出國報告
（出國類別：出席國際會議）

赴美國參加國際防火研究領導人論壇（FORUM）出國報告

服務機關：內政部建築研究所
姓名職稱：王天志助理研究員
派赴國家：美國
出國期間：96 年 10 月 13 日至 96 年 10 月 21 日
報告日期：96 年 11 月

摘　　要

本次會議行程於美國新墨西哥州阿爾伯克爾基市（Albuquerque）及德州聖安東尼市（San Antonio）舉辦 2007 年國際防火研究領導人論壇（International FORUM of Fire Research Directors，簡稱 FORUM）年度會議，同時參訪 Sandia National Laboratories 及 Southwest Research Institute 兩個研究機構。

出席會議預期達成目的爲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。

本所近來已完成鋼結構樑柱接頭火害行爲實驗，並於會議中簡報，與各會員分享交流研究成果，藉以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。

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），乃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（包括對人命、財產及環境生態所造成的損害及影響）。

FORUM 的會員必須是一個國家或地區主要防火研究組織或機構的負責人，本所於 85 年正式申請入會，本所所長為正式會員。目前共計有 24 位會員，包括我國（ABRI）、美國（CIB W14、Ex-officio、NIST/BFRL、FM Global、SwRI、Sandia National Labs）、英國（BRE）、德國（Idf、BAM Germany）、加拿大（IRC-NRC）、日本（BRI、NRIFD、TBTL）、澳洲（CSIRO）、中國大陸（SKLFS、TFRI）、韓國（KICT）、義大利（ITC-CNR）、紐西蘭（BRANZ）、芬蘭（VTT）、捷克（FTI）、挪威（SINTEF-NBL）及瑞典（SP）。FORUM 每年輪流由歐、美、亞洲其中一個會員單位主辦會議，今年則輪由美國舉辦。

第二節　依據及計畫內容

一、計畫依據

都市及建築防災與建築防火科技發展方案中程綱要計畫

- 建築防火安全科技計畫

二、計畫內容

1.參加於美國阿爾伯克爾基舉行之 FORUM 年度會議。

2.參訪 Sandia National Laboratories 下的 Fire Science Technology 單位。

3.參加於美國聖安東尼舉行之 FORUM 年度會議。

4.參訪 Southwest Research Institute 下的 Fire Technology 單位。

5.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參考，亦可藉此參與國際研究合作並增加國際會議參與度。

第二章　會議行程及概要

本章說明本次奉派赴美國參加FORUM年度會議成員、時間及會議概要。

第一節　會議行程

一、代表人員名單

姓名	職稱	專長
王天志	助理研究員	建築防火、結構分析及設計

二、出國期間

民國 96 年 10 月 13 日至 10 月 21 日。

三、會議行程

本次 FORUM 年度會議行程如表 2-1。

表 2-1 FORUM 年度會議行程

日　　期	活　　動　　內　　容	備　　註
10 月 14 日(日)	會議報到	
10 月 15 日(一)	議程討論 會務報告 年度應辦事項進度討論 會員報告：ABRI、NRCC、IAFSS、NIST、CIB W14 主辦會員簡報：Sandia National Laboratories	
10 月 16 日（二）	Sandia National Laboratories 參訪 路程-轉至聖安東尼市	

10 月 17 日（三）	年度應辦事項進度討論（續） 邀稿簡報及討論 -heat flux measurements Position papers 簡報 SwRI 實驗室參訪	
10 月 18 日(四）	年度應辦事項進度討論（續） Sjölin award 提名討論	
10 月 19 日（五）	會議紀錄討論(閉幕)	

與加拿大NRCC、日本建築研究所代表及鍾教授基強合影

第二節　FORUM概要

FORUM 是世界各地防火研究組織負責人連繫交流的一個組織，工作重點在尋找策略夥伴，利用對火的科學知識、被認可的計算工具、可靠的研究資料；以適當的訓練和教育，合作增進防火安全工程學（Fire Safety Engineering，FSE）。FORUM 支持能促進改善在所有 FSE 方面的研究，其目的在於改進社會的能力，以降低及管控火災的風險和防火安全的費用。

FORUM 的角色包括確認先進防火研究策略的制定、建立資訊共享網路，讓 FORUM 成員達到共同的目標和減少重覆性研究。關於防火研究和防火安全工程學策略的討論包括火災研究、共同計劃、研究人員交流、研究設施分享使用等。FORUM 責任在緊密維繫相關組織，譬如:

- International Council for Building Research Studies（CIB）
- International Standard Organization（ISO）
- International Association for Fire Safety Science (IAFSS)
- North American Fire Testing Laboratories (NAFTL)
- European Group of Organizations for Fire Testing, Inspection and Certification（EGOLF）
- 其它國際防火安全組織

第三章　參與年度會議過程

第一節 年度會議（**2007/10/15**）

一、會議地點：美國，阿爾伯克爾基市

二、會議內容簡要：

1. 主席報告及調整會議議程。
2. 秘書單位報告經費帳戶更動及使用概況。
3. 2006 年會議（威靈頓，紐西蘭）結論應辦事項初步檢討。
   3.1 請秘書單位更新組織負責人異動資料。
   3.2 詳列下次 FORUM 會議預定邀請之組織負責人或其他代表人。
   3.3 請秘書單位聯繫相關人員，估計已繳交之 Position Paper 何時可以集結發行；並了解相關智財權問題。
   3.4 草擬回顧有關不確定度實驗相關文獻。
4. 本所近期研究成果分享「Recent Studies of the behavior of loaded steel beam-column joints under fire」簡報。
5. 加拿大 NRCC 簡報近期 Fire Risk Management Program。重要內容節錄如下：
   5.1 單位區分爲 3 部分，Ottawa main campus、Ottawa Almonte campus 以及與 Carlton 大學合作部份設施。
   5.2 大型燃燒實驗館（55 * 30 m），內有 calorimeters、3 storey test facility、ISO room、3 storey house facility 等設備。
   5.3 與 Carlton 大學合作主要設施有 tunnel system（10 * 37.5 m）及 10 storey atrium（17.5 * 20 m）。
   5.4 未來主要研究課題包括 Fire Performance of Houses in the 3 storey house structure、Tunnel Fire Detection project、Completing Compressed Air Foam Studies 等。
6. FM Global 簡報，重要內容節錄如下：
   6.1 近期策略研究方向包括 Fire hazards and protection、Risk reliability and failure prevention 及 Innovaitve strategic research.
   6.2 主要研究項目有 Rack storage fire protection、Numerical simulation of fire

protection、Accelerated risk improvement 等。

6.3 未來重點方向爲 Technical collaboration、Improving protection 及 International codes and strandards。

會議過程討論情形

第二節 **Sandia National Laboratories（SNL）**參訪（**2007/10/16**）

一、參訪地點：**Sandia National Laboratories，Albuquerque，NM**

二、實驗室簡介：

1. 為隸屬於美國軍方研究機構，Fire science & technology部門。
2. 研究領域包括Phenomenology、Modeling and simulation及Experimental三大類。
3. Phenomenology Thrusts 研究包括 Hydrocarbon fires、Propellant fires、Heat transfer in fires、High consequence failure of engineered systems。
4. Modeling and simulation 研究主要針對Fire & multiphysics simulation，應用領域包括火燄模擬、燃燒行為模擬、材料/結構力學、流體力學等。
5. 新建實驗設施包括 Horizontal wind tunnel for fires in cross wind、Vertical wind tunnel for fires in calm conditions、Full scale radiant heat lab 及 Abnormal thermal environment lab。
6. 本單位為軍事單位下的研究機構，參訪時須先留下基本資料及配戴附有相片的臨時通行證，參訪全程不得攜帶相機及行動電話。

① Horizontal Wind Tunnel for Fires in Cross Wind

② Emission control

③ Vertical Wind Tunnel for Fires in Calm Conditions

④ Full Scale Radiant Heat (Fire Loading Simulator) Lab

⑤ Abnormal Thermal Environment Lab

各會員代表於Vertical wind tunnel前合影

第三節 年度會議（**2007/10/17，續1**）

一、會議地點：美國，聖安東尼市

二、會議內容簡要：

1. 2006 年會議（威靈頓，紐西蘭）結論應辦事項初步檢討（續）。

   1.1 有關車輛火災資料庫的建置，有鑑於實驗用車輛不易取得，或實驗對象過於老舊，致使實驗數據與現況顯有落差，請持續與車輛製造商聯繫，以獲取最新實驗資料。

   1.2 Sjölin award 提名初步討論，請出席會員依被提名人對防火研究貢獻度給予排序後，明日提交委員會彙整。

   1.3 有關 Performance Based Design for Fire Code Applications 的 position paper 草稿業已完成，提請會員討論修訂後予以定稿。

2. 邀稿專題報告（1）「Passive Sensors for Heat Flux Measurements in Large Scale Fire Safety Tests」 - Ned R. Keltner，重點節錄如下：

   2.1 近年來，製造商、檢驗中心及研究者對傳統 thermocouple 所量測及控制的溫度值是否確實反映 thermal exposure，彼此間屢有爭議。

   2.2 在不同試驗爐及試驗單位所做的比對試驗，也反映彼此間的數值確實有所差異。研究指出，thermocouple 容易受到設計、安裝及與火源間相互影響，因此建議改採量測 heat flux 類的 passive sensor 設備，可降低量測差異。

   2.3 為改善此現象，ISO 834 已改採 plate thermometer 來量測、控制，同時已驗證此設備可降低不同單位之量測差異。

   2.4 有許多 Passive sensor 可用來量測 Heat flux，如 Directional Flame Thermometer 及 Plate Thermometer，具有以下特點：

      2.4.1 比 Schmidt-Boelter gauges 更為堅固耐用。

      2.4.2 設備及安裝成本較低。

      2.4.3 經適當清潔，可以重複使用。

      2.4.4 已經驗證過適用於 Pool 及 Enclosure fires。

      2.4.5 可量測更大範圍的 Heat flux，提供更快反應的能力。

      2.4.6 經實驗驗證，Passive sensor 在不同單位間的量測差異值，小於 3 %。

3. 邀稿專題報告（2）「Adiabatic surface temperature for calculating heat transfer to

fire exposed structures」 - Ulf Wickström，Dat Duthinh，Kevin McGrattan，重點節錄如下：

3.1 Plate Thermometer（PT） 比傳統 thermocouple 有更好的爐內溫度控制。

3.2 藉由 radiation 和 convection 傳遞到曝火表面的熱傳公式，可以利用 adiabatic surface temperatures （AST） 來計算，其公式如下：

$$\dot{q}''_{\mathrm{tot,SM}} = \varepsilon\sigma(T^4_{\mathrm{AST}} - T^4_{s,\mathrm{SM}}) + h(T_{\mathrm{AST}} - T_{s,\mathrm{SM}})$$

其中， $\dot{q}''_{\mathrm{tot,SM}}$ 模擬程式中的 total heat flux

T_{AST} 模擬程式中的 adiabatic surface temperatures

$T_{s,SM}$ 模擬程式中的 absolute temperatures

3.3 實務上，T_{AST} 可由 Plate thermometer 所量測到的溫度值 T_{PT} 來代表，則公式可改寫爲如下：

$$\dot{q}''_{\mathrm{tot}} = \varepsilon\sigma(T^4_{\mathrm{PT}} - T^4_s) + h(T_{\mathrm{PT}} - T_s)$$

3.4 AST 是可以被量測到的，且被使用於火災模擬中，可將火的模擬（CFD）結果，有效的轉換到熱的模擬（FEM）中。

3.5 PT 設備較爲低廉且耐用，其理論亦已經過實務驗證可行。

Ulf Wickström進行邀稿專題報告

會議進行討論情形

4. Fire Technology Department，Southwest Research Institute（SwRI）參訪

4.1 SwRI 簡介

4.1.1 SwRI 為美國最大的獨立、非營利研發機構（有點類似我國的工研院）。

4.1.2 整個機構有超過 250 棟的建築，實驗室面積超過 185,000m^2。

4.1.3 本次參訪單位為 FIRE TECHNOLOGY DEPARTMENT，成立於 1949 年。

4.2 重要實驗設施簡介- 泡沫滅火實驗館

4.2.1 尺度：20 x 20 x 20 m（長寬高），可移動天花板。

4.2.2 113,000 L 供應水槽，4500 L/min 壓縮幫浦。

4.2.3 151,000 L 廢水處理水槽。

4.2.4 除塵裝置-可過濾 99% 大於 1um 的顆粒。

4.2.5 兩具大型排氣風車 28 m^3/s。

4.2.6 可執行火源熱量達 25 MW。

泡沫滅火實驗館外觀

垂直與水平耐火爐

建築外牆火焰延燒試驗設備

4.3 Fire resistance section 研究項目包括 Fire resistance testing、Exterior surface flame spread、Plastic fuel tank evaluation、Pool fire tests 及 Jet fire tests。

4.4 Material flammability section 研究項目包括 Combustibility and Ignitability、Surface flame spread、Smoke and toxicity 及 Small and Intermediate scale calorimetry。

4.5 Engineering and research section 研究項目包括 Large scale calorimetry、Suppression testing、Hydrogen research 及 Computer modeling。

4.6 近期重點研究爲利用 ASTM E119 規範，規劃驗證 Performance Base Code。

王助理研究員天志與天津消防研究所經所長建生合影

第四節 年度會議（**2007/10/18，續2**）

一、會議地點：美國，聖安東尼市

二、會議內容簡要：

1. 2006 年會議（威靈頓，紐西蘭）結論應辦事項初步檢討（續）。

    1.1 近期有 3 項研究，包括汽車燃燒基本資料庫建置、Room test 火災模擬行爲研究及 Passive sensor 量測設備比對實驗，請各會員有興趣者，直接與各項研究負責人連繫，俾利提供後續規劃研究細節。

    1.2 2008 年度會議預計於瑞典舉行，同時期於當地有 IAFSS 研討會進行，請主辦單位安排兩會議可以接續進行，以節省各會員時間。

2. Sjölin award 提名討論

    2.1 過去得獎名單爲 Vytenis Babrauskas, Jim Quintiere and Paula Beever（2001）、Dougal Drysdale（2005）及 Geoff Cox.（2006）。

    2.2 請會員提名對防火安全科技研究有重大貢獻者名單，同時須說明提名理由。

    2.3 名單計有 15 位，包括 Ronald Alpert（FM Global, USA）、Craig Beyler（Hughes Assoc., USA）、Andy Buchanan（Un. of Canterbury, NZ）、Richard Gann（NIST, USA）、Robert Bill（FM Global, USA）、Beth Weckman（Un. of Waterloo, Canada）、John deRis（FM Global, USA）、Tuula Hakarainen（VTT, Finland）、Heat flux gauge working group、Gunnar Heskestad（FM Global, USA）、Jose Torero（U of Edinburgh, UK）、Collen Wade（BRANZ, NZ）、Fan Weicheng（State Key Un., China）、Christopher Wieczorek（FM Global, USA）及 Fire research group（SKLFS Laboratory, PRC）。

    2.4 經會員初步投票後，排名前 5 名分別爲 Richard Gann、 John deRis、Heat flux gauge working group、Gunnar Heskestad 及 Ronald Alpert。

3. 本組織除了進行研究業務外，爲推動防火安全科技教育，規劃提供在學學生或近期剛取得博士學位研究者優秀論文獎勵措施，歡迎會員廣爲宣傳、鼓勵投稿。

王助理研究員天志與部分會員代表於SwRI合影

第五節 年度會議（**2007/10/19，續3**）

一、會議地點：美國，聖安東尼市

二、會議內容簡要：

1. 2009 年亞洲區會員主辦年度會議，目前有 Fan Weicheng（China）表達有意承辦，另 KICT（Korea）為新進會員尚未承辦過，請 KICT 考慮是否有意願承辦。
2. 請會員踴躍推薦目前尚未加入但其研究頗有成就或具地方代表性的防火研究單位加入本組織，以利共同研究發展，特別是如 India、France 等國。
3. 2006 年會議（威靈頓，紐西蘭）結論應辦事項未完成者，請積極於下一年度完成。
4. 本次會議討論事項決議、整理及決定後續應辦事項之期程。

第四章心得與建議

1. FORUM 組織目標為提供世界各地防火研究組織負責人連繫交流的一個平台，因應需求規劃研究方向，尋找策略夥伴分工，避免研究資源重複，以極大化研究成果。本所參與此組織，可增進與其他先進研究單位交流，對本所研究有極大助益，值得積極參與。
2. 本所應藉用 FORUM 平台，積極與本所研究目標相近且較為先進的單位合作，例如 SwRI，並派遣研究人員至對方單位進行短期研究，以培訓專業人員並可提升本所研究能量及改善國內防火科技。
3. 本次會議參訪 2 個實驗室，SNL 及 SwRI，其特色為實驗場地寬廣，研究經費充裕，訂定長期研究主軸，逐年進行特定主題，以集中資源得到最大及最佳的研究成果。對應本所研究環境，夠大但還不夠精，因應近來政府人力精簡，研究經費逐年減少情況下，本所應訂定優先研究主題及本所具有領先優勢的研究設施，集中資源、人力進行，方能獲得最大及有效的成果應用。
4. SNL 為附屬於軍事機構下的研究單位，其對於建築火災的研究較少，但著重於基礎火焰、燃燒研究及軟體模擬分析，尤其在分析軟體發展有很大的成果，建議本所可與其合作，派員學習該軟體並爭取授權該軟體之使用，對國內基礎火災研究有相當大的助益。
5. 蒐集國際最新防火新知，與其他國外研究單位交流目前研究方向及先進設備之應用，不僅可使得本所防火實驗中心設備實驗成果符合國際化、標準化，亦可藉此參與國際上會議活動以增加國際會議參與度。

附錄

FORUM 會議相關資料

本頁空白

The International FORUM of Fire Research Directors Annual Meeting

Sunday, October 14, through Friday, October 19, 2007

Sandia National Laboratories, Albuquerque, NM

Sunday, October 14

6:00 pm Welcome Dinner, Marriott Hotel

Monday, October 15

7:15 am Breakfast

7:45 Update I-94 information for SNL visit on Tuesday

8:00 Announcements (Sheldon Tieszen)
Review agenda (Bill Grosshandler)
Review of the minutes from October, 2006 meeting in Wellington (Franco Tamanini)
Finances, Membership (Franco Tamanini)
Sjölin Award (Giovanni Gallina)
Liaison reports: NAFTL (Marc Janssens); EGOLF (Marc Janssens); IAFSS (Craig Beyler)

10:30 Break

10:45 New member introductions and brief statements

- Debbie Smith, Director, Building Research Establishment
- Ulrich Krause, Head, Fire Engineering Division, Federal Institute for Materials Research and Testing
- Jukka Hietaniemi, Team Leader, Fire Safety Engineering, VTT
- Sheldon Tieszen, Manager, Fire Science and Technology Department, Sandia

Regional member presentations

- J. Russell Thomas, Director, Fire Risk Management Program, NRC-C
- Lou Gritzo, Vice President and Manager of Research, FM Global

12:15 Catered Lunch

1:15 pm Regional member presentations (continued)

- Bill Grosshandler, Chief, Fire Research Division, NIST
- Marc Janssens, Department of Fire Technology, Southwest Research Institute

- Sheldon Tieszen, Manager, Fire Science and Technology Department, Sandia National Laboratories, Albuquerque

3:15 Break

3:45 Report from CIB W14 (Dick Bukowski)

4:00 Open discussion on the relationship among CIB W14, FORUM, and TC 92

5:00 Adjourn

6:00 Dinner

<u>Tuesday, October 16</u>

7:00 am Checkout of Marriott and load luggage onto bus

7:15 Grab and go breakfast

7:30 Bus to tour Sandia fire facility

11:00 Drop off at airport

Those on the 12:30 ExpressJet flight need to go directly through security. Others can dine on their own at Gardunos Restaurant just before security.

Fly to San Antonio

Southwest Research Institute, San Antonio, TX

7:00 pm No-host cocktails, McLeod's Pub, Sheraton Gunter Hotel, San Antonio, TX

7:30 No-host Dinner (to be determined)

Wednesday, October 17

8:00 am Continental breakfast in designated meeting room, Sheraton Gunter Hotel

8:30 Status of action items from 2006 meeting -- attached (all)

10:30 Coffee Break

10:45 Invited presentation on heat flux measurements (Ned Keltner)

11:15 Open discussion on heat flux measurements (all)

noon Lunch

1:00 pm Status of current position papers

- Heat Transfer Boundary Conditions (Ulf Wickstrom)
- Uncertainty in Experiments and in Model Results(Lou Gritzo)
- Inter-Laboratory Data Transfer (Marc Janssens)
- Egress Modeling and its Evaluation (Bill Grosshandler)
- Performance Based Codes and Design (Bill Grosshandler)

3.00 Coffee break

3.30 New position papers

4:00 Transportation to Southwest Research Institute

4:30 - 5:30 Laboratory tour

6:00 - 7:30 Dinner reception, hosted by SwRI

Return to Sheraton Gunter Hotel

Thursday, October 18

8:00 am Continental Breakfast in designated meeting room, Sheraton Gunter Hotel

8:30 Review of current collaborations (all)

New collaborations (all)

10:00 Coffee break

10:30 Continued discussion (all)

noon Lunch

1:00 pm Future meeting sites
Formation of nominating committee for Chair and Deputy Chair

New business (all)

3.00 Coffee break

3:30 Adjourn

Sight-seeing in San Antonio, dinner on your own

Friday, October 19

8:00 am Continental breakfast in designated meeting room, Sheraton Gunter Hotel

8:30 Review of action items (Franco Tamanini, all)

10:00 Coffee break

10:30 Open discussion (all)

noon Lunch

1:00 pm Adjourn

Summary of Action Items

1. Secretary to get acknowledgement (plaques) to members who have left the FORUM (Farshad Alamdari, David Yung, Esko Mikkola).
2. Set up a list of people to be notified of upcoming FORUM activities, meeting in particular – Marc Janssens to invite as guests: chairs of EGOLF, IAFSS, SFPE, UL, FPRF-Kathleen Almand, IRCC..
3. Secretary to contact Dougal Drysdale to get an estimate of publication date for position papers that have been submitted.
4. Secretary to resolve issue about copyright restriction on posting of position papers on FORUM web site – Do by Nov 30, 2006.
5. Lou Gritzo (lead), Marc Janssens and Reinhard Grabski to develop a draft for review of paper on experimental uncertainty by September 1st, 2007.
6. Lou Gritzo (lead), Marc Janssens, Russ Thomas, Sheldon Tieszen and Reinhard Grabski to develop an outline of paper on modeling uncertainty by September 1st, 2007.
7. Marc Janssens to transfer car fire test database to Russ Thomas who will make it accessible from a web site for testing – to be done by April 1, 2007.
8. Russ Thomas to contact Debbie Smith to find out if she wants David Charters to keep working on the paper on egress modeling. Starting point would be consideration of Dick Bukowski's comments.
9. Bill Grosshandler to contact Ulf to tell him that the group wants to proceed on the basis of setting up a working group (including one FM rep, Marc and Bill) to evaluate applicability of the AST concept by Dec 31st, 2006.
10. Regional representatives (Giovanni Gallina, Russ Thomas and Hyun-Joon Shin) to identify at least one nominee for each of two categories (team and early/mid career awards) for Sjölin award by July 07. Other nominations to be sent by the same date to GG, with copy to the other regional representatives (JRT and HJS).
11. Bill Grosshandler to incorporate information from the discussion on PBD in the workshop final report and distribute by Nov 30, 2006.
12. Richard Bukowski and Bill Grosshandler (w. Lou Gritzo assisting) to draft the FORUM position in a PBD position paper and distribute to membership for comments by Dec. 31, 2006.
13. Agreed on collaborations on three projects, with leads (Bill Grosshandler, Richard Bukowski and Russ Thomas) submitting a plan to the Secretary for distribution to the members by March 30, 2007:
    1: CSIRO, SwRI, NRCC, and NIST (lead)
    2: FM Global, NIST (RB has draft of plan - lead), SKLFS
    3: NIST, NRCC (lead), SwRI
14. Summary plan for 2007 meeting and links (for hotels, airlines) to be sent by Marc Janssens to the members as soon as possible (ASAP - say 30 Nov), with members providing responses on their ability to participate by Jan. 31, 2007.
15. Secretary to notify Ulf of acceptance of offer to hold the FORUM meeting at SP in 2008, and suggest dates to be back-to-back to the IAFSS conference (to be held 22-28 September 2008 in Karlsruhe).
16. Marc to solicit Efectis for membership. Secretary to solicit VNIIPO again and Tom Chapin (UL).
17. Secretary and Weicheng Fan to solicit application from new director of ABRI.

2007 年度會議決議至 **2008** 年應辦事項

Summary of 2007 Action Items

1. Secretary to mail acknowledgement (plaques) to the members who have left the FORUM (Farshad Alamdari, David Yung, Esko Mikkola) and get new plaques made for Vince, Kjell and Rick Tontarski. Solicit replacement for SINTEF.
2. Ulf Wickström, as host of the 2008 meeting, to set up a list of people to be notified of the upcoming FORUM activities and meeting to invite as guests: chairs of Efectis, EGOLF (Kjell), IAFSS, SFPE, UL, FPRF-Kathleen Almand, IRCC. Secretary to supply list to Ulf.
3. Secretary to resolve issue about copyright restriction on posting of position papers on FORUM web site – Do by Jan 1, 2008.
4. Lou Gritzo (lead), Marc Janssens and Reinhard Grabski to develop a draft for review of paper on experimental uncertainty by Feb 1st, 2008.
5. Lou Gritzo (lead), Marc Janssens, Russ Thomas, Sheldon Tieszen and Reinhard Grabski to develop an outline of paper on modeling uncertainty by February 1st, 2008.
6. Bill Grosshandler to contact Debbie Smith to find out if she wants David Charters to keep working on the paper on egress modeling. Starting point would be consideration of Dick Bukowski's comments. By Dec 1, 07.
7. Bill Grosshandler to collect comments on PBD position paper and submit to Fire Safety Journal by Dec 1, 07
8. Lou Gritzo to contact Indian Fire College in India and IRSN in France. Ulf Wickström to contact INERIS. Last two to be invited to the next meeting.
9. **Secretary to obtain updated bio information from the new director of ABRI (Jimmy Ho).**
10. Shuitsu Yusa, Shaoyu Zhang and Colleen Wade to put together a description of how Japan, China, Chinese Taipei, Korea and Australia/New Zealand coordinate their internal activities (like EGOLF in Europe and NAFTL in North America). By the end of Dec. 07.
11. Bill Grosshandler to develop a response to Craig Beyler on supporting the IAFSS fire database by Jan 1, 08.
12. Bill Grosshandler to prepare a statement on the position of the FORUM on the future of CIB W14 and circulate it for member approval. Position to go to Dick Bukowski for further transmittal to CIB by Dec 1, 07.
13. **Tien-Chih Wang (ABRI) to communicate with Bill or Secretary about the results of their projects on connections and plans for future work by Dec. 1, 07.**
14. Marc Janssens to send information on NAFTL upcoming testing (loaded walls) to FORUM members when finalized.
15. Ulf Wickström to be in charge of leading the effort on the thermal characterization project. Contributing organizations (Sandia, SwRI, TBTL, SP, KICT, IRCT, FM Global, TFRI, NIST), by end of November, should get something in writing back to Ulf with what they are willing to contribute to the effort. By year end, Ulf will report back to the chair with the agreed-on plan. (Ulf to circulate the overall objective to the members ASAP (with possible minor editing) and by Jan 1 interested parties to respond with a one-page test plan describing what they plan to do and a schedule. Ulf to collate responses

and assess whether an overall plan can be put together or another round is required to converge on a coherent project.

16. Marc Janssens to send NAFTL testing protocol for Phase I (Calorimeter calibration) to Secretary by mid November. Secretary to distribute to the members upon receipt.
17. Ulf Wickström to get information on the EGOLF program and submit it to the Secretary (include time and cost estimates and specifications on the wall) when finalized. Secretary to distribute to the members upon receipt.
18. Colleen Wade to contact her coworker at CSIRO and send to Secretary more information on the virtual community project for distribution by Dec 1, 07.
19. Lou Gritzo (with Yoshiteru Murosaki and Giovanni Gallina) to prepare and circulate a draft of a position paper on fire science/engineering education (start with the position and then develop later the steps to achieve the sought result) by Jan 1, 08.
20. Giovanni Gallina to send out the summary of the current Sjölin award nominations by Nov 1, 07. Request confirmations of existing nominations by members and new nominations by Feb 1, 08. The committee to send out ballots by March 1, 08 (no nominations accepted after that date). FORUM members to respond by May 1, 08 back to GG.
21. Bill Grosshandler to contact Dougal Drysdale and Craig Beyler indicating the recipient (Richard Gann) of the 07 award and to get an 08 award decided before the IAFSS meeting.
22. Bill Grosshandler to write a letter notifying Dick Gann of the award consistent with previous notifications.
23. Sjölin Committee (Greg Baker, Sheldon Tieszen and Debbie Smith) to set criteria and objectives of to-be-named award for best paper by Dec 1 (preliminary draft), with finalized version by Jan 1. Bill Grosshandler to communicate with Craig Beyler to enlist IAFSS support immediately after receipt of information from committee (to include publicizing availability of award to the entire IAFSS mailing list). Committee to handle selection process, with completion by May 15, 08.
24. Greg Baker (with Lou Gritzo's help) to report back at the next FORUM meeting on how a mid-career award could operate.
25. Ulf Wickström to confirm the meeting dates and a rough schedule of the meeting in Borås by mid March, 08.
26. Hyun-Joon Shin to send a letter confirming the offer to host the 2009 meeting of the FORUM by Dec 1, 07.
27. Shuitsu Yusa, with the support of two other members serving with him on the nomination committee for chair and vice chair (Marc Janssens for North America and Giovanni Gallina for Europe), to manage nomination process. Send email asking for nominations by Feb 1, 08. Send ballots out according to dates set in the bylaws by May 1, 08.
28. Weicheng Fan as vice chair to see to it that the web site reflects the change in bylaws. Franco Tamanini as Secretary/Treasurer to change the application form to be consistent by Dec 1, 07.
29. Marc Janssens to bring to closure the car fire test database with Russ Thomas. To be done by the next FORUM meeting.

Sjölin Award

The Sjölin Award recognizes an outstanding contribution to the science of fire safety or an advance in the state of the art in fire safety engineering practice of extraordinary significance. It is presented to the individual or group whose efforts are primarily responsible for or traceable to the specified advance. The Prize consists of a plaque and an honorarium. Recipients of the FORUM Prize are selected and announced annually and the awards are delivered at the tri-annual symposia of the International Association for Fire Safety Science.

Past Award Winners:

2001 - Vytenis Babrauskas, Jim Quintiere and Paula Beever;
2005 - Dougal Drysdale;
2006 - Geoff Cox.

FORUM Sjölin Award Nominees

Lifetime contributions

Dr. John L. deRis, Principal Research Scientist, FM Global
Sponsored by: Lou Gritzo

John deRis has long been recognized as one of the original leading researchers in the field of fire science and flammability both inside FM Global and by the general fire science community worldwide. His work on flame radiation in the pyrolysis and flame zones is considered classic, and is essential for a full understanding of fire spread and growth. He has several landmark publications in his early career and in recent years, including leading works on fire radiation, fire growth and fire modeling. He has contributed profoundly to the recent success of including radiation in the FDS computer code.

John also has been instrumental in guiding others in their work, whether inside or outside FM Global. His involvement in the recent FORUM project on measuring heat flux in fires is both typical and noteworthy. Also noteworthy is the fact that he has contributed enormously in helping others set up viable, strong university research groups of their own. He is now working closely with young FM Global scientists who are focused on fire modeling and flammability measurements. His insights and guidance are key in helping FM Global link small-scale FPA property measurements to sophisticated fire computer models in order to achieve the ultimate long term capability of conducting our large-scale fire tests on a computer.

Dr. Gunnar Heskestad, Consulting Research Scientist (Retired), FM Global
Sponsored by: Lou Gritzo

Dr. Heskestad has not only achieved many breakthroughs in the science of fire and suppression, he also brought this science into cost-effective practice. Because of this dual effectiveness, he is held in high esteem by both the fire science and fire protection engineering communities.

In the past 30 years, he has published many milestone papers establishing new understandings of fire safety phenomena, and participated in numerous consensus efforts for new approaches to fire protection. These have included the areas of fire plume dynamics, ceiling jet dynamics, sprinkler dynamics, fine spray mechanisms, spray curtains, reduced scale fire modeling, fire detection, fire calorimetry (small and large scale), smoke venting, smoke control and positive pressure ventilation.

He has published numerous refereed papers, and is probably the most cited author of technical publications in the fire field. Because his objectivity and thoroughness in work efforts is widely recognized, his position on an issue can carry significant influence. He has also worked personally with student groups, helping them to see the challenges, needs and rewards of a career in fire research and engineering.

In addition to his publications, Dr. Heskestad holds several patents, is the recipient of several professional awards, and is the author (by invitation) of a monograph article on the dynamics of the fire plume in the prestigious Philosophical Transactions of the Royal Society of London.

Dr. Ronald L. Alpert, Principal Research Scientist (Retired), FM Global
Sponsored by: Lou Gritzo

Ron Alpert recently retired after a 35-year career in research at FM Global, during which he made several contributions to many areas of fire research. His achievements qualify him for consideration to be recognized for lifetime contributions to the field. There are four main areas of his work that have led to advances that are broadly recognized:

- Model for turbulent ceiling jet– The main contribution of this modeling and experimental work is the development of correlations for the ceiling flow produced by fire plumes, which still provide a benchmark for many practical applications. These range from the estimate of heat transfer to the ceiling to the prediction of the response of sprinkler or other detection devices.

- Pressure modeling of fires – He was responsible for a detailed analysis of the validity of this modeling technique. His contribution was critical in defining the role of flame radiation as a function of pressure. This part of the work has formed the basis for a modified version of the approach (radiation modeling) that better accounts for this dominant heat transfer mode.

- Droplet-flow interactions – The mass, momentum and energy transfers between water droplets and fire gases characterize the impact of water-based extinguishment systems on fire development. His work on the numerical prediction of the interaction of water sprays with fire plumes has elucidated the mechanisms that affect the effectiveness of sprinkler systems.

- Material flammability – The activity in this area has focused on achieving recognition of the FM Global flammability apparatus (know as the FPA) as an ASTM standard. This apparatus measures properties of materials that characterize their behavior in fire situations. The importance of this work lies in the idea of using properties derived from laboratory-scale experiments as inputs to models that can predict fire development in systems of larger scale.

Craig Beyler

Sponsored by: Ulf Wickström

- I would like to nominate Craig Beyler for the Sjolin award for his contributions to the SFPE handbook and to IAFSS, and to numerous scientific papers. - Ulf Wickström

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Prof Fan Weicheng, member of Chinese Academy of Engineering
Sponsored by: Giovanni Gallina

- He graduated from the Department of Engineering Thermophysics, University of Science and Technology of China in 1965. He became professor in 1987, and was elected as a Member, Chinese Academy of Engineering in 2001. He is now Executive Member, International Association for Fire Safety Science, Honored Chairman, Asia-Oceania Association for Fire Safety Science and Technology, Vice President, Chinese Fire Protection Association and Vice President, Chinese Association for Engineering Thermophysics.

- His main research area is fire science and safety engineering. He has published 8 book and 268 journal papers. His work has been widely recognized both domestically and internationally.

- He is the first to propose the State Key Lab of Fire Science in China, and has been Director of the lab since then. 90 SCI journal papers were published from the lab in 2005. The work done in the lab has become well known worldwide.

- He is also one of the founders of the Asia-Oceanion Association for fire Science and Technology, and was a Chairman of the association for 6 years. The association has been quite active since its establishment.

- He applied and successively hosted the 8th International Symposium on Fire Safety Science in Beijing, which was the first such a symposium held in a developing country. The number of both paper submitted and participants in this symposium is the largest in the IAFSS symposium history.

Moving research into practice

Andy Buchanan, Un. of Canterbury, NZ
Sponsored by: Marc Janssens

……….

Dr. Richard Gann, NIST
Sponsored by: Bill Grosshandler

Dr. Richard Gann, a Senior Scientist at NIST, has spent his 30-year career in the heart of fire science. His research interests and expertise include materials flammability, ignition phenomena, flame suppression chemistry, atmospheric and combustion chemical kinetics, smoldering combustion, fire detection and suppression,

confined space fires, smoke generation and toxicity, fluid flammability, and fire model validation.
Dick continuously demonstrates an extraordinary ability to distill the scientific essence of complex, far reaching technological issues, to assemble a high quality research team to tackle the technical obstacles to a solution, and to carry the results of his team's research through to implement changes in codes and standards, or to support legislative remedies proposed by others that positively impact the health and safety of the public. Dick is the founding Chairman of the Interagency Working Group on Fire and Materials, and has chaired the Technical Study Group for the Cigarette Safety Acts of 1984 and 1990; the U.S.-Japan-Canada Working Group on the Toxicity of Smoke from Building Materials; the Halon Alternatives Research Consortium, Technical Planning Committee; International Standards Organization Committee on Fire Safety, Subcommittee on Fire Safety Threat to People and the Environment; and the NFPA Toxicity Advisory Committee. He has been the U.S. Coordinator of the U.S.-Japan Panel on Fire Research and Safety, is a member of the editorial boards of *Fire and Materials, Combustion and Flame,* and *Fire Technology.*
His contributions to three major research programs with significant and measurable impacts stand out as highlights in a long and distinguished career:

Propensity of Cigarettes to Ignite Soft Furnishings -- Dick received the Department of Commerce Silver Medal for his contributions to the development of a scientific method for measuring the propensity of a cigarette to ignite fabrics. The significance of that work has now been firmly established. It has enabled (1) ASTM to develop a draft standard for rating different cigarette designs, (2) the state of New York to adopt legislation requiring the ignition propensity of cigarettes to be rated, and (3) the tobacco industry to develop a marketable cigarette that is significantly less prone to starting an unintentional fire on upholstered furniture.

Scientific Foundation for Selecting Fire Suppressants for Aircraft Applications -- Dick is recognized internationally for his leadership in finding alternatives to the ozone depleting halon family of fire suppressants. As the technical leader of the Next Generation Program (NGP) sponsored by the Department of Defense, he expertly coordinated the research of dozens of researchers in academic, commercial and government laboratories that pushed the frontier of fire suppression science and technology. His program guided the U.S. Air Force to select the optimal candidates for full-scale evaluation as a substitute for halon 1301 in existing aircraft engine nacelles and dry-bays.

World Trade Center Disaster -- Dick led the team of fire researchers who predicted the fire spread and thermal and tenability environment within the buildings. This required significant fire experiments to be completed from the simple (to gather data on the burning characteristics of the jet fuel) to the more complex (a complete WTC office mock-up complete with furnishings) to validate the simulations that would ultimately guide many of the recommendations.
When the investigation was completed, the output of all individual projects was 42 reports totaling approximately 10,000 pages. Dick synthesized the information from all project reports and prepared the single volume, “Final Report,” that now stands as the definitive record of the NIST investigation throughout the building and construction industry.

Dr. Robert G. Bill, Jr., Measurements & Models Area Director, FM Global
Sponsored by: Lou Gritzo

Robert G. Bill has a lifetime of significant accomplishments in bringing research into practice. While his technical achievements stand on their own merit, he has been particularly adept at bringing research results into fire protection engineering practice. The following results are particularly worthy of notice:

- He has brought to fruition the ISO Standard for the measurement of the Response Time Index (RTI) for sprinkler sensitivity. This is an important parameter, whose value is essential for the prediction of the time of sprinkler activation.

- He has led the project to develop (and subsequently revise) the Approval Standard for Residential Sprinklers. In working towards this process, he has identified the shortcomings of existing data and established a reliable foundation for the design of these systems.

- He developed the accepted methodology for protecting turbine enclosures using fine sprays. This promising protection strategy, which is now adopted by industry, still needs to be evaluated on a case by case basis. Bob has laid the technical foundations for ongoing work aimed at generalizing the treatment of these protection systems.

- He has been the force behind the FM Global specification testing for flammability of clean room materials. This has become the “de facto” standard used by the semiconductor industry in selecting materials for applications where sprinklers are not required. The resulting mitigation of the fire hazard in provides an invaluable benefit in the management of the risk in these high-value occupancies.

Early career accomplishment

Beth Weckman, Un of Waterloo
Sponsored by: Sheldon Tieszen

Recommendation that Professor Beth Weckman, University of Waterloo, be considered for the Sjolin award for a mid-career individual. The specific advance that Professor Weckman has made is a seminal contribution to obtaining detailed data sets for validation of CFD based fire models.
Throughout the history of fire science, measurements have been made to characterize global characteristics of fire in the form of dimensionless correlations. With the advent of CFD based fire models beginning in the 1980’s it became clear that detailed measurements would be necessary to validate these CFD based models. For nearly a decade, Professor Weckman worked with laser-doppler-velocimetry to

obtain velocity field measurements within a turbulent pool fire, producing a seminal paper in 1996,

- Weckman, E. J., and Strong, A. B., 1996, “Experimental investigation of the turbulence structure of medium-scale methanol pool fires,” Combustion and Flame, V105:245-266.

In the mid-1990’s, Sandia National Laboratories initiated a collaborative agreement with Professor Weckman, recognizing her as the senior researcher in the fire science community committed to obtaining detailed data sets for validation of CFD models. She recognized that spatial and temporal resolution of individual physics components, such as velocity fields, would advance the science. Working with particle-image-velocimetry and planar laser induced fluorescence, this collaborative agreement produced two additional seminal validation studies of which she is a coauthor,

- Tieszen, S. R., O’Hern, T. J., Weckman, E. J, and Schefer, R. W., 2004, “Experimental Study of the Effect of Fuel Mass Flux on a One Meter Diameter Methane Fire and Comparison with a Hydrogen Fire,” Combustion and Flame 139:126-141
- O’Hern, T. J., Weckman, E. J., Gerhart, A. L., Tieszen, S. R., Schefer, R. W., 2005, “Experimental Study of a Turbulent Buoyant Helium Plume,” Journal of Fluid Mechanics, 544:143-171

Recognizing the importance of scale and boundary conditions, particularly wind loads, Prof. Weckman has constructed a large fire rated wind tunnel at Waterloo and continues her work, in collaboration with Sandia and others.

- C.S. Lam, E. Randsalu, E.J. Weckman, A. Brown, W. Gill, and L.A. Gritzo, 2004, "Fuel Regression Rates of Hydrocarbon Pool Fires in Crosswinds", INTERFLAM 2004, 10th International Fire Science and Engineering Conference, July 2004, Edinburgh, 117 - 128.
- C. Lam and E. Weckman, 2007, "Heat Flux Measurements in Radiative and Mixed Radiative-Convective Environments", INTERFLAM2007, In London.
- C. Lam and E. Weckman, 2007, "The Thermal Environment in a Wind Blown Fire Plume", INTERFLAM2007, In London.

Dr. Christopher J. Wieczorek, Senior Research Scientist, FM Global
Sponsored by: Lou Gritzo

Though a recent addition to the research staff at FM Global, Chris has shown great promise through his enthusiastic approach to a number of research issues. He has demonstrated great skill in performing large-scale fire tests, as well as dealing with the difficult technical and business issues associated with them. More specifically, Chris has:

- Conducted large-scale experiments to examine appropriate fire protection schemes for turbine halls which examined existing and recommended protection schemes against pool, spray, and three-dimensional spill fires. In addition to conveying the findings of the research within FM Global and to FM Global clients, the work will be presented as a 2-hour technical session at the 7th Annual ASME Electric Power, April 2005 entitled “Research to Practical Solutions for Turbine Driven Equipment Fire Protection”.

- Developed a test methodology to evaluate the performance of smoke detection systems within refrigerated spaces. Assisted in the development of RTI values for rate-of-rise, rate compensated, and line heat detectors. This work has formed the basis for a paper presentation at the 16th Annual NFPA Fire Suppression and Detection Research Application Symposium held in Orlando, Florida, 21-23 January (2004) entitled “Methodology for Determining Detector Spacing”.

Tuula Hakarainen,VTT:
Sponsored by: Marc Janssens

Work in the field of reaction to fire which have been presented at international conferences, e.g. Interflam 2001.

Prof. Jose Torero, U. of Edinburgh
Sponsored by : Russ Thomas

Jose Torero is nominated for the Sjolin Award because of the significance of his contributions to fire protection engineering education and to advancing fire science through research. Jose Torero’s career is characterized by revitalizing different programmes around the world. He was a driving force for the revitalization of the University of Poitiers fire research programme, he played a pivotal role in the research turn around of the Department of Fire Protection Engineering at the University of Maryland, he was instrumental in the creation and growth of the Fire Laboratory at the Catholic University in Chile and has turned the Edinburgh programme from a 1 staff, 1 student operation to a full blown undergraduate programme with 5 permanent staff and more than 30 PhD students and post doctoral researchers. His trajectory has resulted in significant research contributions, strong alliances between academia and industry and a large output of professionals of the highest quality. He has received numerous research awards and has been consistently voted as best instructor in by students, has directed numerous MS and PhD students, and has served as advisor to the student chapter of SFPE. He is systematically involved in numerous committees and is regularly seen lecturing at professional societies and Universities.

Collen Wade, BRANZ:
Sponsored by: Bill Grosshandler

For her very good work on developing the code for Branzfire.

Group Nomination

The following group of fire scientists is being nominated:

Heat Flux Gauge Working Group

Sponsored by: Russ Thomas

William M. Pitts, NIST, USA
Annageri V. Murthy, NIST, USA
John L. de Ris, FM Global, USA
J. R. Filtz, LNE French National Testing Laboratory, France
Kjell Nyård, Norges branntekniske laboratorium, Norway
Debbie Smith, FRS, UK
Ingrid Wetterlund, SP, Sweden

I would like to nominate the above group for the Sjolin Award for 2006. They have been leading an international effort to bring order and understanding to the critical measurement of heat flux in fire testing and research. This work was initiated following a FORUM workshop in 2000 that identified measurement needs for furthering fire science. The fruits of the group's efforts have culminated in a final report, "Round Robin Study of Total Heat Flux Gauge Calibration at Fire Laboratories," that has been accepted for publication in *Fire Safety Engineering*. Encouraging the collaboration across international borders on important problems of mutual interest to FORUM members is one of the main objectives of the Sjolin Award. The work undertaken by this group was in the spirit of this award; the amount of time it has taken to complete the project is indicative of the technical complexity of heat flux measurements, the precision required for a meaningful result, and the logistical complexity of conducting experimental research on two continents. The quality and relevance of the final product is evident in the article that is attached.
This was (I believe) the first FORUM-initiated, FORUM-executed , and FORUM-completed research project, and the team's efforts need to be appropriately acknowledged.

SKLFS Laboratory
Sponsored by: Giovanni Gallina

The State Key Laboratory of Fire Science (SKLFS) was began to found in 1989 and named in 1995. SKLFS is the **ONLY NATIONAL** research institution in the field of fire safety science and engineering in China. Now it includes eight research divisions, covering most aspects of fire safety science and engineering research:

SKLFS	Building fire Division
	Industrial fire Division
	Forest and urban fire Division
	Fire risk assessment Division
	Fire simulation Division
	Fire chemistry Division
	Fire detection Division
	Fire suppression Division

Academic Achievements

SKLFS has achieved great progress. In 2003, SKLFS was rated **EXCELLENCE** during the evaluation of 29 state key labs in engineering sciences by the Ministry of Science and Technology of China. From 2000 to now, more than 470 SCI-indexed and 70 Ei-indexed papers were published at the journals of combustion and flame, combustion science and technology, fire safety journal, journal of fire science and so on, and 17 books were published in Chinese and English. SKLFS was one of the organizer who has organized the 8th International Symposium on Fire Safety Science successfully, and was the institution with most oral-presented papers. SKLFS still continues a strong rising trend in the fundamental research of fire safety science, which mainly includes fire dynamics, key technology of fire protection and theory and methodology of fire safety engineering.

Fire Dynamics

SKLFS has made great achievements in the research of fire dynamics. The major innovative research highlights of SKLFS include:

(1) Solid pyrolysis plays a key role in fire ignition and growth. A new kinetic model named as “First Order Pseudo Bi-component Separate-stage Model (PBSM)” was developed for the kinetic description of the thermal decomposition of natural cellulosic combustibles. The new model was verified and further extended for other polymer materials by other authors. The relevant researches, such as the theoretical source of the instability of the Freeman-Carroll (FC) method for kinetic modeling of solid thermal decomposition processes, a two-stage Gaussian smoothing strategy for pre-treatment of decomposition data of cellulosic materials, the theoretical error level of different integral decomposition kinetic methods, were highly remarked by international scholars.

(2) New ideas for the research of the physical processes involved in the pyrolysis and ignition of solid combustibles under fires were proposed, whereby a modified pyrolysis model and a new ignition criterion for cellulosic materials under varying heat flux was established. The relevant results were remarked by international scholars as “It is well executed and is indicative of growing quality fire research emerging from P.R.China.”

(3) A new backdraft experimental apparatus was designed and constructed, which has been granted as a China national invention patent. Experimental study shows that the mass fraction of total hydrocarbons is a key parameter determining the

occurrence of back-draft. A nonlinear dynamical model for backdraft was established, which was appraised by international scientist as “presenting a very good nonlinear analysis to a difficult fire engineering problem”. This research was awarded “IAFSS Best Thesis Award” for 2001-2004.

(4) Very large fire whirl experiments have been finished in SKLFS with the flame height of over 8.5 meters. The behavior of fire merging and fire whirl occurrence due to the interaction of many fire sources, which models the situation of large urban fire are investigated, and the occurrence criteria were proposed based on the burn-out time of each fire source. The encouraging work was presented at the 31st International Symposium on Combustion and reported by Asahi TV Broadcasting of Japan.

Key Technology of Fire Protection and Fire Safety Engineering

SKLFS has also always been making important contributions to fire protection technology and fire safety engineering of China, which including fire detection, fire suppression, fire retardant and performance-based fire safety engineering.

（1） SKLFS had developed modern new fire detection techniques, such as in-site photoacoustic CO detection technique, optical section smoke detection technique, dual waveband video flame detection technique and vision based water gun. In-situ photoacoustic CO detection technique was developed by SKLFS. The photoacoustic cell was filled with CO gas to work as a gas filter and would produce an initial photoacoustic signal when the light hit the gas. Once the gases to be measured pass through the path, the CO component will reduce the radiation that reaches the cell at specific wavelengths and attenuate the initial photoacoustic signal. Optical section smoke detector and vision based water gun were developed for fire protection engineering in atrium-like large spaces buildings. The water gun with dual waveband video flame detector can rotate in horizontal and vertical directions to search, position and suppress a fire automatically by using computer video-based technique. These achievements successfully resolved the problem for early fire detection in large volume space due to the complex background disturbances, and were entitled “2001 National Award for Science and Technology Progress” of China.

（2）In the field of fire retardant, new clean flame retardant principles and technologies of polymeric materials had been developed by SKLFS, to improve the comprehensive properties and fire safety of the polymeric materials through increasing the mechanical and flame retardant properties of polymeric materials, and also greatly reducing the toxic combustion products and smokes. These include: new polymer nanocompsite principle and technology for increasing the thermal, mechanical and flame retardant properties; new synergistic flame retardant principle and technology for increasing the compatibility between the flame retardants and polymer matrix and increasing the thermal and flame retardant properties of the flame retardants; new synergistic flame retardant nanocomposite principle and technology; polymer modification principle and technology for improving the compatibility between the flame retardants and polymer matrix and improve the mechanical, thermal and flame retardant properties of flame retardant polymers;

（3）SKLFS also developed fire suppression mechanisms with novel technologies, such as water mist with/without additives, clear and effective gas agents, etc. A new type film-forming additive was developed from the fundamental molecular design principles, and the fire suppression effectiveness was evaluated through full scale fire test. The Physical and chemical combined suppression mechanisms of multi-component water mist and mixed gaseous agents were explored from the fundamental principles. The effects of mist characteristics, fuel type and additives on the suppression effectiveness of water mist/additive were identified. The relationship between the critical extinction limit and the additive concentration was obtained.

（4）The fire safety assessment methodology was developed by SKLFS from the statistic theory on small fire-event sampling and fire dynamics. The probabilistic risk assessment theory was developed for evacuee behavior and loss assessment in building fires with consideration of both deterministic and stochastic factors.　SKLFS also contributed largely to the Draft of Performance-Based Fire Codes of China, which was cooperatively worked out with TFRI (Tianjing Fire Research Institute) of China. The counter flow behavior was studied with decision-making prediction of the evacuee according to his surrounding pedestrians within certain radius. A evacuation model, CAFÉ mode, was developed with friction, repulsion and attraction forced involved, which can quantify the basic phenomena of emergent evacuation, including arching, clogging, faster-is-slower, etc., as good as the social force model introduced by Helbing et al. A Multi-grid model, with finer lattice is used thus each pedestrian occupies multiple grids instead of one, was also developed. Interaction forces among pedestrians or those among pedestrians and constructions can be calculated quantitatively by the number and position of the overlapped grids, together with the model rules.

The above innovative fire protection technologies had been successfully applied to fire safety engineering of many new large complex buildings in China, such as sports stadiums of 2008 Olympic Games, the Great Hall of People, China Central Television Studio, National Grand Theater, etc. These achievements were entitled “2006 National Award for Science and Technology Progress” of China.

Education Achievements

SKLFS has made great contributions to academic education of fire safety science and engineering in China. It has set up a successful bachelor-master-doctor degree education system in the specialty of safety science and engineering. Over 300 full time students had got their degrees in SKLFS, including 56 doctors and 143 masters. In 2001, SKLFS set up a new program for Master degree of Engineering. Until now, it has trained over 200 part time students from fire brigades all over China, which has greatly enhanced the scientific levels and efficiency of Chinese fire brigades. All these graduates are now making good contributions to fire safety science research and engineering of China, and of the world. Because of the great contributions to education, SKLFS has won China National-Level Teaching Achievement Awards twice (1997 and 2001).

During decades of development, SKLFS has become a famous fire laboratory with excellent achievements both in fire science and fire safety engineering, which have impelled the development of fire safety science and engineering of China and even partly of the East Asia. SKLFS has also made and is still making large contributions to the development of international fire safety research.

A new draft Forum position paper on heat transfer in fires

Heat transfer to structures

A basic and common understanding of heat transfer in fires is of great significance for the development of fire safety engineering. Nevertheless, often confusions occur because various researchers have sometimes vague and deviating understandings of fundamental concepts of heat flux by radiation and convection. There are also different ideas on how these quantities can be measured and used when calculating temperatures in fire exposed structures. This Forum position paper is intended to shed some light on these issues. The concept of adiabatic surface temperature is introduced and its relation to fire resistance furnace testing and plate thermometer measurements are briefly outlined and discussed.

Introduction

The fire resistance of structural elements is traditionally determined by standard fire endurance tests. However there is also a need to be able to predict the response of structures of various designs when exposed to alternative design fire conditions. Accurate and robust analytical methods are then needed. Such methods may also be used for predicting standard tests of for example structural elements which can not be tested due to e.g. size, or for extending test results to modified structures.

It is necessary when using analytical methods as well as when interpreting test results and their relations to real fires to understand the fundamental physics governing the thermal behavior of fire exposed structures. The focus in this chapter is to meet these needs. The content is based on text-books on heat transfer theory, like reference [[1]] and others, and from various publications in the field of fire safety engineering.

Analytical methods for the design of fire resistance of structures have three main components.

1. Determining the duration and level of thermal fire exposure
2. Calculating the heat transfer and the internal temperature distribution
3. Estimating the structural response and the loadbearing capacity

The first step is in general very complex and requires many more or less uncertain assumptions. Most often the fire exposure is assumed according to standardized time-temperature curves as specified in ISO 834, ASTM E-119 or EN 1363-1. Time-temperature developments determined by fire models or measured at ad hoc tests are more seldom applied. The next step is very crucial as the deterioration of material strength etc. depends upon the temperature obtained. This chapter focuses on this second step. More information on the first and third steps of an analytical design procedure is outlined elsewhere in this section of the handbook.

The temperature calculation methods presented here disregard in general any

[1] Holman, J.P., Heat Transfer, 4th ed., McGraw Hill, 1976

mechanical failures that may occur which could alter the thermal conditions. Protection systems may for example fall off in case of fire exposure and completely change the thermal conditions. Such phenomena must be investigated by full scale tests and therefore new types of structural systems must in general be tested in full scale in standard furnace test as a basis for type approval etc. Calculation methods can, however, be used for generalizations or extensions of test results to various dimensions and configurations.

Heat is transferred from hot fire gases to structures by radiation and convection. The contributions of these two modes of heat transfer are in principal independent and must be treated separately.

Thus the total heat flux $\dot{q}''_{tot}$ to a surface is

$$\dot{q}''_{tot} = \dot{q}''_{rad} + \dot{q}''_{con} \qquad \text{Eq. 1}$$

where $\dot{q}''_{rad}$ is the net radiation heat flux and $\dot{q}''_{con}$ the heat transfer to the surface by convection. Details of these two contributions are given below.

The net contribution by radiation $\dot{q}''_{rad}$ depends on the incident radiation $\dot{q}''_{inc}$, on the surface emissivity/absorptivity and on the fourth power of the absolute temperature T_s of the targeted surface. The heat exchange at a surface is illustrated by Figure 1.

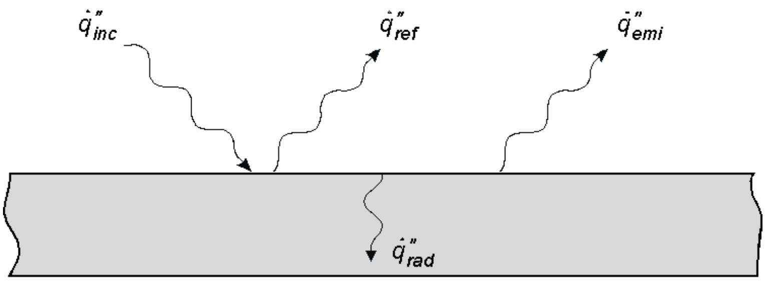

Figure 1 **The heat transfer by radiation to a surface depends on incident radiation and the surface absolute temperature and the surface emissivity.**

Part of the incident radiation is absorbed and the rest $\dot{q}''_{ref}$ is reflected. Then the surface emits heat by radiation $\dot{q}''_{emi}$ depending of the emissivity and the surface absolute temperature to the fourth power. Thus

$$\dot{q}''_{rad} = \alpha_s \dot{q}''_{inc} - \varepsilon_s \sigma T_s^4 \qquad \text{Eq. 2}$$

where α_s and ε_s are the target surface absorptivity and emissivity, respectively. The surface emissivity and absorptivity are assumed equal according to the Kirchhoff's identity, and the incident radiation is expressed in terms of a radiation temperature T_r. Then Eq. 2can be written

$$\dot{q}''_{rad} = \varepsilon_s \sigma (T_r^4 - T_s^4) \qquad \text{Eq. 3}$$

The heat transferred by convection from adjacent gases to a surface varies a lot depending on adjacent gas velocities and geometries. It may be written as

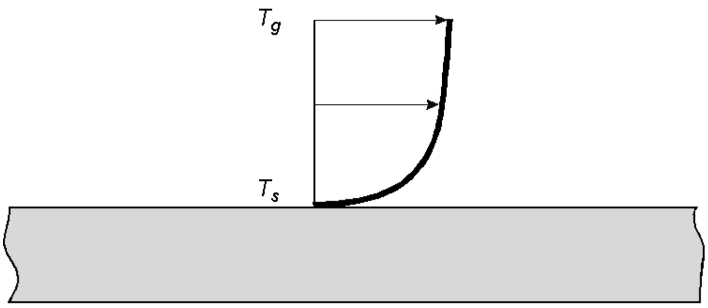

Figure 2 **Gas velocity profile. The heat transfer by convection depend on the temperature difference between the adjacent gases and the target surface, and on the gas velocity.**

$$\dot{q}''_{con} = h(T_g - T_s) \qquad \text{Eq. 4}$$

The convective heat transfer coefficient *h* depends mainly on flow conditions near the surface and not so much on the surface or the material properties.

The total heat transfer to a surface may now be obtained by adding the contributions by radiation and convection:

$$\dot{q}''_{tot} = \varepsilon_s \sigma (T_r^4 - T_s^4) + h(T_g - T_s) \qquad \text{Eq. 5}$$

Alternatively the two boundary temperatures in Eq. 5, T_r and T_g, may be combined to one effective temperature T_{AST}, the adiabatic surface temperature. This temperature is defined as the temperature of an ideally perfectly insulated surface when exposed to radiation and convection heat transfer [2]. Thus T_{AST} is defined by the surface heat balance equation

$$\varepsilon_s \sigma (T_r^4 - T_{AST}^4) + h(T_g - T_{AST}) = 0 \qquad \text{Eq. 6}$$

The value of T_{AST} is always between T_r and T_g.

Then the total heat transfer may be written as

$$\dot{q}''_{tot} = \varepsilon_s \sigma (T_{AST}^4 - T_s^4) + h(T_{AST} - T_s) \qquad \text{Eq. 7}$$

The adiabatic surface temperature T_{AST} can in many cases be measured, and it may be used for calculating heat transfer to fire exposed surfaces based on practical tests.

It can also be obtained from numerical CFD modelling of fires using computer codes like FDS [2,3].

The emissivity ε_s is a surface property, which can be assumed equal 0.8 for most building materials except for e.g. shiny steel where a lower value may be assumed. The convection coefficient h is not decisive for the temperature development near a fire exposed surface of a structure as the radiative heat transfer dominates at high temperatures. In Eurocode 1 [4] a value of 25 W/m^2K is recommended at fire exposed surfaces. The temperature on the non-exposed side of separating structures will on the other depend very much on the heat transfer conditions including the convection coefficient. In Eurocode 1 a convective heat transfer coefficient value of 4 W/m^2K is recommended in this case.

In many cases, however, fire exposed surfaces will get temperatures very close to the fire temperature, i.e. $T_f \approx T_s$. This approximation applies in particular for insulation materials with a low density and a low thermal conductivity. It may facilitate calculations considerably, e.g. when calculating temperature in insulated steel structures. Even a normal weight concrete surface will get a temperature of 90% of the fire temperature already after 30 min.

The heat transfer conditions may on the other hand be very decisive for the temperature development in a fire exposed bare steel structure. They are also very important for the temperature development on the backside of a fire separating element, in particular for low density materials.

Calculating heat transfer using Plate Thermometer temperatures

So called *plate thermometers* are used to monitor the temperature in fire resistance furnaces according to the international standard ISO 834 and the European standard EN 1363-1. A plate thermometer (PT) consisting of an inconel plate insulated on its backside is shown in Figure 3a. A thermocouple fixed to the plate registers its temperature. Figure 3b shows its position in a vertical furnace with the front side facing into the furnace and the insulated back side facing the specimen. The front side of the PT is exposed to approximately the same heating conditions including radiation as the specimen. As the exposed surface of the PT is relatively large, it is sensitive to convective heat transfer in the same way as the specimen surface. The inconel plate is thin, only 0.7 mm, and responses therefore quickly to temperature changes. As a matter of fact the PT in a standard fire resistance test measures approximately the temperature of an adiabatic surface, i.e. the temperature of an ideally perfect insulator exposed to the same heating conditions as the specimen surface. See Eq. 6 and Eq. 7 above.

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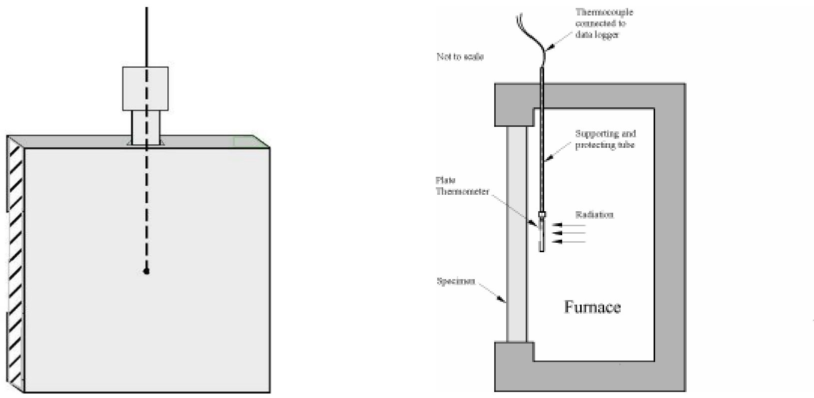
2 Wickström,U.,Duthinh, D. and McGrattan, K.B., Adiabatic Surface Temperature for Calculating Heat Transfer to Fire Exposed Structures, Interflam 2007.

3 McGrattan, K.B., Hostikka S., J.E. Floyd, H.R. Baum and R.G. Rehm, *Fire Dynamics Simulator (Version 5), Technical Reference Guide*, NIST SP 1018-5, National Institute of Standards and Technology, Gaithersburg, Maryland, July 2005

4 EN 1991-1-2, Eurocode 1: Actions on structures – Part 1-2: General actions – Actions on structures exposed to fire



(not to scale)

a) **A thermocouple welded to the center of a 0.7 mm thick inconel plate which is insulated on its back side. The exposed front face is 100 mm by 100 mm.**

b) **PT:s are placed in fire resistance furnaces with its front side exposed to radiation from the furnace interior.**

Figure 3 The plate thermometer according to ISO 834 and EN 1363-1

The PT was introduced mainly to harmonize fire endurance tests, see ref. [5], but the measured temperatures are also well suited as input for calculating heat transfer by radiation and convection to fire exposed surfaces.

As the plate thermometer approximately measures the adiabatic temperature an approximate alternative expression of the net heat transfer $\dot{q}''_{tot}$ to a specimen surface can now be obtained by replacing T_{AST} with T_{PT} in Eq. 7:

$$\dot{q}''_{tot} = \varepsilon_s \sigma (T_{PT}^4 - T_s^4) + h(T_{PT} - T_s) \qquad \text{Eq. 8}$$

This rewriting of equation Eq. 5 facilitates the calculations in many cases. Notice that it contains no reduction factor of the type "furnace emissivity". The only emissivity in this equation is the surface emissivity of the exposed surface. Such effects of the furnace are included in the plate thermometer readings.

The error $\Delta\dot{q}''$ introduced can be quantified by a simple algebraic analysis as:

$$\Delta\dot{q}'' = (\varepsilon_s - \varepsilon_{PT})\sigma(T_r^4 - T_{PT}^4) + (h_s - h_{PT})(T_g - T_{PT}) \qquad \text{Eq. 9}$$

Thus the error is small when the surface emissivity of the PT and the specimen are nearly the same and when the convective heat transfer coefficients are nearly the same. Therefore the surfaces of the PTs are blasted and heat treated before being

[5] Wickström, U. and Hermodsson, T., *Fire Safety Journal*, **26**(4)(1996) 327-350

used to get an emissivity of about 0.8. As T_{pt} always has a value between T_r and T_g the error vanishes when these two temperatures are close.

Heat transfer in fire resistance furnaces

Nominal time-temperature relations are clearly defined in fire resistance test standards like ISO 834, EN 1363-1 and ASTM E119. However, furnaces have various characteristics depending on the difference between the black body radiation temperature T_r and the gas temperature T_g. In addition there is a time delay of the temperature recording due to the thermal inertia of the monitoring thermocouples. Therefore when theoretically simulating fire resistance tests it must be considered how the temperature has been measured in the various standards. When plate thermometers has been used the heat transfer can be calculated according to Eq. 8.

The furnace temperature shall be monitored with plate thermometers PT:s (see ISO 834-1 and EN 1363-1). The time delay or in other words the time constant of the PT:s in a furnace tests is small. Therefore the heat transfer to a specimen surface can accurately be calculated according to Eq. 8.

Sometimes it is of interest to know the *incident radiation* q_{inc} level under a furnace test. This can be obtained from Eq. 6 for times after the first 5 to 10 minutes when the effects of the plate thermometer inertia can be neglected by replacing T_{AST} with T_{PT}. At shorter times a transient term must be added to account for the thermal inertia of the plate.

$$q_{inc} = \sigma T_{pt}^4 - h_{pt}(T_g - T_{pt}) / \varepsilon_{pt} \qquad \text{Eq. 10}$$

The latter term in Eq. 10 is relatively small and may be treated as an error term. For values of the emissivity ε_{pt} and the convection heat transfer coefficient h_{pt} equal 0.8 and 25 W/m^2 K, respectively, a temperature level of 1 000 K and a gas temperature T_g deviating from the plate thermometer temperature T_{pt} by as much as 50 K yields the latter term of Eq. 10 to be less than 3%. At higher temperature levels and at minor deviations between gas and radiation temperatures this error is much smaller and probably seldom greater than must be anticipated when measuring incident radiation directly with heat flux meters.

The standard thermocouples specified in the American test standard ASTM E-119 for monitoring the furnace temperature is very thick and therefore very slow. According to the standard it shall have a time constant τ within the range from 5.0 to 7.2 min. This means the actual temperature is much higher then the temperature recorded. Based on reasonable assumptions of heat transfer conditions, Figure 4 shows the actual effective furnace temperature rise in a furnace controlled ideally precisely according to ASTM E-119. Notice that the real or effective furnace temperature, which corresponds to the adiabatic surface temperature, is much higher then indicated by the slowly responding ASTM type of shielded thermocouples. It must, however, be noted that the above analysis assumes that the furnace radiation and gas temperatures are equal. That is, however, seldom the case. The gas temperature may be higher than radiation temperature and therefore the differences in practice between the ASTM thermocouple and the plate thermometer may be much less, as the ASTM thermocouple is more sensitive convective heat transfer than the plate thermometer. The general observation from this theoretical analysis agrees with the test results from various furnaces in north America reported Sultan [6]. The difference between the ASTM type of thermocouples and plate thermometer is insignificant after 10 min.

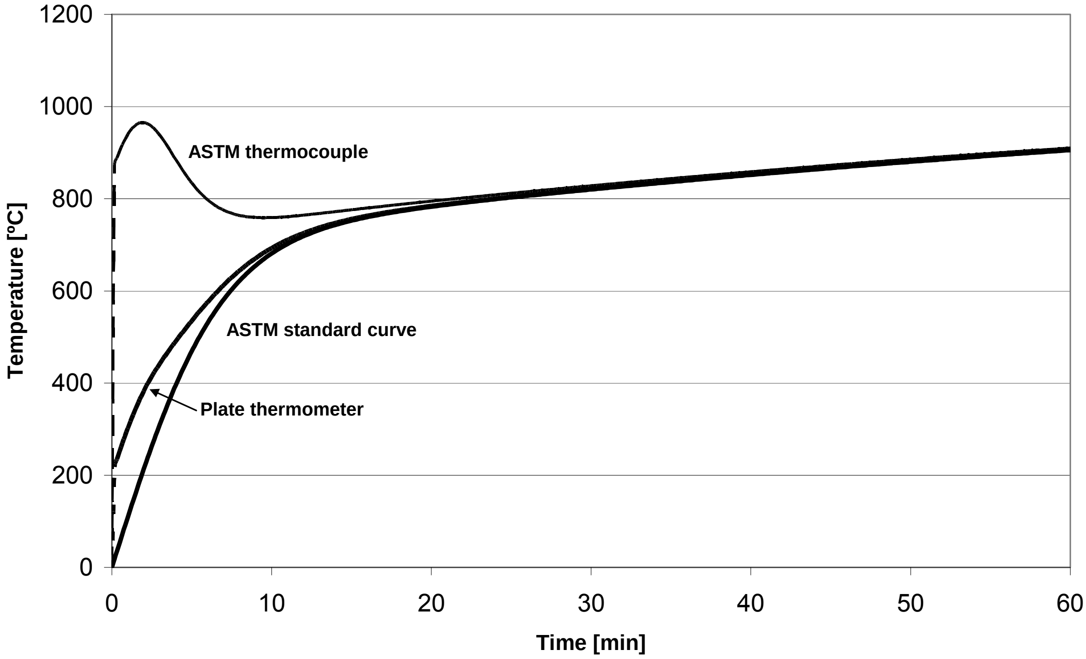


Figure 4 **Temperatures ASTM E-119 and ISO 834 (plate thermometer), respectively, must follow to obtain the effective furnace temperature T_f according to ASTM-E119 due to time delay.**

Summary

In this FORUM position paper certain very fundamental aspects and concepts of heat transfer in fire safety engineering are laid down. The FORUM agrees that:

1. The heat transfer to a fire exposed surface can be calculated based on plate thermometer recordings.
2. Thus the plate thermometer can be used for obtaining harmonized testing.
3. Adiabatic surface temperatures AST can be used for calculating heat transfer to a surface at a given temperature.
4. The plate thermometer measures AST in fire resistance tests.
5. AST can be calculated by CFD models and is an efficient tool for transfering data from CFD calculations to e.g. with finite element codes for calculating temperatures inside fire exposed structures.

6 Sultan, M.A., A comparison of heat exposure in fire resistance test furnaces controlled by plate thermometers and by shielded thermocouples, Interflam 2004, Edinburgh, Scotland, July 5-7, 2004, pp. 219-229.

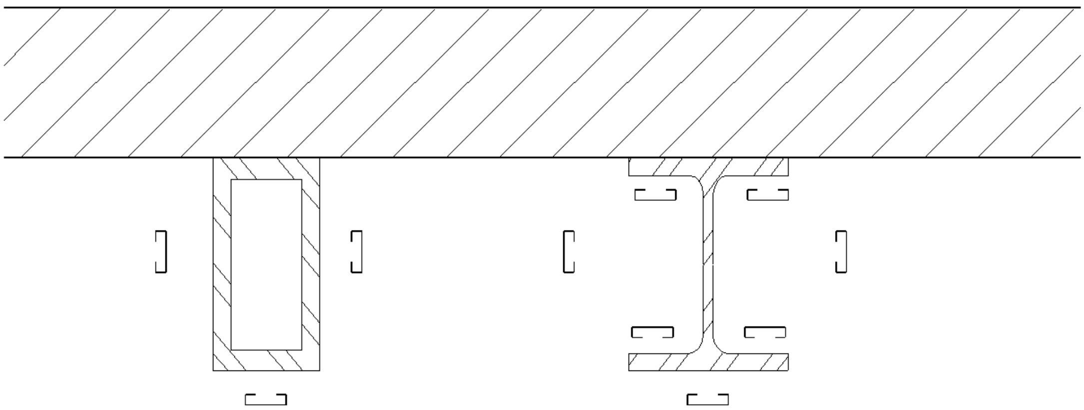
A project proposal to Forum (first draft)
By Ulf Wickström, SP

Heat transfer measurements and calculations - A proposal for a Forum research project

Heat transfer to fire exposed structures has been discussed intensively in Forum and elsewhere (ISO, CEN, and Egolf). Various theories have been proposed. In this research proposal it is suggested that a few well defined experiments are carried where temperature is measured in fire exposed steel beams. The thermal impact is measured at various positions by plate thermometers and possibly by other means. In addition this same thermal impact is calculated with a CFD model, e.g. FDS. The temperature at various positions in the steel beams is then calculated based PT measurements (or other means) and based on the CFD calculations.

Experiments

A standard fire resistance test according to ISO 834 is performed in a fire resistance furnace. The temperature is controlled with PTs. Additional PTs are placed around the two specimens as indicated in the figure below. More instruments for monitoring the thermal conditions can be added if requested. Test duration 60 min.



A second experiment is carried out in room of about the same size as a horizontal furnace, i.e. about 3 m by 5 m, and 2.5 m high. The heating source could either be a gas burner at constant rate of 500-1000 kW or a wood crib giving about the same heat output, or both.

The steel beams could be about 300 mm high. Steel beams are chosen as their temperatures are easy to measure and easy to calculate.

Calculation

Input data are given to modellers of fire development CFD) as well as to modellers of the steel temperatures (FEM). Only the room tests should be modelled. CFD modellers could report their results as adiabatic surface temperatures AST or else wise.

Analysis and reporting

Comparisons should then be made between

1. measured PT and CFD calculated adiabatic surface temperatures (only room tests)
2. calculated steel temperatures based on PT measurements and measured steel temperatures
3. calculated steel temperatures based on calculated AST and measured steel temperatures (only room tests)

Realization, time, and costs

The tests could be carried out at one or two fire test laboratories. They should be completed within six months to give time for calculations and writing of a final report in time for the Forum meeting in 2008. The costs for the test program including reporting are in the order of US$ 150-200. The costs for computer analyses are not included.

The International FORUM of Fire Research Directors[7]

A Position Paper on Performance Based Design for Fire Code Applications

Paul A. Croce,[i, #] William L. Grosshandler,[ii] Richard W. Bukowski,[ii] and Louis A. Gritzo[i]

[i] FM Global, 1151 Boston-Providence Highway, Norwood, Massachusetts 02062, U.S.A.
[ii] Building and Fire Research Laboratory, National Institute of Standards and Technology, Gaithersburg, Maryland 20899-8660, U.S.A.

Background

Fire codes and standards are developed and regulations implemented in most countries with the objective of protecting societies and reducing their losses from fire. For the majority of traditional buildings with low hazard occupancies, modern prescriptive building and fire codes, when enforced, achieve this objective. Nontraditional buildings include many of society's largest and iconic structures, such as opera houses, museums, sports stadiums, transportation centers, super-high-rise structures, and some government buildings. Prescriptive codes cannot anticipate all of the requirements that these nontraditional structures impose; prescriptive codes do not adapt rapidly to changing materials and methods of construction, nor to radical architectural designs; and prescriptive codes based upon historical loss experiences are not designed to deal with very low probability, very high impact events or other threats such as from terrorism.

Regulating the design, construction, and operation of buildings on the basis of performance is viewed as a means to overcome many of the shortcomings of prescriptive codes for nontraditional structures, as well as for more traditional buildings on unusual sites, or for an existing building undergoing renovation or a change of occupancy. While an additional up-front investment is required to design and evaluate a project on the basis of performance rather than prescription, performance-based codes provide much greater flexibility and promote innovation in building design, materials, products and fire protection systems. Deemed-to-satisfy provisions provide continuity with prior prescriptive regulations and ensure that existing buildings do not come into violation. However, this assumes that the prescriptive rules are sufficient in all cases to meet the performance objectives, which may not be the case.

ISO TC92 has established a framework for the long term standardization of fire safety in support of performance-based design.[8] A guide for conducting performance-based fire

[7] http://www.bfrl.nist.gov/info/forum/ The International FORUM of Fire Research Directors (FORUM) was formed in 1991 with a goal to reduce the burden of fire (including the loss of life and property, and effects of fire on the environment and heritage) through international cooperation on fire research. Our members include many who were involved with writing PB codes; we have met and worked with regulators, practitioners and educators worldwide; and we have carefully examined and discussed these factors in the effective application of PB design for regulation.
[#] retired
[8] "Framework for Standards for Fire Safety," TC92 N 983, International Organization of Standards.

protection design has been developed by the Society of Fire Protection Engineers (SFPE), which spells out the steps from the definition of the design scope, through the expression of the performance criteria, selection and evaluation of design fire scenarios, and ultimately to the final design.[9] Even so, the success of performance-based design (PBD) for fire code applications hinges on the establishment of critical solution-enabling tools, a profession properly educated to implement these innovations, and code officials capable of evaluating the safety of PBD. Further, when expressing the performance criteria, serious consideration should be given to public well-being as an appropriate overall goal of performance-based regulation. An approach committed to public well-being can broaden the beneficial societal impact with likely more reliability.

Challenges of Performance Assessment

Buildings are complex collections of systems, materials and arrangements that are highly variable and interactive, and the performance objectives of the regulations relate primarily to the performance of the system as a whole. Deficiencies in one area can in some cases be compensated by use of other materials or systems and this is central to the flexibility afforded by performance-based regulation. However, compensation or substitution is not easily evaluated and not always proper or prudent. The ability to quantify the in-use performance of many fire safety systems is mixed, made difficult by: the physics of the fire, the fire protection systems, and the response of the building to the fire; our incomplete knowledge of human behavior in a fire emergency; and the complexity of validating computational design tools over a wide range of fire scenarios.

Experimental tools, e.g., mid- and large-scale calorimetry, are well developed and widely available for measuring the heat release rate of real objects and fuels (along with the yield fractions of smoke and major species) under fully ventilated fire conditions, but how these may change for vitiated conditions or when impacted by external radiant heating cannot be predicted in a quantitative sense. Small-scale testing can be particularly helpful as an economical approach if implemented in a manner that is compatible with PBD[3]; clearly, though, more work is needed. Initial sprinkler activation times can be estimated to reasonable accuracy but the influence of the water spray on the fire environment and on the combustion process, along with subsequent sprinkler activation times, can be only crudely estimated.

There has been great progress in recent years with fire models that can predict the

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[9] *The SFPE Engineering Guide to Performance-Based Fire Protection Analysis and Design of Buildings*, National Fire Protection Association, Quincy, MA, U.S.A., 2000.

[3] Bill, R.G. and Croce, P.A., "The International FORUM of Fire Research Directors: A position paper on small-scale measurements for next-generation standards," *Fire Safety Journal*, Vol. 41, 2006, pp. 536-538.

[4] "Standard Guide for Evaluating the Predictive Capability of Deterministic Fire Models," ASTM E 1355-05a, ASTM International, West Conshohocken, PA, U.S.A., 2005.

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[6] *Final Report on the Collapse of the World Trade Center Towers,* NIST NCSTAR 1, National Institute of Standards and Technology, Gaithersburg, MD, U.S.A., September 2005.

[7] Cardington …………………………………………….

[8] Grosshandler, W. (editor), "FORUM Workshop on Establishing the Scientific Foundation for Performance-Based Fire Codes: Proceedings," NIST SP 1061, National Institute of Standards and Technology, Gaithersburg, MD, U.S.A., December 2006.

development and spread of fires and the fire's impact on the internal environment of the building. A number of computational models are available and are now routinely accepted for some regulatory applications. Some models have been adequately validated for specific applications, but many have not been validated for broad classes of complex problems because validation-quality data are available for only limited geometric arrangements and fuel conditions. Guidance exists for fire model verification and for documentation;[4] however, few organizations have pursued the rigorous verification and validation supported by the FORUM.[5] Therefore, application of these models typically requires extrapolation to the design of interest and the associated validation.

Given the thermal environment established by a fire model, finite element models are available for predicting the resulting temperature distributions within the structure; and models have been developed to predict the stresses and response of the structure to the changing thermal environment. However, combining these models to obtain a comprehensive picture of the response of the overall structure to, say, a full building burnout is problematic. The individual models operate on vastly differing time and length scales that pose significant problems for solution of the governing equations. Sequential calculation methods recently have been employed to solve this problem,[6] but these are tedious and too costly for regular use in design and regulation. The prediction of incipient failure of individual elements is on relatively firm ground. The reaction of connections to thermally induced stresses and creep, the effects of high heating rates and thermal gradients (as well as numerical convergence difficulties near imminent structural collapse) were examined in the series of tests conducted in Cardington;[7] however, there is much yet to be learned.

Performance assessments generally involve the application of considerable engineering judgment and are subject to manipulation by the selection of calculation method and input data. This issue depends on two factors to assure confidence for regulation. First, individuals performing the calculations are generally required to be licensed or chartered and subject to the ethical constraints of a design professional. Second, most performance-based regulatory systems require third-party review of all calculations and assumptions. With a concerted long term program to increase the educational level and minimum qualifications of regulators, the issue may be brought under control within the limitations of the design tools themselves. More, however, needs to be done to assure adequately accurate models, a better educated profession, and more appropriate model application.

Research Needs

Representatives from the FORUM membership and other technical experts were invited to develop a common, international vision for how the scientific foundation might be bolstered for the next generation of performance-based design tools.[8] Methods for the attainment of this vision were identified that included the establishment of:

- a hierarchy of meaningful benchmark fire experiments and simulations;
- tractable combustion models that capture the essence of materials and finished products, and with simple multi-step reaction mechanisms for prediction of CO and soot;
- data sets and experimental facilities for unraveling the relationships within and interactions among fire dynamics, structural dynamics, and human behavior;
- efficient interfaces among fire, structural, human behavior, and risk models;
- data and means to track uncertainty in risk and hazard analysis, and to incorporate rare, high consequence events.

Five areas were identified at the top of the list of research priorities for the members of the

FORUM:

- improvement of our ability to predict the impact of active fire protection systems on fire growth and the distribution of combustion products;
- estimation of uncertainty and the means to incorporate it into hazard and risk analyses;
- the relationship between aspects of the building design and the safety of building occupants;
- the impact of material and geometry changes on fire growth and products of combustion;
- the prediction of the response of a structure to full building burn-out.

FORUM Position

It is the FORUM's position that:

- the level of understanding of fire science by practitioners and the capabilities of the current generation of FPE tools are useful and adequate to support some aspects of performance-based regulations, codes and design, although numerous practical design applications and requirements exist that remain beyond the limits of these tools, and uncertainties in the predictions have not been or cannot be quantified;
- accurate tools must be available and used expertly; and PBD must be applied uniformly and consistently by properly educated practitioners and evaluated uniformly and consistently by adequately trained authorities having jurisdiction;
- for performance-based regulation to be effective, a commitment must be made to public well-being, both in the public and private sectors.

A coordinated and sustained global effort of research among FORUM members, universities, and other research organizations in support of PBD can lead to enhanced and more certain predictions of: the effects on performance of changes in building materials, active and passive fire protection systems, compartmentation, and egress systems; the structural response of a building to large fires including those leading to full building burn-out; the impact of fire on neighboring buildings and infrastructure; and the uncertainty in deterministic predictions for incorporation into reliable probabilistic calculations of hazard and risk.

FORUM members are committed to documenting and disseminating to the international regulatory, codes and standards communities progress on these collaborative efforts as well as the results of their individual research programs in support of the beneficial aspects of performance-based codes and performance-based design for fire applications.

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