High-Rise Façade Fires
A World Wide Concern

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Overview

In 2013, the National Fire Protection Association (NFPA) Research Foundation initiated a project with the goal of developing the technical basis for evaluation, testing, and fire mitigation strategies for exterior wall systems with combustible components.

They established an international team with CSIRO (Commonwealth Scientific and Industrial Research Organization, Australia's national science agency) and FireSERT (the Institute for Fire Safety Engineering Research and Technology at the University of Ulster), with the objective of gathering information on fire incidents involving combustible exterior walls, compiling relevant test methods and listing criteria, identifying the knowledge gaps and relevant fire scenarios, as well as a testing approach for future efforts.
Phase I of the Study

Included review of available fire statistics, fire incidents, literature and test methods relating to combustible external wall assemblies including:

- Exterior Insulation Finish Systems (EIFS, or synthetic stucco)
- External Thermal Insulation Composite Systems (ETICS)
- Metal Composite Material (MCM) cladding
- High-pressure laminates
- Structural Insulation Panel Systems (SIPS) and insulated sandwich panel systems
- Rain Screen Cladding (RSC) or ventilated facades
- Weather-resistive barriers (WRB) and combustible wall cavity insulation
- External timber panelling and facades including cross laminated timber (CLT)
This Presentation will provide an increased understanding of:

- Fire protection aspects of High-Rise Building Exterior Facades
- Why these requirements exist
  - fire losses
- Related fire dynamics
- Associated fire tests
- Applicable US (IBC) requirements
- The level of protection intended by those requirements
Why do we care?
(Notable Losses)
March 28, 2016

Fire engulfed at least two residential towers in the UAE city of Ajman, causing panic among residents.

Attributed to aluminum composite panel cladding.
The Address Downtown Dubai hotel
Police forensic experts said the fire that engulfed the 63-story hotel on New Year's Eve was started by an electrical short-circuit.

Dubai's government said 14 people suffered minor injuries, one person was moderately injured and another had a heart attack due to overcrowding and smoke at the site. "People started to panic, crushing each other trying to get down the stairs."

“Most Dubai towers built before 2012 ‘have non fire-rated exterior panels’
Torch Tower Fire; Dubai
Saturday 21 February 2015

Started around the 50th floor on one of the building’s balconies and burned until it ultimately reached the roof (86 Stories)

One of the tallest residential buildings in the world (1,105 ft). Opened in 2011.

Hundreds were evacuated and dozens suffered smoke inhalation.

Out of 676 units, 101 apartments were not considered habitable.
Estimates are that there may be hundreds of high-rise building exterior facades (≈ 70%) in the UAE with non-fire resistant aluminium composite panels.
Fire spread through external balcony channel lined with 3 mm thick aluminum composite cladding.
Construction had just completed in this unoccupied, 40-story high rise building. Ignition attributed to a short circuit in an air conditioner on upper floors. Fire spread to engulf the façade from ground level to the roof. Façade materials believed to be metal composite panels, but actual details not reported.
The Monte Carlo Façade Fire
January 25, 2008

Jesse J. Beitel
Senior Scientist / Principal
Hughes Associates, Inc.

Douglas H. Evans, P.E.
Fire Protection Engineer
Clark County Building
Blobs of burning goo raining down on terrified occupants fleeing the towering inferno.
Palace Station
Las Vegas
July 20, 1998

Palace Station,
Las Vegas, Nevada
July 20, 1998 6:37 A.M.
12-21-99 "Don Belles" Letter to CCBD
Dryvit Facia with 1 inch Expanded Polystyrene Insulation over 5/8 inch Gypsum Board

Dryvit Soffit with 1 inch Expanded Polystyrene Insulation over 5/8 inch Gypsum Board

Polyurethane Small Corbel Beyond Large Corbel

3 inch Thick Polyurethane Panel Beyond Large Corbel

Large Polyurethane Corbel

Urethane Coated Expanded Polystyrene Light Trough Beyond Large Corbel

Polyurethane Capital

8 inch Radius EIFS Column with 1 inch Expanded Polystyrene Insulation

Section 'A- A'

Las Vegas Palace Station

12-21-99 "Don Belles" Letter to CCBD
Eldorado Hotel

Reno, Nevada
September 30, 1997

A 120 ft long by 60 ft high “sign”.

Constructed of a hard coat polyurethane over EPS.

Flames extended 50 m above the second floor roof.
Aluminum composite panels with a 3 mm polyethylene core. The fire started on the fourth floor due to a spark from an electrical outlet. A vertical “U” shaped channel enhanced fire spread through re-radiation and chimney effect.
Mandarin Oriental Hotel
44 Stories
Beijing
CHINA
Feb 9, 2009
Ignited by fireworks
The upper portion of the China Central Television headquarters (CCTV) facade was ignited by illegal fireworks. The fire spread to involve the majority of the facade over the entire height of building, which is believed to have included polystyrene insulation.
Mandarin Oriental Hotel

- [youtube.com/watch?v=v4_8sTHC7wU&NR=1](https://youtube.com/watch?v=v4_8sTHC7wU&NR=1)
- [youtube.com/watch?v=eINSQ3YQ65I&feature=related](https://youtube.com/watch?v=eINSQ3YQ65I&feature=related)
- [https://youtu.be/3B1OnhSucP8](https://youtu.be/3B1OnhSucP8)
- [ireport.com/docs/DOC-210419](https://ireport.com/docs/DOC-210419)
- [https://youtu.be/3Ob8cxZNGb8](https://youtu.be/3Ob8cxZNGb8)
April 19, 2009
50 Story Center
International Plaza
Nanjing City China
Shanghai
November 15, 2010

Reported ignition source:
- welder’s torch

- 58 killed, 70 injured
- 28-story building destroyed
Additional Losses

- **Baku, Azerbaijan, May 19, 2015**
  - 15 people killed; 63 injured

- **Polat Tower, Istanbul, Turkey, July 17, 2012**
  - Fire started by faulty air conditioning unit

- **Al Tayer Tower, April 28, 2012**
  - ACPs Ignited by cigarette butt

- **Water Club Tower at the Borgata Casino hotel, Atlantic City, September 23, 2007**
  - ACPs with polyethylene core

- And many more.....

- Additional Countries not discussed previously.
  - Australia, New Zealand, Hungary, UK, Scotland, Germany, Canada, India, Spain, Qatar, ...
Information Gathering

For US losses, information was collected from the U.S. Fire Administration’s (USFA’s) National Fire Incident Reporting System (NFIRS) and the National Fire Protection Association’s (NFPA’s) annual survey of local/municipal fire departments.

In other portions of the world loss information is not as accessible.

March/April 2016 NFPA Journal quotes Donald Bliss; “Few nations collect detailed information about fire and some won’t reveal the data they do collect ... even the definition of a “fire death” can vary from country to country.”
Exterior wall fires are low frequency events, but the potential for loss can be very high.

The majority of fire incidents have occurred in countries with poor regulatory controls or where the construction is not in accordance with regulations.

Internal fires that spread to the exterior wall are the most common ignition scenario.

Re-entrant corners and channels that form “chimneys” led to more extensive flame propagation.
For all building types analyzed, exterior wall fires accounted for:

- 3% of all structure fires,
- 3% of civilian deaths and injuries, and
- 8% of property damage.
- 42% started on the exterior wall surface,
- 32% were where the item first ignited was exterior wall covering, and
- 26% were where the item contributing most to fire spread was an exterior wall.

- It should be noted that specific construction of the exterior wall cannot be ascertained from the NFIRS data and these statistics present a more general view of fires involving exterior walls. 98% of exterior wall fires occur in buildings less than 6 stories high.
Fire Dynamics
(The Physics)
Fire Sources

- Initiated within the building
  - Often post-flashover
  - May be pre-flashover with open window

- Exterior
  - Examples: Adjacent burning buildings, balconies, courts, walking paths, refuse enclosures, vehicles, ...
MECHANISMS OF FIRE SPREAD

- Flames eject from a window, breaking window above causing ignition on the floor above (leap-frogging), secondary interior fires and level to level fire spread.
- Heat causing degradation/separation of non-combustible protective skin resulting in flame spread to combustible elements internal to the wall system.
- Flame spread over the external surface of the wall.
- Secondary external fires to lower levels due to falling burning debris.
- Flame spread via vertical or horizontal cavities within the exterior wall assembly.
- Fire spread within cladding (through a combustible core).
- Failing fire stopping between the floor slab edge and exterior wall.
Various international façade fire tests were reviewed as part of this study. A summary of the full scale, intermediate scale, and small scale tests is provided here.

**Full Scale Façade Tests**
The research indicates that the exposure to the exterior wall system is generally more severe for an internal post-flashover fire that spreads via windows, etc. Most full scale façade fire tests simulate this scenario. Table 1 below summarizes the full scale façade tests from around the world.
<table>
<thead>
<tr>
<th>Test</th>
<th>Arrangement</th>
<th>Fire Source</th>
<th>Façade Dimensions</th>
<th>Std Fire Source</th>
<th>Test Duration</th>
<th>Failure Criteria</th>
</tr>
</thead>
</table>
| ISO 11925-2002 Part 2                    | Re-entrant corner “L” arrangement (wing wall) | Flames emerging from window | H: 4m above window lintel  
W: 3m  
Wing Width: 1.2m | 5.5 MW gas burner in enclosure | 23-27 minutes | None specified                      |
| BS 8414 Part 1 and Part 2 (British Standard) | Re-entrant corner “L” arrangement (wing wall) | Flames emerging from a window | H: 6m above window soffit  
W: 2.6 m  
Wing Width: 1.5 m | 3 MW timber crib in opening | 30 minutes | Exterior or interior fire spread 5 m above window within 15 minutes |
| DIN 4102-20 (Draft of German standard)    | Re-entrant corner “L” arrangement (wing wall) | Flames emerging from a window | H: 5.5 m  
W: 2 m  
Wing Width: 1.4 m | 320 kW gas burner in opening | 20 minutes  
(combustible facades); 30 minutes  
(noncombustible facades) | Exterior or interior fire spread 3.5 m above window |
| NFPA 285 (US standard)                    | Single wall surface                | Flames emerging from a window | Two story test frame;  
H: 5.3 m  
W: 4.1 m | 900 kW gas burner in bottom enclosure and 400 kW gas burner in window (ignited 5 min after room burner) | 30 minutes | Exterior fire spread > 3.05 m above window |
| SP FIRE 105 (Swedish standard)            | Single wall surface                | Flames emerging from a window | H: 6 m  
W: 4 m  
Includes a 500 mm eave at top | 2.5 MW Heptane fuel tray in enclosure | 15 minutes | Exterior fire spread > 3.2 m above window |
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<tbody>
<tr>
<td>CAN/ULC S134 (Canadian standard)</td>
<td>Single wall surface</td>
<td>Flames emerging from a window</td>
<td>H: 7.25 m above window</td>
<td>5.5 MW propane burner or timber crib in enclosure</td>
<td>25 minutes</td>
<td>Exterior fire spread &gt; 5 m above window</td>
</tr>
<tr>
<td>GB/T 29416 (Chinese standard)</td>
<td>Re-entrant corner “L” arrangement (wing wall)</td>
<td>Flames emerging from a window</td>
<td>H: 9 m W: 2.6 m Wing width: 1.5 m</td>
<td>Timber crib or gas burner in enclosure</td>
<td>Unknown</td>
<td>Unknown</td>
</tr>
<tr>
<td>ANSI FM 4880 25 ft corner test*</td>
<td>Re-entrant corner “L” arrangement (wing wall) for end use up to 30 ft</td>
<td>External fire source located at base of wall of a re-entrant wall corner; Can mount ceiling assemblies on test rig</td>
<td>H: 7.54 m Wall 1 W: 15.7 m Wall 2 W: 11.96 m</td>
<td>340 kg timber crib (oak pallets stacked to 1.5 m)</td>
<td>15 minutes</td>
<td>Fire spread to the limits of test structure</td>
</tr>
<tr>
<td>ANSI FM 4880 50 ft corner test*</td>
<td>Re-entrant corner “L” arrangement (wing wall) for end use over 30 ft</td>
<td>External fire source located at base of wall of a re-entrant wall corner; Can mount ceiling assemblies on test rig</td>
<td>H: 15.2 m W (both walls): 6.2 m</td>
<td>340 kg timber crib (oak pallets stacked to 1.5 m)</td>
<td>15 minutes</td>
<td>Walls up to 50 ft: fire spread to limits of test structure; Walls over 50 ft: fire spread to limits of test structure or to the intersection of top of wall and ceiling</td>
</tr>
</tbody>
</table>

* Note: ANSI FM 4880 test are not specifically external façade tests and are not referred to by building codes for regulation of external facades. The test is summarized in this table because it provides a possible method for assessing performance in response to external fire sources.

Table 1 – Summary of Full-Scale Façade Tests (White and Delichasios 2014)
Intermediate Scale Façade Tests
Examples of three intermediate scale façade tests are summarized in Table 2.

<table>
<thead>
<tr>
<th>Test</th>
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<th>Failure Criteria</th>
</tr>
</thead>
<tbody>
<tr>
<td>ISO 13785:2002 Part 1 (International Standards Organization)</td>
<td>Re-entrant corner “L” arrangement (wing wall)</td>
<td>External fire source located at base of main wall</td>
<td>H: 2.4 m</td>
<td>100 kW gas burner</td>
<td>None specified</td>
<td>None specified</td>
</tr>
<tr>
<td>Vertical Channel Test (Canadian standard)</td>
<td>Single wall surface installed at rear of a channel formed by noncombustible projections on each side of the specimen wall</td>
<td>Flames emerging from a window</td>
<td>H: 7.32 m W: 0.8 m</td>
<td>1.16 MW propane burner in enclosure</td>
<td>20 minutes</td>
<td>Fire spread &gt; 5 m above bottom of specimen</td>
</tr>
<tr>
<td>FM Parallel Panel Tests</td>
<td>Two parallel panels with burner at the bottom</td>
<td>External fire source located between panels</td>
<td>H: 4.9 m W: 1.1 m Separation of panels: 0.5 m</td>
<td>360 kW sand burner</td>
<td>None specified</td>
<td>HRR &gt; 1100 kW (Used to predict results for the 25 ft and 50 ft corner tests)</td>
</tr>
</tbody>
</table>

Table 2 – Summary of Intermediate-Scale Tests (White and Delichatsios 2014)
DISCUSSION

Reviewing the preceding table, it can be seen that:

- Dimensions and physical arrangement of facade tests vary. For example, some large-scale tests involve external corner walls 8 meters high (UK) or 5.7 m high (Germany and ISO) and 2.4 m and 1.3 m wide.

- There are significant differences in the ignition source used to simulate a fire in the room of origin. Wood cribs, liquid pool fires and gas burners are used to generate maximum heat fluxes on the façade in the range of 20 to 90 kW/m2.

- Test durations, measurements and acceptance criteria vary.
DISCUSSION

• The degree to which passive protection and fire spread through joints, voids and windows in a façade are tested varies.

• Large-scale facade tests do not measure key combustibility properties of façade elements for direct input into modelling, but do provide useful validation for fire spread modelling.

Which of these fire tests represent a reasonable exposure for real life situations?
"Bench-type" testing should initially be conducted to determine if adverse behavior of the specific material can be predicted under actual fire conditions.

Failure to achieve ignition in small-scale tests is not substantial proof of non-combustibility.

Many materials incapable of achieving self-supporting fire in bench test configurations prove to be very combustible when subjected to larger scale testing.
Front View

ISO 13785
Part 2

5.5 MW
Natural gas
Side View
ISO 13785
Part 2
5.5 MW
Natural gas
BS 8414 of 300mm EPS with inorganic coating
Simulates flames emerging from a window at the base of 5.5 m high wall.

The sample installed as a re-entrant corner arrangement.

The façade is representative of the end use.

The ignition source is a 320 kW constant HRR linear gas burner or a 25 kg wood crib.
US TEST - NFPA 285 Multi-Story Fire Test

- Can the wall covering/panel resist:
  - Flame propagation over face of the wall covering
  - Vertical flame propagation within the combustible core or components
  - Flame propagation over interior surface from one floor to the next
  - Lateral Flame propagation to adjacent compartments

- Does not address floor-line joint per se.
Multi-Story Fire Test Code Development

- Code change incorporated into Plastics Section of 1988 UBC
- Full-scale test adopted as UBC 17-6
Originated as:
Full scale – 2 story test
UBC 17-6 / UBC 26-4
Multi-Story Fire Test
2nd Generation – Code Adoption

- Test submitted to NFPA Committee on Fire Tests and was adopted as NFPA 285 in 1998.
- IBC specifies NFPA 285
NFPA 285 – Test Apparatus

1st: burn room burner is ignited
2nd: after 5 min, window burner is ignited
3rd: after 30 minutes, both burners are shut off.
4th: residual burning is monitored until complete

Thermocouples here cannot reach 1,000 deg F

Test Wall

Window burner

Burn room burner

18’

10’

7’ 6” min.
NFPA 285 test in progress
NFPA 285
Post-test Damage of assembly
FM Global 50 ft. Corner Test
11/09/99
US Requirements

2012 International Building Code

- Chapter 14: Exterior Walls
- Chapter 26: Plastics
SECTION 1403
PERFORMANCE REQUIREMENTS

1403.5 Vertical and lateral flame propagation.

- Exterior walls on buildings of Type I, II, III or IV construction that are greater than 40 feet (12 192 mm) in height above grade plane and contain a combustible water-resistive barrier shall be tested in accordance with and comply with the acceptance criteria of NFPA 285.
SECTION 1406
COMBUSTIBLE MATERIALS ON THE EXTERIOR SIDE OF EXTERIOR WALLS

- 1406.2.1.1 Ignition resistance.
  - Tested in accordance with NFPA 268.

- 1406.2.3 Where the combustible exterior wall covering is furred out from the exterior wall the concealed space shall be fireblocked.
SECTION 1407
METAL COMPOSITE MATERIALS (MCM)

- **1407.1.1** The plastic core of the MCM shall not contain foam plastic insulation.
- **1407.10.1** Shall have a *flame spread index* not more than 25 and a smoke-developed index not more than 450 when tested as an assembly in the maximum thickness intended for use.
- **1407.10.4** Tested in accordance with NFPA 285 in the maximum thickness intended for use.
What are MCM?

- A MCM is a bonded laminated material usually consisting of three layers (sometimes these layers are referred to as “laminates”).
- Laminate: “a material made by bonding together, usually under pressure, two or more layers.”
- Light weight
- Excellent façade skin properties
- Easy to install
- Attractive
What are MCM?

Consists of layers (laminates) which are either

- **Non-combustible**
  - aluminum

- **Deemed non-combustible**
  - PVDF paint and other coatings

- **Combustible**
  - Polyethylene
ALCOPLA’s Composite Panels

- Primer + Top Coat or Other Finish
- Metal Skin (0.1 - 1.5 mm) Pre-Treated with Chromate
- Adhesive Film
- Polyethylene
- Adhesive Film
- Metal Skin (0.1 - 1.5 mm) Pre-Treated with Chromate
- Wash Coat or Other Finish
Prior to the 2009 IBC, EIFS was not compliant.

- Industry worked with ES to develop Acceptance Criteria for EIFS
- Industry used Evaluation Reports for code acceptance
- Each EIFS manufacturer has one or more ES Report(s)
- Reports describe the EIFS, its components, uses, application and Code acceptance.

The 2009 IBC added a new Section in Chapter 14 to specifically address EIFS.
SECTION 1408 (EIFS)

- 1408 Primarily addresses weathering.
- 1408.6 Installation shall comply with the 1704.2 and 1705.15
- For Fire Safety Aspects, see 2603.5
To be considered EIFS, the assembly must have all these components in the specified thickness.
External Thermal Insulation Composite System. ETICS

1. Adhesive
2. Thermal insulation material
3. Anchors
4. Base coat
5. Reinforcement, usually glass fiber mesh
6. Finishing layer: finishing coat with a key coat (optional) and/or a decorative coat (optional)
7. Accessories, e.g. fabricated corner beads, connection and edge profiles, expansion joint profiles, base profiles, etc.
1409.10.1 Shall have a flame spread index of not more than 25 and a smoke-developed index of not more than 450 when tested in the minimum and maximum thicknesses intended for use.

1409.10.4 Shall be tested in accordance with NFPA 285 in the minimum and maximum thicknesses intended for use.
High-pressure laminates

Manufactured at high temperature and pressure (typically >1000 psi), which is necessary for the thermosetting poly-condensation process of the resin used.
Although Chapter 26 governs the use of plastics for various aspects of building construction, the following overview is intended as guidance for use on exterior facades.

**Sections to discuss**

- 2603 Foam Plastics
- 2612 Fiber-Reinforced Polymers
Foam Plastic Insulation

**Shortened Definition**

- Expanded for insulating or acoustical purposes
- Density less than 20 pounds per cubic foot
2603 Foam Plastics

- §2603.1 Foam Plastic in buildings and structures
- §2603.2 – Listed and labeled at the job site
- §2603.3 – Surface-burning characteristics
  - Class B
- §2603.4 – Thermal barrier
  - required to separate foam from interior
- §2603.5 – Exterior Walls of any Height
  - For Type I, II, III or IV Construction
Thermal Barrier

- Required to separate foam from interior of building
- ½ inch gypsum wallboard or equivalent
- Temp rise on unexposed surface limited to 250 °F after 15 minutes
- Thermal barrier retards heat transmission to the foam and delays ignition.
- Exposed foam on interior of buildings essentially not allowed
- EIFS not allowed inside buildings
- §2603.9 Special tests allow exposed foam
§2603.5 - Requirements For Type I, II, III or IV

- §2603.5 applies to buildings of any height
- §2603.5.1 - Maintain fire resistance rating
  - (ASTM E119)
- §2603.5.2 - Foam separated from interior of building by a Thermal Barrier
- §2603.5.3 - Limits thickness of foam (btu/ft²)
  - NFPA 259
- §2603.5.4 – 25/450 Flame-Spread/Smoke-Developed indices for each combustible component (ASTM E84)
- §2603.5.5 - Meet requirements of NFPA 285
  - (Multi-story fire test)
- §2603.5.6 – Label required
- §2603.5.7 - No ignition when tested via NFPA 268
  - (Radiant heat exposure test)
§2603.5.3 - NFPA 259
Potential Heat Test

- Potential heat (calculated based on area) of the foam plastic is not allowed to exceed that tested via NFPA 285 (multi-story test).

- Uses NFPA 259 – Measures amount of heat released when burned in pure O$_2$
  - Bomb calorimeter test

- Data from test expressed in Btu/lb (mJ/kg).
  - EPS has ~ 18,000 Btu/lb (~41.8 mJ/kg)

- Convert this to Btu/ft$^2$ (mJ/m$^2$) using thickness and density of foam plastic.

- Allows calculation for different densities/thickness combinations.
§2603.5.7 NFPA 268
Radiant Heat Exposure Test

- Addresses ignition potential of exterior wall coverings exposed to a radiant heat source.
- Commonly accepted threshold for piloted ignition of wood is 12.5 kW/m².
- Exterior walls should be designed to limit the radiant heat transfer to adjacent structures to 12.5 kW/m².
- Thus, exterior walls should not ignite at radiant heat exposures $\leq 12.5$ kW/m².
§1705.15 Special Inspections for EIFS

- Required for all EIFS applications.
  - Exceptions:
    1. Not required for EIFS installed over a water-resistive barrier with a means of draining moisture to the exterior.
    2. Not required for EIFS installed over masonry or concrete walls.

- 1705.15.1 The water-resistive barrier complying with ASTM E 2570 requires special inspection when installed over a sheathing substrate.
1705.16 Fire-resistant penetrations and joints.

- Through-penetrations, membrane penetration firestops, fire-resistant joint systems and perimeter fire barrier systems in
- high-rise buildings or
- buildings assigned to Risk Category III or IV.

- 1705.16.1 Penetration firestops.
  - Shall be conducted by an approved agency in accordance with ASTM E 2174.

- 1705.16.2 Fire-resistant joint systems.
  - Shall be conducted by an approved agency in accordance with ASTM E 2393.
2612 Fiber-Reinforced Polymers

- §2612.1 – Fiber-reinforced polymers in and on buildings.
- §2612.2 – Listed and labeled at the job site
- §2612.5 permitted on *exterior walls* of any type of construction when meeting 2603.5. Fireblocking required in accordance with 718.
  - Compliance with 2603.5 not required if quantity, and/or height of fiber-reinforced polymer limited.
Presentation Focused On

- Fire protection aspects of High-Rise Building Exterior Facades
- Why these requirements exist
  - fire losses
- Related fire dynamics
- Associated fire tests
- Applicable US (IBC) requirements
- The level of protection intended by those requirements
ACKNOWLEDGEMENTS

- The National Fire Protection Association (NFPA) Research Foundation
  - Fire Hazards of Exterior Wall Assemblies Containing Combustible Components (154 PAGES)

- Dr. Jonathan Barnett
  - Technical Director
  - RED Fire Engineers