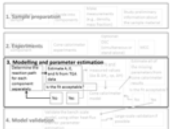
Component	Material	Mass fraction	Density
		(-)	(kg/m³)
Sheath	PVC	0.24	1542
Insulation	PE	0.18	1153
Conductor	Copper	0.58	8954

Step 2: Experiments



- Sheath and insulation:
  - TGA 10K/min, air and N_2
  - MCC 60 K/min
- Whole cable:
  - Cone calorimeter at 25, 50, 75 kW/m²
- Whole cable:
  - Radiant panel (various radiation levels)

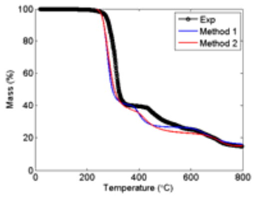




Step 3: Modelling and parameter estimation

- Choose reaction path
  - Parallel, consecutive, competing
  - Based on user preference
  - Based on material information

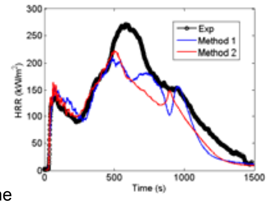
Here, two alternative reaction paths:
  - Method 1: Simple, parallel
  - Method 2: Based on information of polymer decomposition
- Fit kinetic parameters (A, E, N)
  - Genetic algorithm
  - Analytical method



Different reaction paths, different parameters, equally good fit

Step 3: Modelling and parameter estimation

- Fix earlier estimated or measured parameters
  - **These won't be changed anymore!**
- Make cone calorimeter model
  - Geometry
  - Layer structure
- Estimate remaining parameters from cone calorimeter results
  - one or more heat flux



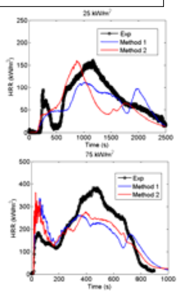
Different parameters → Cannot be mixed or used individually

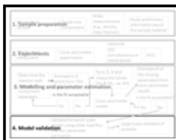
Step 4: Model validation (Bench Scale)

Validation checks the accuracy of the model's representation of the real system

- In pyrolysis modelling, model predicting capability at different circumstances
  - Cone calorimeter test at different heat flux: 25 and 75 kW/m²

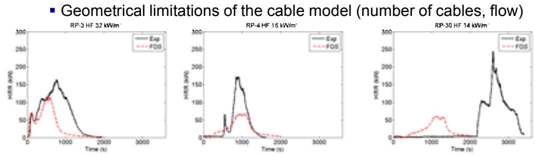
No parameter values changed!





Step 4: Model validation Larger Scale

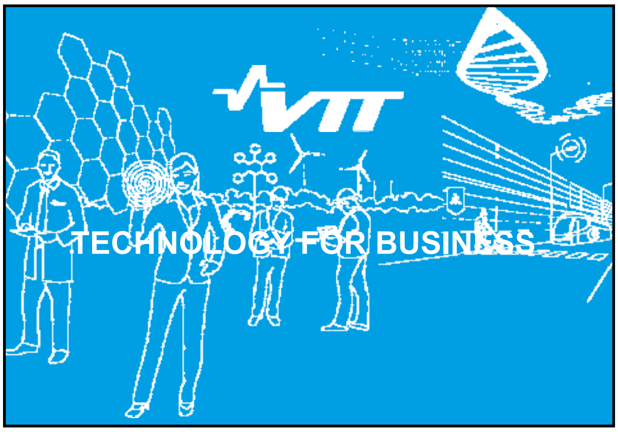
Radiant panel at several heat fluxes
- Large experimental scattering
- Geometrical limitations of the cable model (number of cables, flow)



Loose packing, 44 cables | Loose packing, 22 cables | Dense packing, 44 cables

Conclusions

- Pyrolysis modelling is used at VTT for several applications, whenever possible and reasonable.
- Methods and level of details depend on the application and available experimental data.
  - Lots of modelling choices.
- Here the process for pyrolysis modelling was demonstrated using a PVC cable.
  - Large scale validation on-going also for composites.
- For fire spread simple and detailed pyrolysis models seem to operate equally well (in certain conditions).
  - Differences in heat transfer.
- Large fires easier to predict than small ones.
  - Heat transfer far from flame more accurate than close.



Pyrolysis, Flame Spread, Model Validation, and FDS

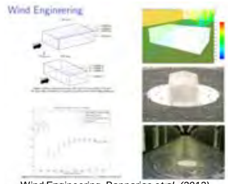
National Institute of Standards and Technology
Gaithersburg, Maryland, USA

K. McGrattan

Modeling Fire Spread and Growth
NIST Validation Experiments

Smoke Venting Validation Experiments, Madrzykowski, Opert, Barowy

US Navy Hangar Experiments, Gott *et al.*



Wind Engineering, Bannarjee *et al.* (2012)

Experimental Study of the Effects of Fuel Type, Fuel Distribution, and Vent Size on Full-Scale Underventilated Compartment Fires in an ISO 9705 Room

Experiments Chapter, FDS Validation Guide

Table 3.10: Summary of important experimental parameters.

- 800 experimental test series (

Test Series	$\dot{Q}$ (kW)	D (m)	H (m)	$\dot{Q}^*$	L_f/H	ϕ	W/H	L/H	r_{cj}/H	r_{rad}/D
Arup Tunnel	5344	1.6	7	1.5	0.8	0.0	1.1	43	0.0 – 1.1	N/A
ATF Corridors	50 – 500	0.5	2.4	0.3 – 3.3	0.3 – 0.9	0.0 – 0.1	0.8	7.1	0.8 – 6.0	N/A
Beyler Hood	8 – 30	0.2	0.5	0.5 – 1.1	0.7 – 1.3	0.2 – 1.7	2.0	2.0	N/A	N/A
Bryant Doorway	34 – 511	0.3	2.4	0.5 – 6.9	0.2 – 1.0	0.0 – 0.2	1.0	2.1	0.6 – 0.8	N/A
Cup Burner	0.3	0.028	Open	2.1	Open	Varying	Open	Open	Open	N/A
FAA Cargo	5	0.1	1.4	1.4	0.2	0.2	2.3	4.8	0.1 – 4.8	N/A
Fleury Heat Flux	100 – 300	0.3 – 0.6	Open	0.3 – 5.5	Open	Open	Open	Open	Open	1.7 – 3.3
FM Panels	30 – 100	0.5	Open	0.2 – 0.5	Open	Open	Open	Open	Open	0
FM/SNL	470 – 516	0.9	6.1	0.6 – 2.4	0.3 – 0.6	0.0 – 0.2	2.0	3.0	0.2 – 0.3	N/A
Hamins CH_4	0.4 – 162	0.1 – 1.0	Open	0.1	Open	Open	Open	Open	N/A	0.1 – 12
Harrison Plumes	5 – 15	0.16	0.5	0.5 – 1.4	0.5 – 1.0	Open	Open	Open	N/A	N/A
Heskestad	10^2 – 10^5	1.1	Open	10^{-3} – 10^4	Open	Open	Open	Open	N/A	N/A
LLNL Enclosure	50 – 400	0.6	4.5	0.2 – 1.5	0.1 – 0.4	0.1 – 0.4	0.9	1.3	0.3 – 1.0	N/A
McCaffrey Plume	14 – 57	0.3	Open	0.2 – 0.8	Open	Open	Open	Open	N/A	N/A
NBS Multi-Room	110	0.3	2.4	1.5	0.5	0.0	1.0	5.1	N/A	N/A
NIST FSE	100 – 2500	0.6 – 1.1	2.4	0.5 – 1.8	0.4 – 1.7	0.2 – 5.9	1.0	1.5	0.4 – 0.8	N/A
NIST/NRC	350 – 2200	1.0	3.8	0.3 – 2.0	0.3 – 1.0	0.0 – 0.3	1.9	5.7	0.3 – 2.1	2.0 – 4.0
NIST RSE	50 – 600	0.15	1.0	5.2 – 63	0.9 – 2.8	0.1 – 1.1	1.0	1.5	N/A	N/A
NIST Smoke Alarms	100 – 350	1.0	2.4	0.2 – 0.3	0.2 – 0.5	N/A	1.7	8.3	1.3 – 8.3	N/A
NRCC Facade	5000 – 10300	4.3	2.8	0.1 – 0.2	0.9 – 1.7	0.6 – 1.2	1.6	2.2	N/A	0
NRL/HAI	50 – 520	0.3 – 0.7	Open	1.1 – 1.2	Open	Open	Open	Open	N/A	0
Sandia Plume	2025 – 5450	1.0	Open	1.8 – 5.0	Open	Open	Open	Open	N/A	N/A
SP AST	450	0.3	2.4	6.1	1.1	0.1	1.0	1.5	N/A	N/A
Steckler	31.6 – 158	0.3	2.1	0.8 – 3.8	0.3 – 0.7	0.0 – 0.6	1.3	1.3	N/A	N/A
UL/NFPRF	4400 – 10000	1.0	7.6	4.0 – 9.1	0.7 – 1.0	Open	4.9	4.9	0.6 – 3.9	N/A
UL/NIST Vents	500 – 2000	0.9	2.4	0.7 – 2.6	0.8 – 1.6	0.2 – 0.6	1.8	2.5	1.0 – 2.3	N/A

Ceiling Jet Chapter. *FDS Validation Guide*

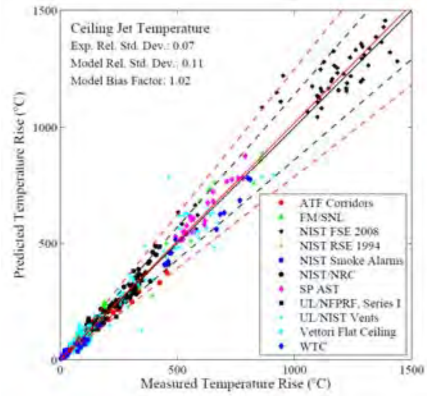


Table 15.1: Summary statistics for all quantities of interest

Quantity	Section	Datasets	Points	$\tilde{\sigma}_E$	$\tilde{\sigma}_M$	Bias
HGL Temperature, Forced Ventilation	5.12	4	111	0.07	0.22	1.27
HGL Temperature, Natural Ventilation	5.12	9	160	0.07	0.07	1.03
HGL Temperature, No Ventilation	5.12	3	32	0.07	0.13	1.23
HGL Depth	5.12	9	177	0.05	0.05	1.03
Ceiling Jet Temperature	7.1.13	11	552	0.07	0.11	1.02
Sloped Ceiling Jet Temperature	7.1.13	2	152	0.07	0.20	0.93
Plume Temperature	6.1.6	7	71	0.07	0.19	1.13
Oxygen Concentration	9.1.4	5	98	0.08	0.11	0.99
Carbon Dioxide Concentration	9.1.4	6	95	0.08	0.11	0.98
Smoke Concentration	9.2.1	1	14	0.19	0.60	2.63
Compartment Over-Pressure	10.3	2	39	0.21	0.23	0.98
Open Compartment Over-Pressure	10.3	2	14	0.15	0.27	1.02
Target Temperature	11.2.4	4	819	0.07	0.21	1.00
THIEF Temperature	11.3.3	2	94	0.07	0.16	1.06
Surface Temperature	11.1.5	3	845	0.07	0.13	1.04
Target Heat Flux	12.2.5	3	267	0.11	0.27	0.98
Flame Impinging Heat Flux	12.1.8	4	52	0.11	0.36	0.93
Surface Heat Flux	12.1.8	2	342	0.11	0.16	0.91
Velocity	8.7	6	211	0.08	0.09	1.00
Sprinkler Activation Time	7.2.1	5	232	0.06	0.15	0.93
Smoke Detector Activation Time	7.3	1	142	0.26	0.26	0.62

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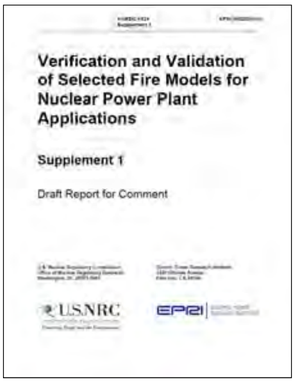
Velocity	8.7	6	211	0.08	0.09	1.00
Sprinkler Activation Time	7.2.1	5	232	0.06	0.15	0.93
Smoke Detector Activation Time	7.3	1	142	0.26	0.26	0.62
Smoke Detector Activation Time, Temp. Rise	7.3	1	142	0.29	0.29	0.86
Cable Failure Time	11.3.4	1	35	0.12	0.16	1.10
Sprinkler Actuations	7.2.2	3	38	0.15	0.29	0.96
Burning Rate	14.5	2	30	0.08	0.21	1.06
Carbon Monoxide Concentration	9.3.5	5	69	0.19	0.41	0.91
Entrainment	6.3	2	87	0.05	0.05	1.12
Extinction Time	13.2	1	39	0.10	0.62	1.96
Species Concentration	9.4	1	126	0.08	0.15	0.98
Low Ceiling Jet Temperature	7.1.13	1	120	0.07	0.15	1.12
Low Heat Flux	12.1.8	[illegible]	18	0.11	0.44	0.97
Low Surface Temperature	11.1.5	1	6	0.07	0.28	1.04
Smoke Obscuration	9.2.2	1	18	0.18	0.18	1.01

From *FDS Validation Guide*, Summary Chapter



Verification and Validation of Selected Fire Models for Nuclear Power Plant Applications

Supplement 1

Draft Report for Comment

U.S.NRC

EPRI

Verification and Validation of FDS, CFAST, Empirical Correlations, recently updated for US NRC

NIST Pyrolysis and Flame Spread Modeling

Microgravity flame spread experiments, S. Olson, NASA

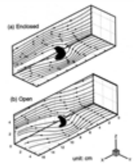
Flame Spread in Microgravity, 1990-2000

T. Kashiwagi, H. Baum, K. McGrattan, W. Mell, S. Olson (NASA)

Mass $\frac{\partial(\rho_s/\rho_{s0})}{\partial t} = -(1-\nu_{C,p})\dot{\omega}_p - (1-\nu_{C,ox})\dot{\omega}_{ox} - (1-\nu_{A,char})\dot{\omega}_{char}$

Pyrolysis: $\dot{\omega}_p = B_p\left(\frac{\rho_s}{\rho_{s0}} Y_p\right)^{n_{Y,p}} \exp\left(-\frac{E_p}{RT_s}\right)$

Pyrolysis reaction parameter [10, 16]	
B_p: frequency factor; 1/s	$3.0 \times 10^{[illegible]}$
E_p: activation energy; kJ/mole	237
$n_{Y,p}$: exponent of Y_p	1.2
$\nu_{C,p}$: mass-based stoich. constant	0.14
$\nu_{F,p}$: mass-based stoich. constant	0.23
q_p: heat of combustion; J/g	64
Thermal & physical properties [10]	
c_{ps}: specific heat of solid; J/(gK)	[illegible] × (T-300)
k_s: thermal conductivity of solid; W/(cmK)	$3.55 + 1.55 \times 10^{-3} \times$ (T-300)
δ: thickness of solid; cm	0.013
ρ_s: surface density; g/cm²	5.7×10^{-3}
ϵ: surface emissivity	0.6
r: surface reflectivity	0.25

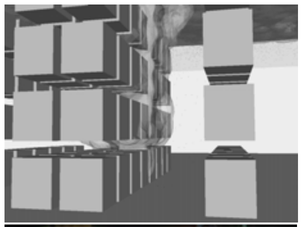


Enclosure Effects on Flame Spread Over Solid Fuels in Microgravity

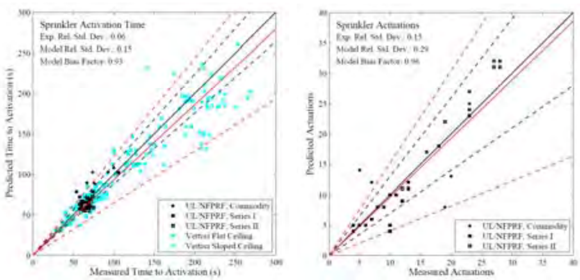
YUJI NAKAMURA, TAKASHI KASHIWAGI, KEVIN B. MCGRATTAN, and HOWARD R. BAUM

Fire Research Foundation
Sprinkler, Vent, Draft Curtain Study
1995-1998

Small scale suppression experiments, A. Hamins (NIST), D. Sheppard (UL)



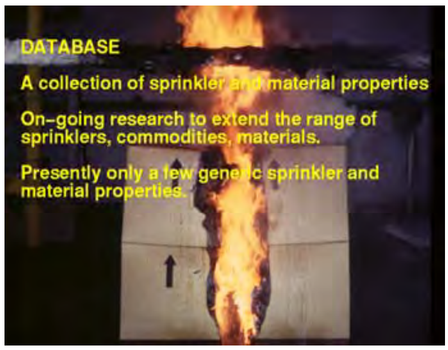
FDS predictions of the time to first sprinkler activation (left) and the total number of activated sprinklers (right). Source, FDS Validation Guide.



Fire PRA Workshop, 2011, San Diego & Jacksonville
Model Uncertainty

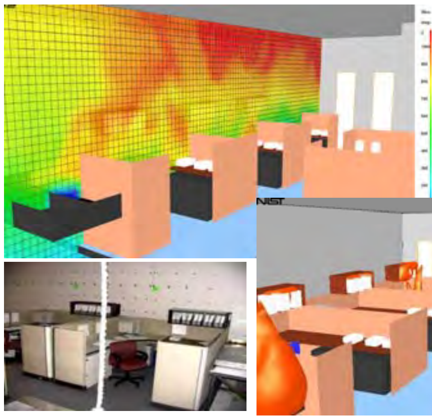
Slide 11

A Collaboration of U.S. NRC Office of Nuclear Regulatory Research (RES) & Electric Power Research Institute (EPRI)



A slide from a presentation at the 2000 Fire Research Foundation Suppression and Detection Meeting, Orlando, Florida

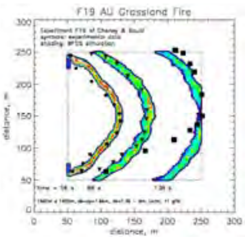
Investigation of a Fatal House Fire
Washington, DC, 2000
D. Madrzykowski and R. Vettori



WTC Investigation
2001-2005

Simulations of Australian Grassland Fires

Ruddy Mell (NIST, Forest Service), 2000-Present

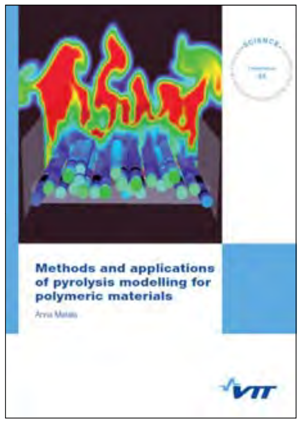


- height = 51 cm
- loading = 0.31 kg m^{-2}
- moisture = 4.8%
- U_2 = 4.8 ms^{-1}
- surface/volume = 12200 m^{-1}
- L_{ig} = 175 m

- Head fire spread rate well predicted.
- Need more testing of flank fire prediction.

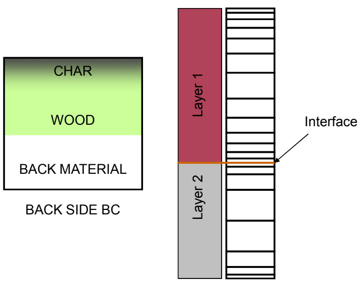
Cable Fire Experiments and Modeling on behalf of US and Finnish Nuclear Regulatory Authorities, 2007-Present

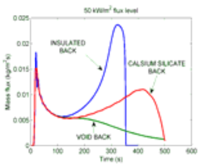
Cable Fire Experiments, K. McGrattan, NIST



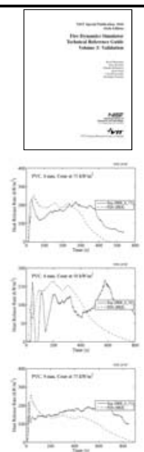
Pyrolysis Model in FDS

S. Hostikka, VTT, Finland, 2003





Charring and Non-Charring Polymers
S. Stoliarov (Maryland), K. McGrattan (NIST)



Summary: Flame/Fire Spread Modeling

1. Is pyrolysis modeling useful in practical fire protection engineering?

   Forensic investigations demands better understanding of flame spread.
2. There is no accepted methodology for measuring input parameters needed for modeling pyrolysis and fire spread.

- In most FDS applications, full-scale experiments are used to "calibrate" fire model parameters. Each model application is special and requires lots of effort
- What are the kinetic and thermophysical properties needed for CFD fire modeling?
- What are the cost-effective standard tests and analysis techniques needed to generate tables of material properties that can be used in CFD calculations? (info for FAA polymers exists, what about other materials?)
- Would a round robin series of standard tests be useful?
  - A non-charring polymer like PMMA (but not PMMA!)
  - A charring polymer or "thermoset" plastic
  - A sample of wood, like pine
  - A low-pile carpet
  - A high-pile carpet
  - PUF, either plain or upholstered

REVISION OF ASTM E1591

Marc L. Janssens

FORUM Pyrolysis Modeling Workshop
Underwriters Laboratories
September 24, 2014

ASTM E1591 REVISION
Change in Scope

- Change of Title and Scope in 2013
  - Original Title: *Obtaining Data for Deterministic Fire Models*
  - Original Scope Section 1.3: "The emphasis in this guide is on compartment zone fire models."
  - Current Title: *Obtaining Data for Fire Growth Models*
  - Current Scope Section 1.3: "The emphasis in this guide is on ignition, pyrolysis and flame spread models for solid materials."
- Deleted 3 of 19 parameters: air/fuel ratio; convective heat transfer coefficient; entrainment coefficient
- Proposed adding 2 parameters: kinetic parameters; thermal conductivity

ASTM E1591 REVISION
Parameters to be Discussed (1)

1. Combustion efficiency
2. Density
3. Emissivity
4. Flame extinction coefficient
5. Flame spread parameter
6. Heat of combustion
7. Heat of gasification
8. Heat of pyrolysis
9. Heat release rate

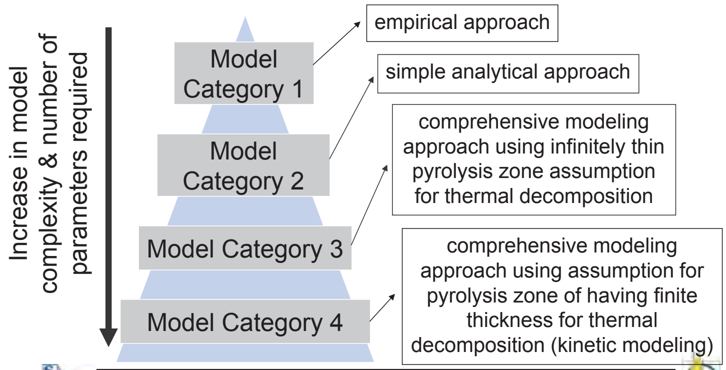
ASTM E1591 REVISION
Parameters to be Discussed (2)

10. Ignition temperature
11. Kinetic parameters
12. Mass loss rate
13. Production rate of species
14. Pyrolysis temperature
15. Radiative fraction
16. Specific heat
17. Thermal conductivity
18. Thermal inertia

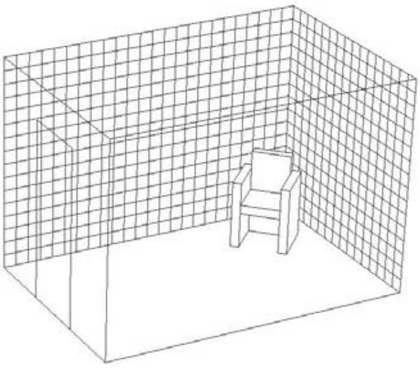
ASTM E1591 REVISION
General Approach

- Measure parameter when possible and appropriate
  - Preferred: Standard method without modifications
  - Second Best: Use standard method with modifications
  - Last Resort: Use non-standard method
- Use optimization technique for parameters that cannot be measured
  - Example 1: Parameters that do not have a physical meaning
  - Example 2: "Apparent" parameters
- If possible, include uncertainty estimates when presenting parameter values

ASTM E1591 REVISION
Pyrolysis Model Categories



CATEGORY 1 MODELS FOR LININGS
Objects vs. Linings

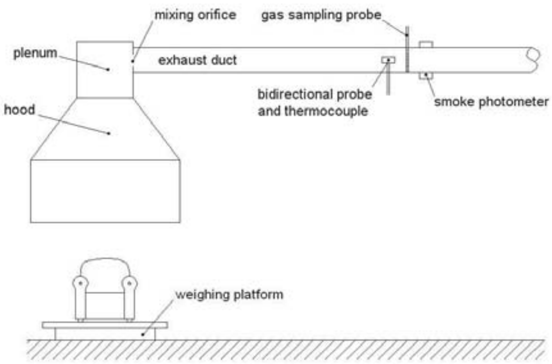


CATEGORY 1 MODELS FOR OBJECTS
Parameter Estimation Methods

- Standard methods are available for measuring
  - Heat release rate
  - Mass loss
  - Smoke production rate
  - Species generation rate
- Non-standard methods are available for measuring
  - Radiative fraction (e.g., NISTIR 7013, FPRF Oxidizer Project)
- Challenges
  - Calculating mass loss rate from mass loss (Savitzky-Golay)
  - Estimating epistemic uncertainty

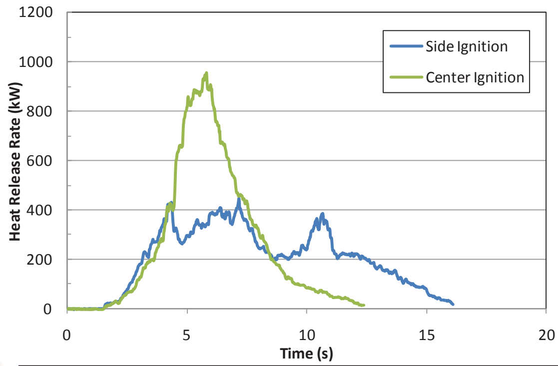
Southwest Research Institute – Fire Technology Department

CATEGORY 1 MODELS FOR OBJECTS
Furniture Calorimeter (ASTM E1537)



Southwest Research Institute – Fire Technology Department

CATEGORY 1 MODELS FOR OBJECTS
Epistemic Uncertainty



Southwest Research Institute – Fire Technology Department

CATEGORY 4 MODELS
Kinetic Parameter Estimation Methods

- Simple methods are available for estimating kinetic parameters from TGA data for isolated reactions
  - Only TGA curve, or TGA curve and its derivative
  - The entire TGA curve is used, the initial part, or the peak MLR
  - Single TGA curve or multiple curves at different heating rates
  - Reaction order is assumed to be equal to one, or left TBD
- Challenges
  - Multiple overlapping reactions
    - Extension of simplified methods (Matala et al., JFS 2012)
    - Optimization (evolutionary methods, Bayesian inference, etc.)
  - Arrhenius equation does not fit the data

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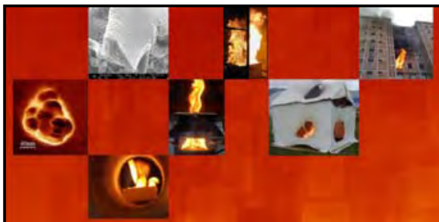
ASTM E1591 REVISION

Southwest Research Institute – Fire Technology Department



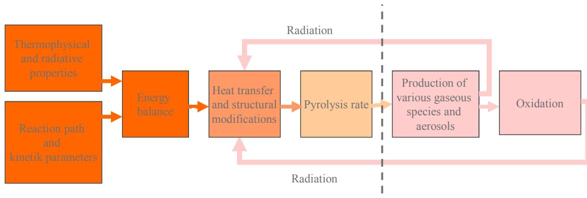
Actual research on multiscale pyrolysis modelling

Eric GUILLAUME, Damien MARQUIS, Fabien HERMOUET

September 2014

Context

Increasing models capability for:
- Generation gases and aerosols, by condensed and flame phases.
- Fire growth calculation

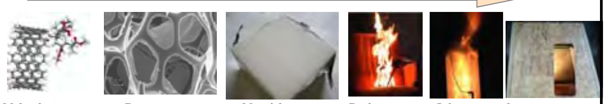


2

Context

Physical and chemical phenomenon:
- Energy transport
- Mass transport
- Chemical reactivity
- Structural changes
- Changes induced to boundary conditions

Analysis scale



How to chose analysis scale?

3

Approaches chosen at LNE

1 - Intrinsic pyrolysis model
- Determination of reaction path
- Determination of A, Ea and n triplets for each reaction
- Use of TGA for input data, at several heating rates
- Use of GA (home-made program)
- Experimental determination of thermal and radiative properties
- Verification at cone calorimeter scale
- Validation in end-use conditions, vs. Large scale tests

2 - Integrated pyrolysis model
- Determination of relations between mass loss rate, time and boundary conditions at material surface
- Use of cone calorimeter to produce boundary conditions (O_2, Heat flux)
- Use of matricial model (« tabulated » pyrolysis rate)
- Verification and validation in end-use conditions, vs. Large scale tests

---

Approach nr 1

Intrinsic pyrolysis model

Approach 1 - Physical properties determination

Condensed phase intrinsic properties
- Thermophysical properties (conductivity, enthalpies, etc)
- Radiative and optical properties (absorption coefficient, emissivity)
- Real chemical decomposition path
- Kinetik parameters (thermodynamics)
- etc

Condensed phase extrinsec properties
- Simplified reaction path (simplified chemistry)
- Kinetik (pseudo) parameters

Numerical approach
- Heuristic optimization method : GPYRO, Thermakin(?)
- Initial values range and fitness factor used
- Not physical but mathematical approach

Experimental approach
- Difficulty to estimate values for all species (especially transient species)
- Difficulty to measure properties in all axes
- Experimental uncertainties, especially at high temperature

Limitation of the number of optimized variables to extrinsic properties

6

Approach 1 - Intrinsic properties

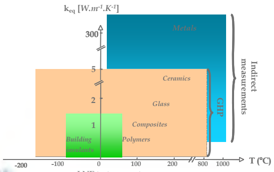
Thermophysical properties – Equivalent thermal conductivity

Orthotropic material

$$\Lambda = \begin{bmatrix} k_{xx} & k_{xy} & k_{xz} \\ k_{yx} & k_{yy} & k_{yz} \\ k_{zx} & k_{zy} & k_{zz} \end{bmatrix}$$

Matrix reduction

$$\Lambda = \begin{bmatrix} k_{xx} & 0 & 0 \\ 0 & k_{yy} & 0 \\ 0 & 0 & k_{zz} \end{bmatrix}$$



LNE test apparatus

High temperature measurement

Transient methods
- Laser flash
- Hot wire, hot discs

Static methods
- Guarded hot plate
- Guarded barrel

Laser flash	Guarded hot plate
Uncertainty LNE* : 3 - 6%	Uncertainty LNE* : 5 - 10%
Metals Composites	Insulants Porous materials (wood, foam) Ceramics Glass Polymers

* Trueness (bias) + fidelity

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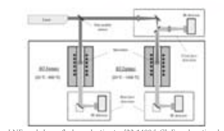
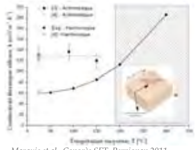
Approach 1 - Intrinsic properties

Thermophysical properties – Equivalent thermal conductivity



LNE made Laser flash conductimeter [23-1400 ° C], French national reference
[Hay B. et al., High Temp.s-High Press,2010;39 (3):181-208]



Marquis et al., Congrès SFT, Perpignan 2011

LNE made Reference Guarded Hot Plate [+23 ; +800 ° C], French national reference

Reference Guarded Hot Plate [-180 ° C ; +700 ° C], French national reference

Actual difficulties :
- k_{eq} measurement during thermal decomposition
- k_{eq} measurement for transient species
- Uncertainty calculation at high temperature

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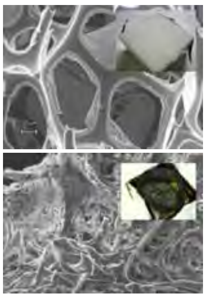
Approach 1 - Intrinsic properties

Thermophysical properties – Equivalent thermal conductivity



L. Bustamante Valencia, *Thèse doctorat*, ENSMA, 2009

Increase of uncertainties with temperature

Problems with thermal changes in material with temp.

- Dimensional changes and molecular modifications to the material during heating.
- GHP : Risk of contact loss between sample and plates (additional contact resistances).
- Errors in temperature measurement in the sample.
- Distortion of heat flux lines.

T_{max} limited by physical and chemical characteristics of the material

High contribution from radiation in the material at high temperature (porous and semi-transparent materials):

- Correspondence between formula in a code and formula in the experimental model, including how internal radiation is considered.
- Problem linked to pores size (and wavelenght) for porous materials
- Problem linked to absorption coefficient for semi-transparent materials

The problem is increased for fire scenarios, where incident radiation could be very important

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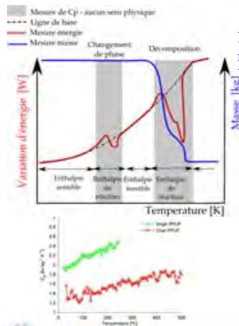
Approach 1 - Intrinsic properties

Thermophysical properties – Enthalpies and Cp measurements



L. Bustamante Valencia, *Thèse doctorat*, ENSMA, 2009

Drop calorimetry (very time consuming measurements)

Differential scanning calorimetry (DSC)
- DSC with heat compensation
- DSC in heat flux mode
- DSC with specific measurement heads

Actual difficulties :
- Crucible contents
- Conditions in crucible
- Determination of baselines
- Transient species characterization
- Uncertainty calculations
- Differentiate sensitive enthalpy from others
- Reference materials

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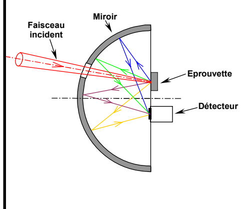
Approach 1 - Intrinsic properties

Radiative properties – Material absorption coefficient



French national reference reflectometer build at LNE [Hay B. et al., *High Temp.s-High Press*,2010;**39** (3):181-208]

Remit :

Directional hemispheric reflectivity

1. **Spectral directional hemispheric reflectivity measurement (reflectometer)**
2. **Transmission factor measurement (FTIR)**
3. **Effect of material thickness**

Semi-transparent material : transmission and reflexion meas.
Opaque material : only reflexion

Notations

τ_λ : Monochromatic transmittivity [m^{-1}]
κ_λ: monochromatic absorption coefficient [m^{-1}]
e : material thickness [m]

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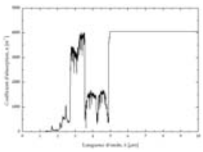
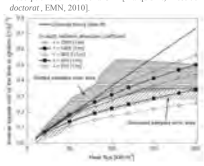
Approach 1 - Intrinsic properties

Radiative properties – Absprption coefficient of the material



Absorption coefficient of a GRP [Marquis D., *Thèse de doctorat* , EMN, 2010].



Influence of κ on PMMA ignition
[Bal & Rein, *Combustion and Flame* **158** (2011) 1109–1116]

Measurement depends of:
- Chemical nature of the material
- Spectral range
- Thickness
- Temperature and decomposition
- Surface topography (rugosity)
- Direction
- etc

Are the values a characteristic of the material ?
Which wavelenght(s)?

Actual problems :
- Blackbody temperature
- Sample temperature
- Structural modifications
- Thickness
- Uncertainty at high temperature [2-5%]

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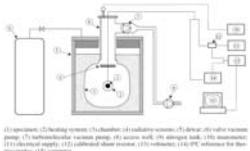
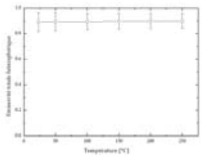
Approach 1 - Intrinsic properties

Radiative properties – Total hemispheric emissivity



Spectral normal hemispheric emissivity reference apparatus at LNE [Hay B. et *al.*, *High Temp.s-High Press*,2010;**39** (3):181-208]



Total hemispheric emissivity of a polyester resin

Measurement depends of:
- Chemical nature of the sample
- Decomposition of the sample
- Surface temperature measurement
- Sample temperature
- Blackbody reference temperature (Nitrogen, 77K)

Actual problems:
- Sampling
- Samples heating
- Samples temperature
- Structural changes
- Uncertainties with temperature

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Approach 1 - Extrinsic properties

Kinetic constants – matter scale

Reaction rate

$$\dot{\omega}_i = f(\alpha)^{n_i} k.Y_{O_x}^{\delta}$$

- **Rate constant** $k_i(t) = A_i e^{\frac{-E_i}{RT(t)}}$
- **Conversion function**

Adaptation of $f(\alpha)$ model
- 1st order: $f(\alpha)=1-\alpha$ ➡ Do we have to optimize « n » ?
- Char oxidation: Ginstling Brounshtein equation $f(\alpha)=3/2\,[(1-\alpha)^{1/3}-1]^{-1}$

➡ Scaling : Determination of kinetik parameters (A, E, n) at matter scale.

Notations

$f(\alpha)$: differential conversion function
k : Rate constant [s^{-1}]
T : temperature [K]
$\dot{\omega}$: Reaction rate [s^{-1}]
A : Pre-exponential factor [s^{-1}]
E : Activation energy [$J.kg^{-1}$]
n : Reaction order
R : Perfect gas constant
Y_{Ox} : Mass fraction of oxidant [$kg.kg^{-1}$]
δ: Reaction order for oxidant
α : conversion progress

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Approach 1 - Extrinsic properties

Kinetic constants – matter scale

1. Analysis of matter reactions (TGA-FTIR)
2. Proposal of a simplified thermal decomposition mechanism

Example of PPUF scheme
[E. Guillaume, *HDR proposal*, ENSMA, 2011]

Hypotheses of TGA (verified ?) :
- Hypotheses not even verified (thermodynamic equilibrium, diffusion neglected, etc)
- Effect of apparent surface
- Influence of heating rate
- Diffusion
- Effect of gas flow

etc

➡ Coupling with FTIR

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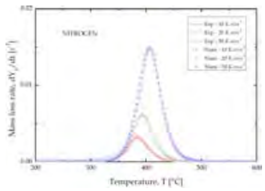
Approach 1 - Extrinsic properties

Kinetic constants – Matter scale

3. Modelling decomposition rate



Results with a unique dataset, reproducing various heating rates, PEST under air. [Marquis D., *Thèse de doctorat* , EMN, 2010].

Transitory species mass loss rate

$$\frac{d}{dt}Y_j = \sum_{\gamma \in H_j} Y_{r_\gamma}\dot{\omega}_\gamma - \sum_{\xi \in G_j}\dot{\omega}_\xi \quad \text{with} \begin{cases} \dot{\omega}_i = f(\alpha)^{n_i} k.Y_{O_x}^{\delta} \\ k_i(t) = A_i e^{\frac{-E_i}{RT(t)}} \end{cases}$$

Y_r : Residual mass fraction [$kg;kg^{-1}$]
H_j represents all reactions producing specie j and G_j, all reactions using this specie as reactive

Total mass loss rate

$$\frac{d}{dt}Y_T = \sum_{j=1}^{M}\frac{d}{dt}Y_j$$

⇨ Non-linear OED equations

4. Determination of kinetik parameters using a heuristic optimization system

Does the solution exists? Is the solution unique?
Are the parameters valid for upper scales?

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Approach 1 - Extrinsic properties

Kinetic constants – Matter scale

⚠ Extrinsic properties: the real and complete thermal decomposition chemistry is unknown
- Occurrence probabilities, concentrations in solid phase ?
- Physical sense of E and A (R interpretation for a solid ?)

Mathematical parameters depending of :
- chosen equation
- test conditions
- thermal decomposition reaction path chosen
- material studied
- people who interprets thermograms

➡ Impossible to compare results with literature

Do we need a model at smaller scales (e.g. molecular) ?

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Approach 1 - Use in fire codes

Heat transfer equations are 1D now (FDS, OpenFoam, etc)
Only valid for uniform incident radiation (case of fully-developed fire).

Advantages:
- Calculation simplification (CPU time)
- Limitation of physical properties measurements needed

Disadvantages:
- Don't represent high flux gradients (spatial discretization)
- Don't represent some heating and flame spread modes (e.g. backflow propagation)
- Don't represent properly complex materials heating
- Unable to consider anisotropic and orthotropic materials

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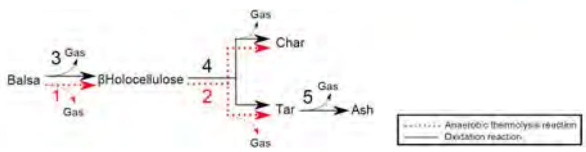
Approach 1 - Example – case of wood (1)

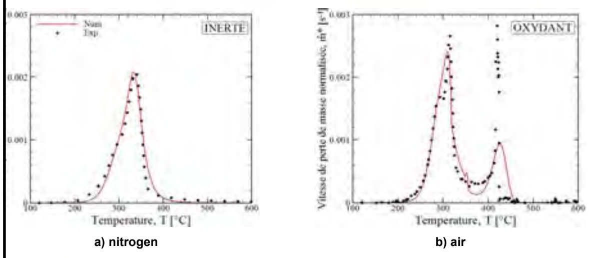


	Réactions	Température (°C)	Réactifs		Produits
1	Pyrolyse	[190-310]	Holocellulose	→	ν_1. β-Holocellulose +(1-ν_1). [Y_k+Y_j+CH_3COOH]
2	Pyrolyse	[310-380]	β-Holocellulose	→	ν_2. goudron + ν_3 charbon+(1-ν_3).[Y_k+Y_j+CH_4]
3	Oxydation	[190-320]	Holocellulose+O_2	→	ν_4. β-Holocellulose +(1-ν_4). [Y_k+Y_j+CH_3COOH]
4	Oxydation	[320-400]	β-Holocellulose +O_2	→	ν_5. goudron + ν_6. charbon+(1-ν_5)[Y_k+Y_j+CH_3COOH]
5	Oxydation	[400-420]	goudron+O_2		ν_7. résidu +(1-ν_7). Y_k

Y_k=CO_2+CO+H_2O+HCOH ; Y_j=CH_3OH+HCOOH ; HCOH : Formaldéhyde ; CH_3OH : Méthanol ; HCOOH : Acide formique

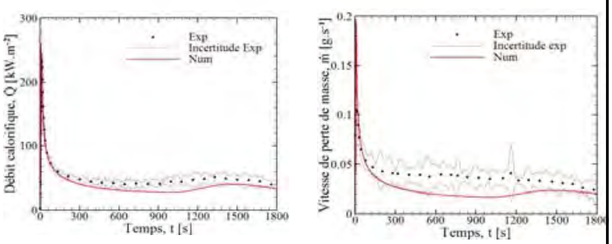
LPA mechanism for wood pyrolysis

Approach 1 - Example – case of wood (2)



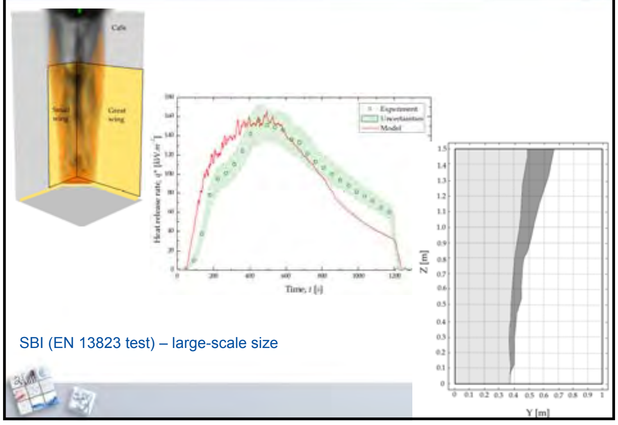
TGA modelling

Approach 1 - Example – case of wood (3)



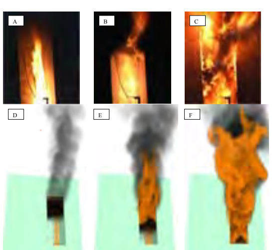
Cone calorimeter modelling (energy and mass) at 50 kW/m²

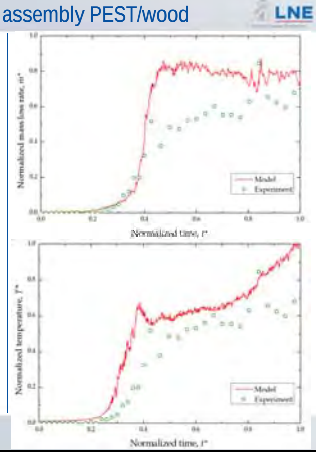
Approach 1 - Example – case of assembly PEST/wood



SBI (EN 13823 test) – large-scale size

Approach 1 - Example – case of assembly PEST/wood





Real scale test and fire modelling
Structure of 20m²

Approach 1 - Conclusions

1. Measurement of thermophysical properties bounded by the decomposition temperature.
2. Parameter optimization "mathematical" only.
3. Difficult to evaluate the properties of transient species.
4. Difficult to assess the experimental uncertainties in temperature.
5. Use of a heat flow equation in the condensed phase 1D not suitable for fire code

Approach nr 2

Integrated pyrolysis model

Approach 2 - New approach

- As the parameters to consider are numerous, some have a particular influence on the thermal degradation of the solid especially in the early phase of fire
  - Oxygen availability
  - Irradiance level received at the material surface
- Thus, the Controlled Atmosphere Cone Calorimeter has been chosen because it allows a variation of the aforesaid parameter within a large range
  - This apparatus have been widely used to assess the reaction-to-fire of polymeric materials in varying oxygen concentration and irradiance level conditions [7, 8, 9]

[7] Mikkola E., *Effects of oxygen concentration on cone calorimeter results*, Proceedings of the 6th International Fire Conference (INTERFLAM), 1993: pp 49-56.
[8] Werrel M. Deubel J.H., Krûger S., Hofmann A., Antonatus E., Krause U. & Deuerler F., *Use and benefit of a controlled atmosphere cone calorimeter*. Proceeding in the 13th International conference Fire and Material, 2013: pp 273-285.
[9] Marquis D.M., Guillaume E., & Camillo A., *Effects of controlled ventilation conditions on combustibility assessment from a controlled atmosphere cone calorimeter*. Proceeding of the 18th international conference on fire safety (2014).

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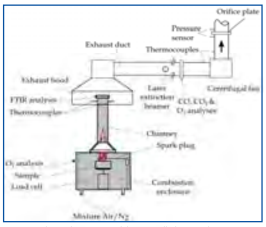
Approach 2 - New approach

- Controlled atmosphere cone calorimeter
  - Evolution of irradiance level and oxygen concentration
  - Evaluation of numerous degradation parameters
    - Ignition time, mass loss, mass loss rate, gaseous emissions, HRR, *etc.*
  - Description of the materials thermal decomposition kinetic



Experimental apparatus of the Controlled Atmosphere Cone Calorimeter

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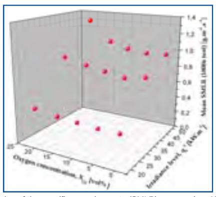
Approach 2 - Methodology

- Using this apparatus, the degradation parameters can be studied on a large domain
  - Oxygen concentration (0, 5, 10, 15 and 21%vol)
  - Irradiance level (20, 35 and 50 kW.m^{-2})
- Considering the specific mass loss rate parameter, the response can be plotted as a surface as follow


Surface representation of the specific mass loss rate (SMLR) averaged on 1800s (test duration) of a Polyisocyanurate foam for chosen irradiance level and oxygen concentrations

28

Approach 2 - Methodology

- From this surface representation a numerical model can be elaborated to model the surface
  - Model is based on multiple linear regression using polynomial models

$$y = a_0 + \sum_{i=1}^{N} a_i x_i + \sum_{i}^{N} a_{ij} x_i^2 + \sum_{i \neq j}^{N} a_{ij} x_i x_j + \dots + \sum_{i \neq j \neq k}^{N} a_{ijk} x_i x_j x_k + a_{i \dots N} x_i \cdots x_N \qquad (Eq\ 1)$$

- With
  - Y: Response of the chosen parameter
  - a_i: Polynomial coefficients
  - x_i: polynomial factors
- The model can then be constructed with X factors and the order of the polynomial is not limited (n order)
  - In this particular case two factors are considered
    - x_1: irradiance level
    - x_2: oxygen concentration

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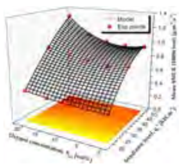
Approach 2 - Methodology

- Thanks to the experimental data (15 response points corresponding to experimental points tested for different couples [irradiance level - Oxygen Concentration])
  - The model coefficients can be determined and a value of the response for a chosen parameter predicted
    - A complete surface can then be created and plotted

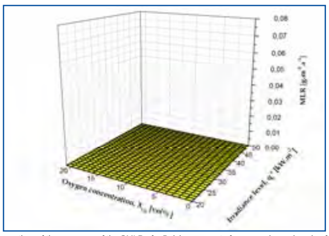
For SMLR


Numerical surface representation of the averaged SMLR (1800s) of a PIR foam on a large domain of irradiance level and oxygen concentration

30

Approach 2 - Methodology

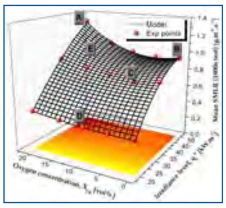
- A surface can be calculated on a averaged parameter on the whole duration of the tests (1800s each), but also for each time step of the tests (5s step)
  - Using the developped methodology it is thus possible to determine the response of a specific parameter over time



Evolution over time of the response of the SMLR of a Polyisocyanurate foam on a large domain of irradiance level and oxygen concentration (Time step of 5s, test duration of 1800s: 360 surfaces)

Approach 2 - Methodology

- As a surface is plotted for each time step the model allow to plot the evolution of a parameter for a chosen couple [irradiance level - oxygen concentration] as a curve allowing
  - To validate the accuracy of the model in comparing the numerical obtained curves to the experimental ones (for the 15 set of reference data)
  - To predict numerical curves when no experimental data are available



Points chosen on the surface representation of the SMLR over time to compare experimental curves to the ones predicted with the model

Approach 2 - Methodology

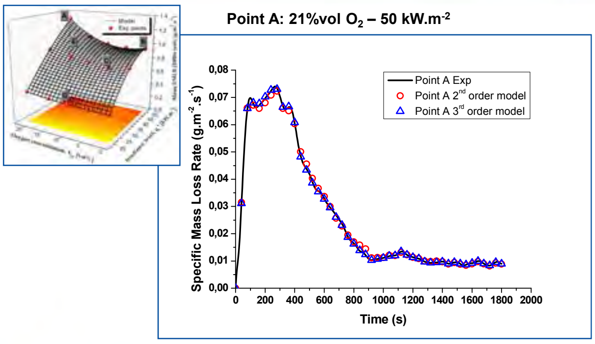


Figure 14: Evolution of the mass loss rate (MLR) over time for a 50 kW.m⁻² irradiance level and a 21%vol oxygen concentration for a Polyisocyanurate foam

Approach 2 - Methodology

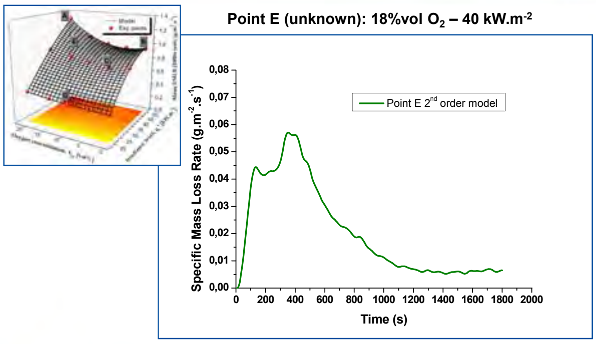


Figure 18: Evolution of the mass loss rate (MLR) over time for a 40 kW.m^{-2} irradiance level and a 18%vol oxygen concentration for a Polyisocyanurate foam

Approach 2 - Methodology

- To assess the trueness and precision of the modelled curve
  - The graphic way is to compare its shape with the nearest experimental curves available

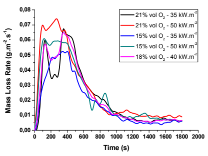


Figure 19: Comparison between one modelled and the four nearest experimental curves to assess the shape of the modelled one

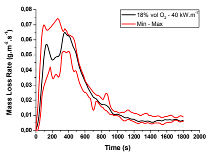


Figure 20: Comparison between the modelled curve and the max and min at each point for the fourth nearest experimental curves

  - The numerical way is to compare the mean and total values of MLR with the ones obtained for the nearest curves values available

Oxygen concentration	15%volO_2	21%volO_2	18%volO_2	15%volO_2	21%volO_2
Irradiance level	35kW.m^{-2}	35kW.m^{-2}	40kW.m^{-2}	50kW.m^{-2}	50kW.m^{-2}
Mean MLR value	0,019	0,022	0,023	0,024	0,027
Total MLR value	6,715	8,088	8,183	8,751	9,714

Table 2: Presentation of the values of both the mean MLR and total MLR associated with each studied conditions

Experimental values – Known
Numerical values – Predictive, Unknown

Approach 2 - Conclusions

- The methodology developed allows
  - to assess the thermal behaviour of a material at small scale thanks to the surface representation (parameters evolution, behaviour and shape of measured parameter)
  - to predict with a great accuracy parameters on area of the domain where no experimental data are available with only a few experiments performed
  - to evaluate the fire growth in tunnels based on solid phase characterisation and to dissociate it from gaseous phase
- Although the methodology is not limited to the study of the effects of two parameters and other conditions can be integrated as fixed or dynamic conditions
- There is still an important work to perform to ensure that the methodology can be used widely in assessing a material thermal degradation

Exceptional service in the national interest

Pyrolysis Modeling at SNL

Amanda Dodd
Principal Member Technical Staff
Thermal/Fluid Science and Engineering Department
Sandia National Laboratories, Livermore, CA

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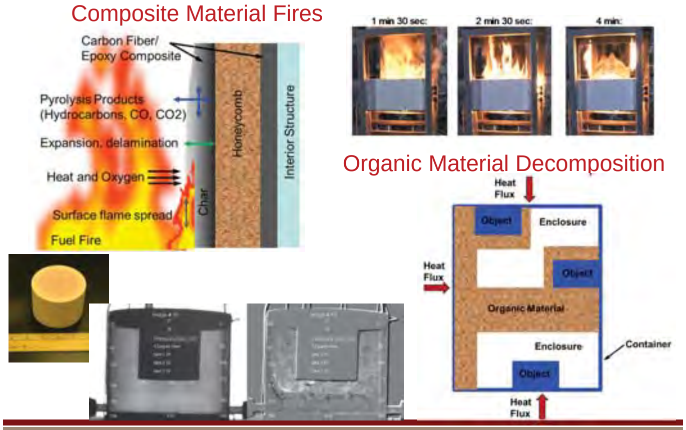
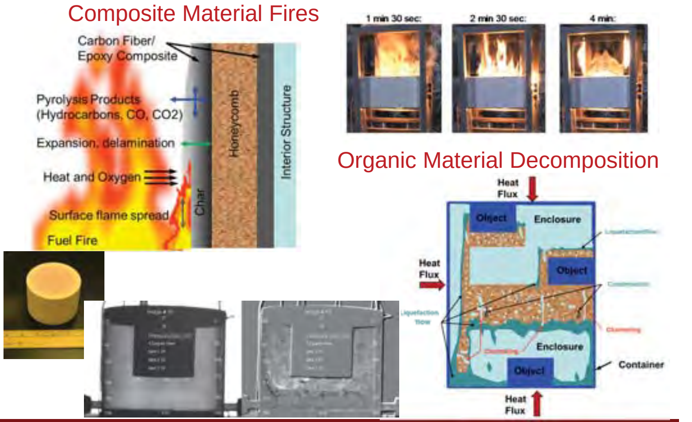
Problems of Interest

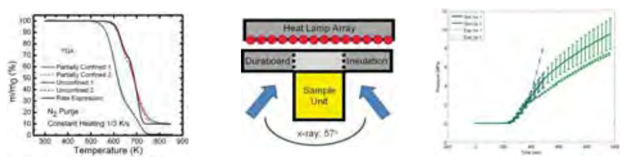


Problems of Interest

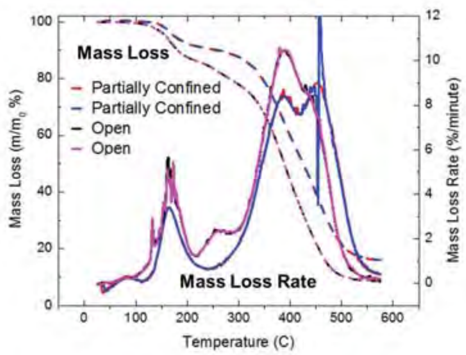


Model Development Approach

- Develop material properties and decomposition models from independent laboratory experiments
- Develop model based on existing conduction-radiation code
- Assess model using small container heat transfer-pressurization experiments with uncertainty quantification
- Decision: add additional uncertainty, new physics, etc.
- Evaluate model in larger scale sub-system experiment



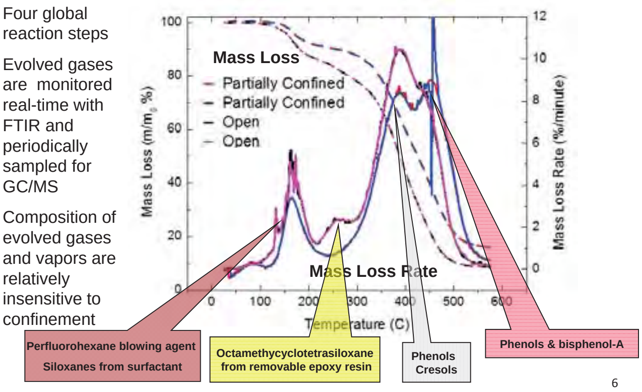
Thermogravimetric Analysis



- Model will be developed for partially confined data and will be a simplified engineering model enabling pressure prediction

Thermogravimetric Analysis

- Four global reaction steps
- Evolved gases are monitored real-time with FTIR and periodically sampled for GC/MS
- Composition of evolved gases and vapors are relatively insensitive to confinement



Decomposition Kinetics Model

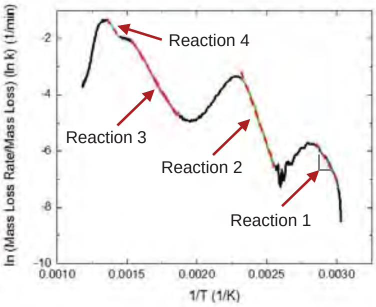
- 4 reaction steps
- Arrhenius rate kinetics:

$$k_i = k_i^0 \exp(-Q_i/RT)$$

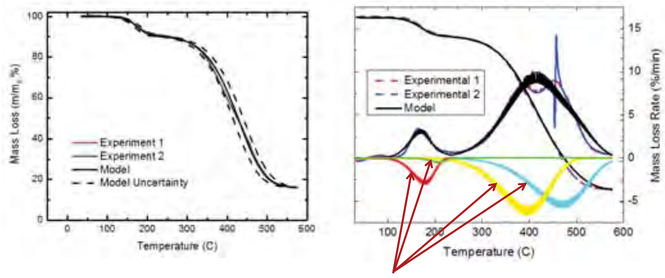
- Plotted:

$$\ln(k_i^0) = k_i^0 - Q_i/RT$$

- Slope of lines give Activation Energy (Q_i/R) and y-intercept gives pre-exponential factor (k_i^0)



Decomposition Model Fit to data



Reaction rates for Reactions 1,2,3,4

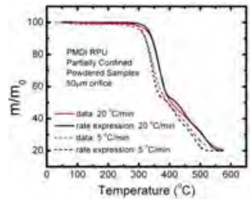
TGA-FTIR and DSC provided data for rate expressions, evolved gases, and ΔH

Polymer = $w_1A_1 + w_2A_2 + \cdots$

$$A_i \xrightarrow{r_i} \xi_{i1}B_{i1} + \xi_{i2}B_{i2} + \cdots$$

$$\frac{dw_{A_i}}{dt} = -k_i w_{A_i} = -r_i \qquad \frac{d\bar{\rho}_{B_{ij}}}{dt} = \rho_B^0 \frac{\xi_{ij} w_i^0}{\bar{M}_{B_{ij}}} k_i w_{A_i}$$

$$k_i = k_i^0 \exp(-Q_i/RT)$$



A_i	W_i	ξ_{ij}	Decomposition Products	MW (kg/mole)	ΔH kJ/kg	K^0 (s^{-1})	Q/R (K)
A_1	0.45	0.56	CO_2	44	0	8.0×10^{12}	21,600
		0.44	Organic vapors	~80			
A_2	0.15	1.0	Organic Vapors	~120	0	1.8×10^{11}	21,600
A_3	0.40	0.50	Organic Vapors	~120	0	8.9×10^{9}	21,600
		0.50	Char				

Heat Transfer-Pressurization Model Formulation

Effective Conductivity with Decomposition Chemistry

Energy Equation

Based on diffusive approximation for optically thick material

$$\rho c \frac{\partial T}{\partial t} = \nabla \bullet (k + k_e)\nabla T + \sum_i \rho r_i(-\Delta H_i)$$

$$k_e = \frac{16\sigma T^3}{3(a+\sigma_s)}$$

Effective radiative conductivity k_e depends on absorption coeff. a and scattering coeff. σ_s[1]

•Note: Absorption coeff. a and scattering coeff. σ_s were calculated using an analytical two-flux model for radiative transfer and the measured values of reflectance R and transmittance T[2,3]

Decomposition Model

Decomposition reactions / rates (r_i)

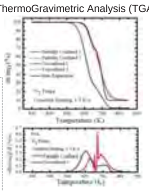
Polymer = $w_1A_1 + w_2A_2 + \cdots$

$$A_i \xrightarrow{r_i} \xi_{i1}B_{i1} + \xi_{i2}B_{i2} + \cdots$$

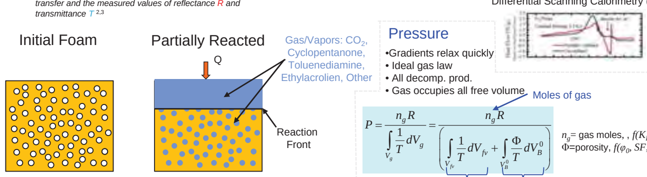
$$\frac{dw_{A_i}}{dt} = -k_i w_{A_i} = -r_i \qquad \frac{d\bar{\rho}_{B_{ij}}}{dt} = \rho_B^0 \frac{\xi_{ij} w_i^0}{\bar{M}_{B_{ij}}} k_i w_{A_i}$$

$$k_i = k_i^0 \exp(-Q_i/RT)$$

ThermoGravimetric Analysis (TGA)



Differential Scanning Calorimetry (DSC)



Pressure

- Gradients relax quickly
- Ideal gas law
- All decomp. prod.
- Gas occupies all free volume

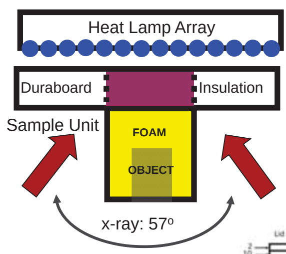
$$P = \frac{n_g R}{\int_{V_g} \frac{1}{T} dV_g} = \frac{n_g R}{\left(\int_{V_{fv}} \frac{1}{T} dV_{fv} + \int_{V_B^0} \frac{\Phi}{T} dV_B^0\right)}$$

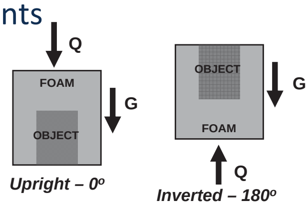
Moles of gas; Free volume/ temperature; Gas Volume: reacted area and pore space

n_g= gas moles, , $f(K_{Bij}, T)$
Φ=porosity, $f(\varphi_0, SF, f_p)$

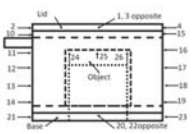
[1]Siegel, R. and Howell, J. R., Thermal Radiation Heat Transfer, 2nd ed., Hemisphere Publishing Corp., Cambridge, 1982, p497-p501.
[2]Reichman, J., *Applied Optics*, 12 (8), August 1973, p1811-p1815.
[3]Erickson et al., BCC 2009.

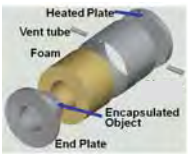
Thermal transport and container pressurization experiments





- Sample container
  - Sleeve 321 SS tubing
    - 8.89-cm OD, 5.40 cm long
    - 1.651-mm wall thickness
  - End plates: 0.602-cm thick 304 SS
    - Laser welded to Sleeve



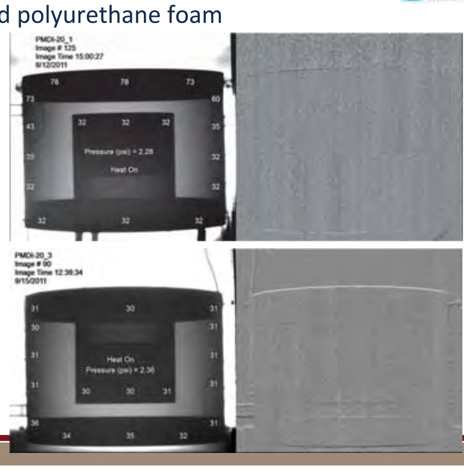


X-ray images showed liquefaction and flow occurring with PMDI-based polyurethane foam

PMDI-based foam
265 kg/m³

Bulk movement was away from the heat source

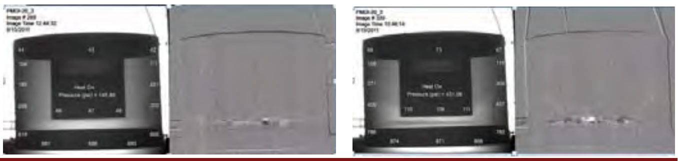
Bulk movement was toward the heat source



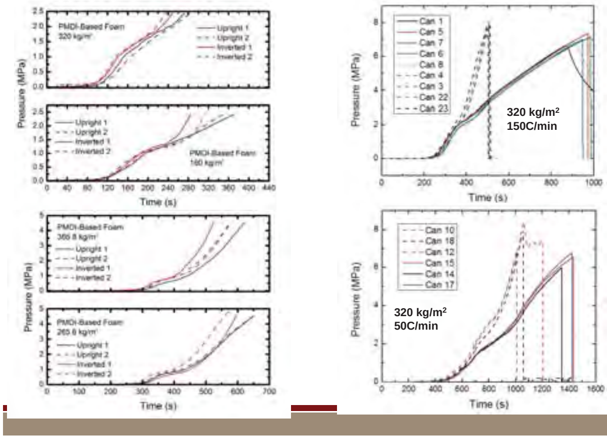
X-ray images showed liquefaction and flow occurring with PMDI-based polyurethane foam

Upright: Bulk movement was away from the heat source

Inverted: Bulk movement was toward the heat source



Pressures observed with PMDI-based foam samples varied less between upright and inverted samples

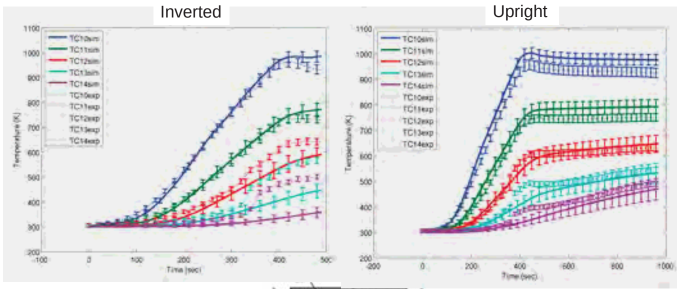


Uncertainty Quantification

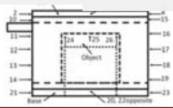
Parameter	Uncertainty (Standard Deviation)
Foam	
Density	1%
Effective Conductivity	10%
Specific Heat	10%
Heat of Reaction	10%
Activation Energy	2%
Stainless Steel	
Thermal Conductivity	10%
Volumetric Heat Capacity	10%
Boundary Conditions	
Heated Plate Temp	1%
Convection coefficient	20%
Convection Temperature	5%

Side wall temperature response

Latin Hypercube Sampling with Normal Distribution on parameters

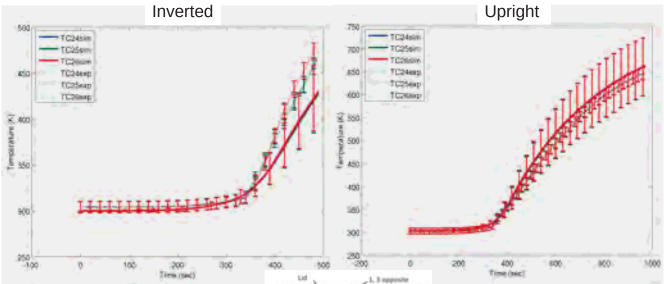


320 kg/m³ PMDI
Upright (Can 5)
Inverted (Can 22)

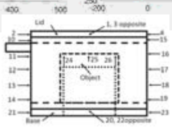


Embedded component temperature response

Latin Hypercube Sampling with Normal Distribution on parameters

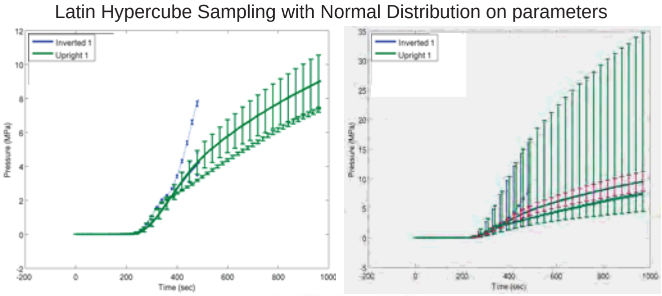


320 kg/m³ PMDI
Upright (Can 5)
Inverted (Can 22)

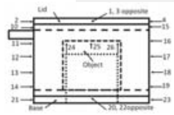


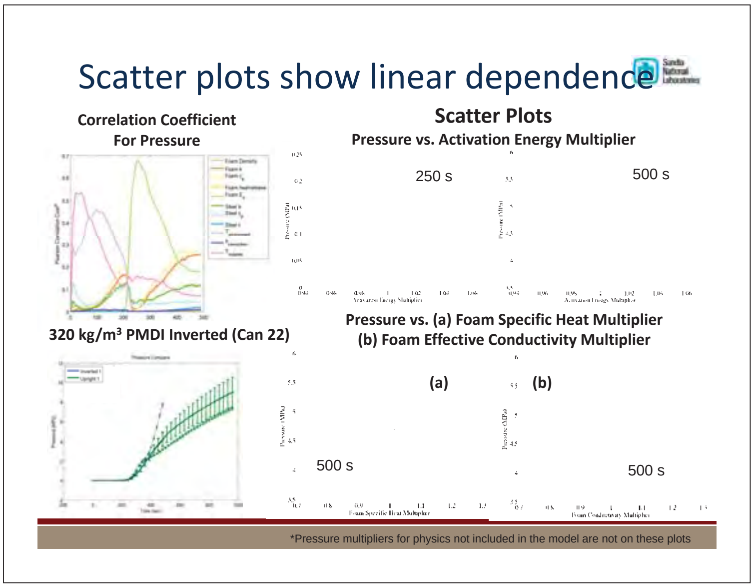
Reduced bounds and new plugin

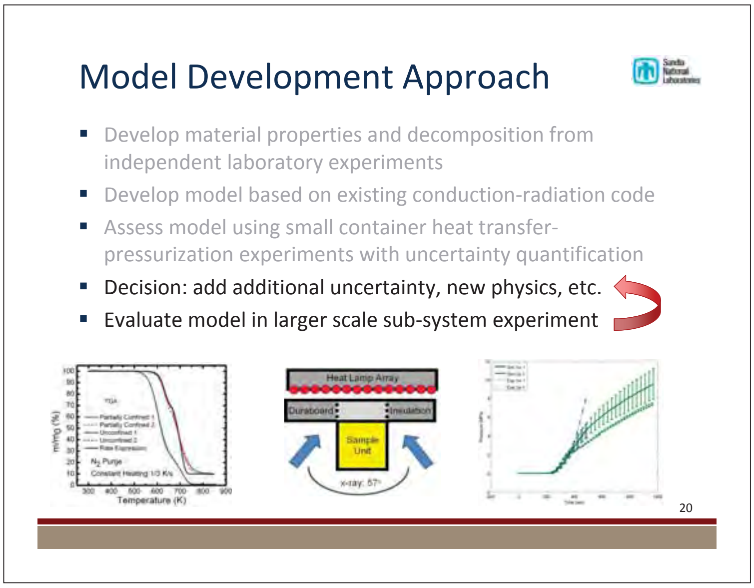
Latin Hypercube Sampling with Normal Distribution on parameters

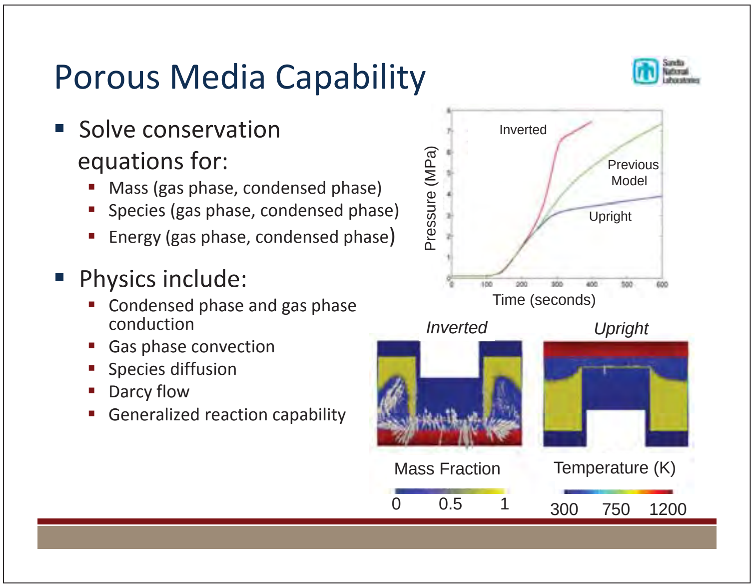


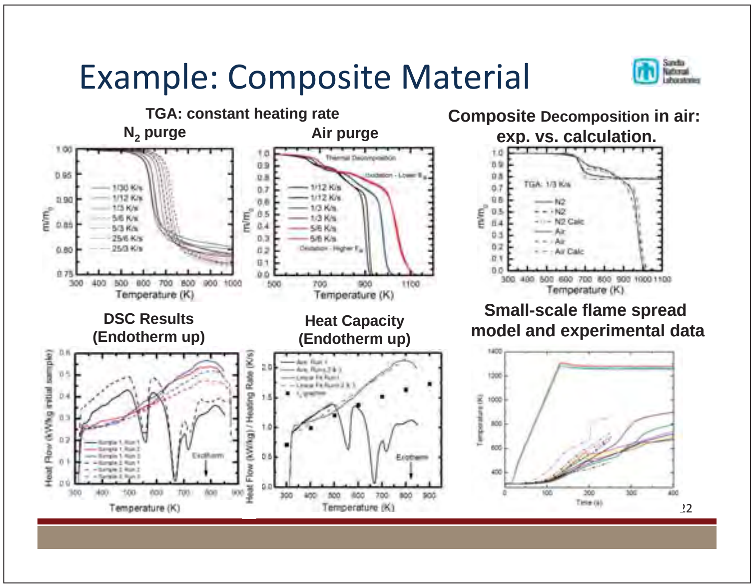
320 kg/m³ PMDI
Upright (Can 5)
Inverted (Can 22)




Scatter plots show linear dependence
Correlation Coefficient For Pressure
Scatter Plots
Pressure vs. Activation Energy Multiplier
250 s
500 s
320 kg/m³ PMDI Inverted (Can 22)
Pressure vs. (a) Foam Specific Heat Multiplier
(b) Foam Effective Conductivity Multiplier
(a)
(b)
500 s
500 s
*Pressure multipliers for physics not included in the model are not on these plots


Model Development Approach
Develop material properties and decomposition from independent laboratory experiments
Develop model based on existing conduction-radiation code
Assess model using small container heat transfer-pressurization experiments with uncertainty quantification
Decision: add additional uncertainty, new physics, etc.
Evaluate model in larger scale sub-system experiment
Heat Lamp Array
Duraboard
Insulation
Sample Unit
x-ray, 57°
Temperature (K)
20


Porous Media Capability
Solve conservation equations for:
Mass (gas phase, condensed phase)
Species (gas phase, condensed phase)
Energy (gas phase, condensed phase)
Physics include:
Condensed phase and gas phase conduction
Gas phase convection
Species diffusion
Darcy flow
Generalized reaction capability
Inverted
Previous Model
Upright
Pressure (MPa)
Time (seconds)
Inverted
Upright
Mass Fraction
0 0.5 1
Temperature (K)
300 750 1200


Example: Composite Material
TGA: constant heating rate
N₂ purge
Air purge
Composite Decomposition in air: exp. vs. calculation.
Temperature (K)
DSC Results (Endotherm up)
Heat Capacity (Endotherm up)
Small-scale flame spread model and experimental data
22

FIRETOOLS

Simulation of fire technical properties of products and construction barriers to support efficient product development in industry

Patrick van Hees
Blanca Andres
Abhishek Bhargava
Karlis Livkiss
Frida Vermina
Konrad Wilkens

The research leading to these results has received funding from the European Union Seventh Framework Programme (FP7/2007-2013) under grant agreement n° 316991

- Description of the project:
  - Overview;
  - Background and necessity;
- Aim of the project
  - Overall objectives;
  - Specific objectives;
  - Challenges;
  - Expected outcomes;
- Research plan
  - General description;
  - Research metodology;
  - Research set-up.

– Description of the project

OVERVIEW

Marie Curie programme EU – Industrial PhD

- Danish Institute of Fire and Security Technology (DBI)
  - Project Manager: Fanny Guay
- Department of Fire Safety Engineering and Systems Safety from Lund University (ULUND)
  - Academic Supervisor: Patrick Van Hees

Participants : 5 PhD students;
Time frame : 4 years; Start January 2013

Overall objective: provide tools to obtain the fire properties of products and constructions on a continuous scale by means of the material data of which they are composed

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- Description of the project:

BACKGROUND AND NECESSITY

- Traditionally: **prescriptive regulations**
  - Provide results in **discrete values** (pass/fail)
  - Offer limited information on fire properties (eg. 1 hour fire resistance)
- Alternative approach: **performance-based codes**
  - Design an objective
  - **Not how** it should be accomplished

- description of the project:

BACKGROUND AND NECESSITY

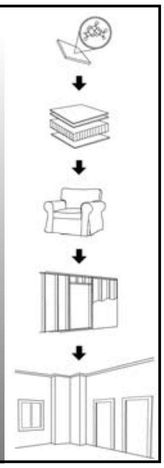
- New materials - new challenges
  - There is today a limited amount of knowledge on material properties on a **continuous scale**
  - **New applications** for materials (e.g. Light weight systems on ships, technical textiles, composites, etc)

Picture:Allianz

- aim of the project:

OVERALL OBJECTIVES

- To develop **tools** for obtaining the **fire properties and behaviour**, on a **continuous scale** for:
  - **Individual products** – e.g. gypsum board
  - **Composites products** – e.g. sandwich panel, furniture
  - **Complete systems** – e.g. fire barriers, structures
- How?
  - By using the relevant material data of which these products are composed.
- These tools may then be used in Performance Based, Fire Engineering and Building Design.

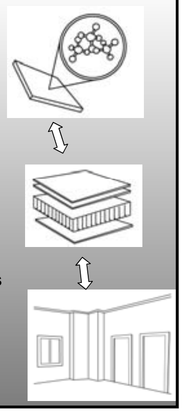


FIRE TOOLS – aim of the project: SPECIFIC OBJECTIVES

- **Development of methods to obtain relevant material characteristics:**
  - through mathematical modelling combination with;
  - small or reduced scale testing
- **Development of a methodology for determination of reaction to fire behaviour of building products and buildings content based on:**
  - mathematical models and;
  - smaller scale fire tests
- **Development of a methodology for determination of fire resistance of building systems and fire barriers based on:**
  - mathematical models and;
  - fire resistance tests

FIRE TOOLS – aim of the project: CHALLENGES

- **Defining common material characteristics** at a **micro scale** which can be used for all types of products used in a building.
- **Establishing a link** between the **material characteristics** at **micro scale** and **solid material behaviour** for materials used in building products, content and barriers.
- **Establishing a link** between **solid material behaviour** and **composite behaviour** for composites used in building products, content and barriers
- **Establishing a link** between **composite** and **system behaviour** for use in building products, content and barriers.



Micro Scale

Bulk material for insulation	Bulk material for sheet	Bulk material for filler

Material Scale

Material sheets	Composite sheets

Product Scale Small scale

Cables

System Scale – Small or Intermediate Scale

Cables on trays

REAL LIFE

Picture:SP

FIRE TOOLS – aim of the project: EXPECTED OUTCOMES

- **Introduction of the models developed into overall fire development software** e.g:
  - Computational Fluid Dynamics (CFD)
  - Finite Element Models (FEM)
- **Obtaining and introducing the use of continuous scale data for fire properties** e.g:
  - heat release rates,
  - temperature as a function of time instead of classic pass/fail criteria or fire classes
- **Merging these methodologies into a set of user-friendly product development tools for industry.**

FIRE TOOLS – research plan: GENERAL DESCRIPTION

- **5 individual PhD projects (ESR)**, interconnected to develop continuous scale data tools for fire industry.
- Research plan structured in three different modelling levels namely:
  - **Solid Modelling Level**
  - **Composite Level**
  - **System Modelling Level**

– research plan:

GENERAL DESCRIPTION

•Application of developed modelling tools to:

- o **Building Products** – e.g. Gypsum, Paint, Composite Panels
- o **Building Content** – e.g. Sofa, Table, Chair
- o **Building Barriers** – e.g. Wall, Window, Door

•Allowing flexibility

SUMMARY

- The overall objective of FIRE TOOLS is to provide tools to obtain fire properties of products and constructions on a continuous scale by means of the material data of which they are composed
- Involved parties: DBI, Lund University, PhD students, 9 associated partners (industry, consultants, universities)
- Planned project time: 2013-2017
- Totally 20 man years of PhD

Thank You for Your attention!

For more information

Patrick van Hees – Lund University, Dept of FSE

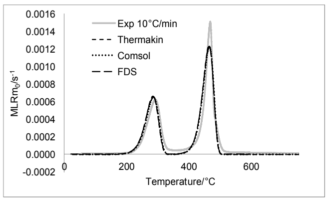
Patrick.van_hees@brand.lth.se

Pyrolysis research at SP Fire Research

FORUM
Chicago

Björn Sundström
SP Technical Research Institute of Sweden
Fire Research
bjorn.sundstrom@sp.se

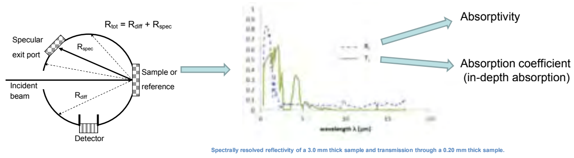
Comparison of models using the same kinetic data



Submitted to Journal of Polymer Degradation and Stability (Lille, UCLAN, SP)

TGA Normalized Mass Loss Rate experimental data collected in nitrogen at a heating rates of 10°Cmin^{-1} presented as a solid grey line and the models prediction presented as dashed lines for ThermaKin, Comsol and FDS

Spectral characterisation for pyrolysis modeling

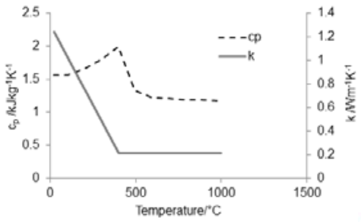


In most models we cannot have spectrally dependent absorption coefficient for in depth absorption

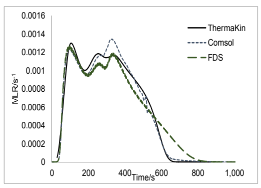
$$I(x) = \int I_\lambda(0) e^{-A_\lambda x} d\lambda \quad \Rightarrow \quad A = -\frac{1}{x} \cdot \ln\left(\frac{\int I_\lambda(0) e^{-A_\lambda x} d\lambda}{\int I_\lambda(0) d\lambda}\right)$$

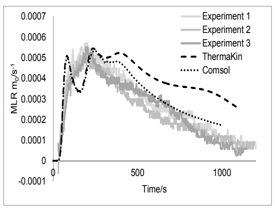
The total absorption coefficient is dependent on the depth, *x*. The parts of the radiation where the spectrally resolved absorption coefficient is high will rapidly be absorbed near the surface. As the radiation penetrates the sample the radiation spectrum will be distorted such that relatively more energy is concentrated to the wavelengths where the absorption coefficient is lower. It should be noticed that the absorption coefficient, A, given by Eq. (9), is *not* the local absorption coefficient at depth *x*. Instead, A is the parameter that gives the correct total irradiance at depth *x* given an irradiation spectrum $I_\lambda(0)$ at the sample surface.
The choice of depth *x* in Eq. (9) is somewhat arbitrary but we propose to use the depth where the total irradiation has decreased to $e^{-2} \approx 0.135$. This depth is sometimes referred to as the skin depth, or the penetration depth of the electromagnetic field. This absorption coefficient can be obtained by an iterative procedure using Eqs. (9) and (7).

Temperature dependence of specific heat and thermal conductivity used in the Comsol and FDS modeling of cable sheating materials.



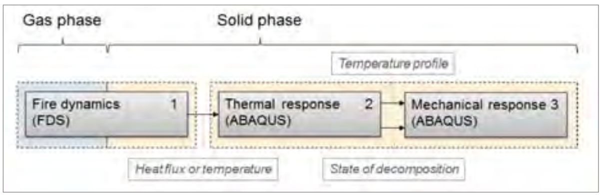
Comparison of models and with experiment





On-going modelling work in the EU-project Fire-Resist

Modelling: VTT (FI), SICOMP (SE)
Validation experiments: SP (SE)



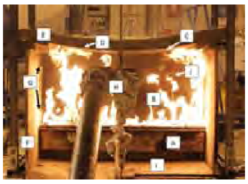
Operational principle of the fire-structure simulation chain. Thermal exposure to surfaces is extracted from the fire dynamics simulation (including pyrolysis model) and used as a time-dependent boundary condition in a subsequent thermal-mechanical analysis.

SP Technical Research Institute of Sweden

FIRE-RESIST

Validation experiments conducted by SP

Mini-furnace test with loading device



Front view of mid-scale test set-up

(A) sand burner, (B) vertical specimen with insulated backing, (C) horizontal specimen, (D) position of left line load (not visible), (E) insulation, (F) side walls made of non-combustible mineral board, (G) plate thermometers mounted in side walls, (H) measurement station in front including a Schmidt-Boelter gauge, a plate thermometer and a copper disc thermocouple, (I) plate thermometer on floor and (J) copper disk thermocouple in the vertical sheet.

SP Technical Research Institute of Sweden

FIRE-RESIST