Washington Group International

Integrated Engineering, Construction, and Management Solutions

# Quantitative Evaluation of Fire Separations and Barriers

Energy Facility Contractors Group (EFCOG), Safety Analysis Working Group (SAWG) 2007 Annual Workshop, May 19 – 24, 2007
Shilo Inn Suites Hotel, Idaho Falls, ID

Connie Blanton and Allan Coutts, FSFPE
803.502.9652, connie.blanton@wsms.com

# Overview

- **Fire Barriers**
  - **Typical Design Criteria**
    Prescriptive life safety and monetary protection requirements
  - **Limitation**
    Inadequate prediction of barrier performance to support full range safety analysis
  - **Alternative Approach**
    Quantitative comparison of barrier capacity to expected fire demand

- **Physical Separations (Standoffs)**
  - **NFPA 80 A**
    Recommended Practice for Protection of Buildings from Exterior Fire Exposures
  - **NFPA 555**
    Guide on Methods for Evaluating Potential for Room Flashover
  - **Comparison of Results**
    Identification of conditions required to produce consistent predictions

# 1928 Technology for 2006 Applications

- Tested combustible mix
  - Wood desks
  - Paper
- Today's mix
  - Plastic
  - Upholstered chairs
- Ventilation was throttled to optimize temperatures
- Discussion
  - Fire duration dominates fire severity
  - Room temperature is a second-order effect
  - Dominate barrier failure mode is by convention
  - Fire tests don't evaluate convection

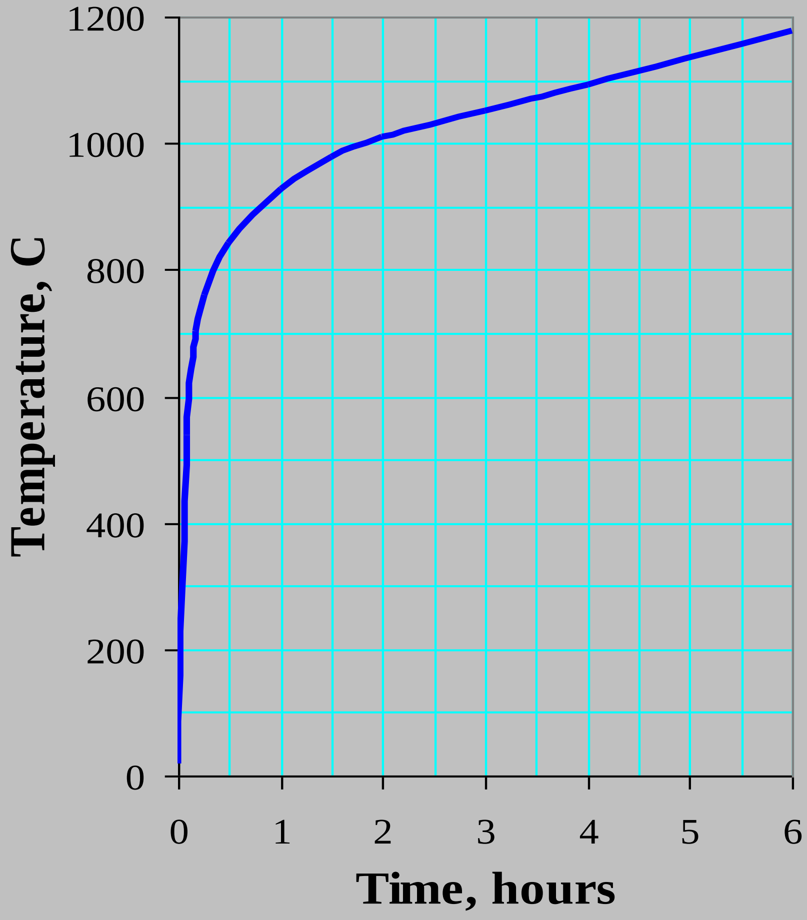
Ingberg Results

| load psf | energy Btu/ft$^2$ | time $hrs_s$ |
|---|---|---|
| 10 | 80,000 | 1 |
| 15 | 120,000 | 1.5 |
| 20 | 160,000 | 2 |
| 30 | 240,000 | 3 |
| 40 | 320,000 | 4.5 |
| 50 | 380,000 | 6 |
| 60 | 432,000 | 7.5 |

# ASTM E 119 - "The Fire Curve"

## Fire Tests of Building Construction & Materials

- **Defines furnace temperature during test**
- **Bounds the observed temperatures in Ingberg's tests**
- **Maximum temperatures**
  - **1200°C at 6½ hours**
  - **1260°C at 8 hours**






Washington Group International

# Barrier Performance Prediction

**Demand**

$$H_d = \frac{1}{\sqrt{k\,\rho\,\rho}} \int_0^{\tau} q\,dt$$

Quantify based on integration of CFAST heat flux prediction

**Capacity**

$H_c = 104[(76.92t_s+29.41)0.5-6.15]$

Calculate based on wall rating

**Failure Probability**

$$\beta = \frac{1}{\sqrt{\Omega_1^{\,2} + \Omega_2^{\,2} + \Omega_3^{\,2}}} \ln\left(\frac{H_c}{H_d}\right)$$

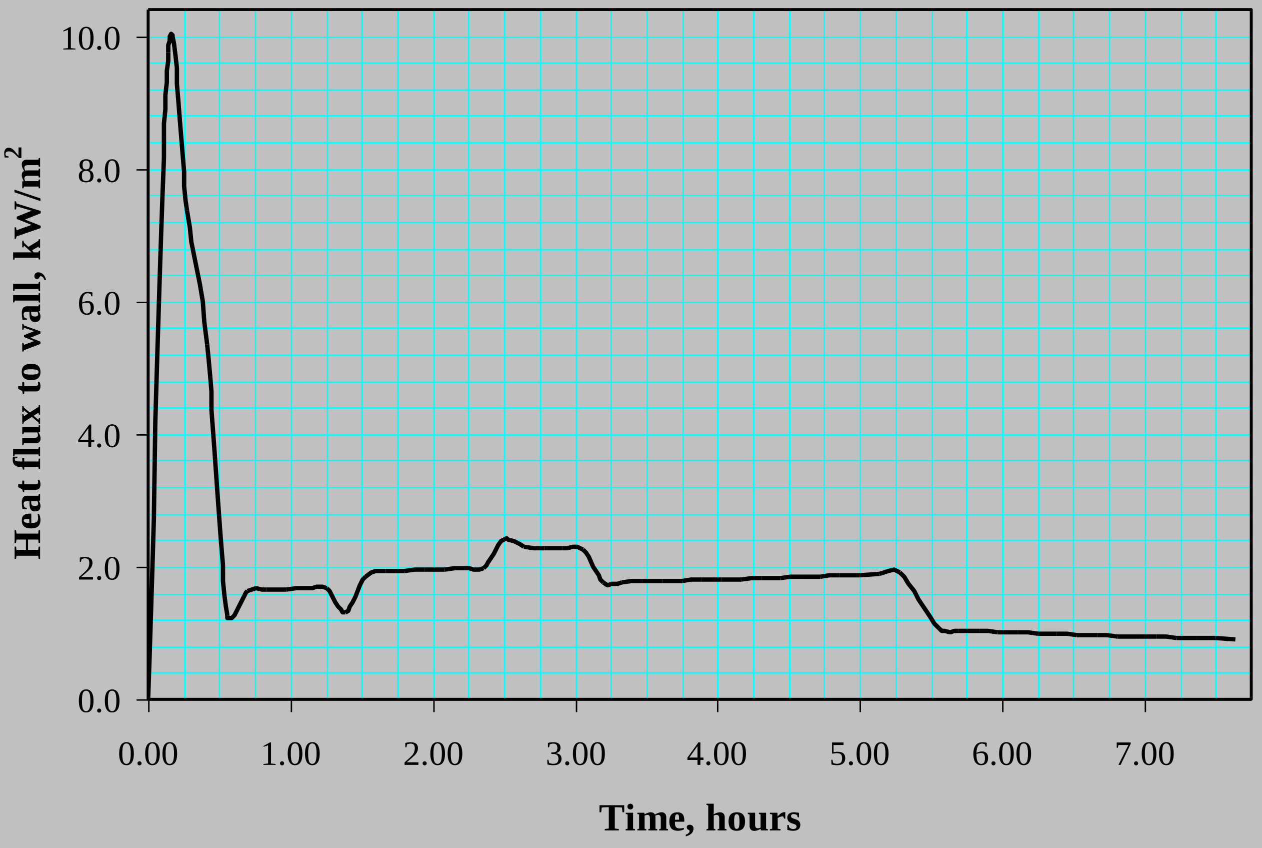
$\Omega_1$ = coefficient of variation for $H_d$

$\Omega_2$ = coefficient of variation for $H_c$

$\Omega_3$ = coefficient of variation for error

$P_f$ = 1 - NormalStandard Distribution ($\beta$)

# Barrier Example Problem (Nuclear Material Storage Facility)




- Compartment size
  - 30,000 ft$^2$
  - 12.5 ft height
- Wall construction
  - Concrete outer
  - Gypsum interior
- Combustible Load
  - 16,000 lb$_{WE}$

# Barrier Example Results (Nuclear Material Storage Facility)

| Time | | Fire flux $W/m^2$ | $H_d$ $s^{1/2}\cdot K$ | 2 hour barrier | | 3 hour barrier | | 4 hour barrier | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | $H_c$ = 73,870 | | $H_c$ = 99,798 | | $H_c$ = 122,100 | |
| sec | hrs | | | β | $P_{fail}$ | β | $P_{fail}$ | β | $P_{fail}$ |
| 0 | 0.00 | 0.0 | 5,180 | 19.64 | 0.00 | 21.87 | 0.00 | 23.36 | 0.00 |
| 1000 | 0.28 | 7.4 | 19,784 | 9.74 | 0.00 | 11.96 | 0.00 | 13.45 | 0.00 |
| 3000 | 0.83 | 1.7 | 29,693 | 6.74 | 0.00 | 8.96 | 0.00 | 10.45 | 0.00 |
| 5000 | 1.39 | 1.3 | 36,624 | 5.19 | 0.00 | 7.41 | 0.00 | 8.90 | 0.00 |
| **7000** | **1.94** | **1.9** | **45,301** | **3.61** | **0.00** | **5.84** | **0.00** | **7.33** | **0.00** |
| 11000 | 3.06 | 2.3 | 64,930 | 0.95 | 0.17 | 3.18 | 0.00 | 4.67 | 0.00 |
| 13000 | 3.61 | 1.8 | 72,879 | 0.10 | 0.46 | 2.32 | 0.01 | 3.81 | 0.00 |
| **14000** | **3.89** | **1.8** | **76,904** | **-0.30** | **0.62** | **1.93** | **0.03** | **3.42** | **0.00** |
| 15000 | 4.17 | 1.8 | 80,971 | -0.68 | 0.75 | 1.55 | 0.06 | 3.04 | 0.00 |
| 17000 | 4.72 | 1.9 | 89,248 | -1.40 | 0.92 | 0.83 | 0.20 | 2.32 | 0.01 |
| 19000 | 5.28 | 1.9 | 96,773 | -2.00 | 0.98 | 0.23 | 0.41 | 1.72 | 0.04 |
| **21000** | **5.83** | **1.0** | **101,377** | **-2.34** | **0.99** | **-0.12** | **0.55** | **1.37** | **0.08** |
| 23000 | 6.39 | 1.0 | 105,745 | -2.65 | 1.00 | -0.43 | 0.67 | 1.06 | 0.14 |
| 25000 | 6.94 | 0.9 | 109,948 | -2.94 | 1.00 | -0.72 | 0.76 | 0.77 | 0.22 |
| **27000** | **7.50** | **0.9** | **113,024** | **-3.14** | **1.00** | **-0.92** | **0.82** | **0.57** | **0.28** |

# Cautions – Propagation Mechanisms

- Destruction
- Conduction
- Radiation
- Convection
- Branding
- Jetting
- Projection

# Standoff Evaluation

NFPA provides two primary methods:

## NFPA 80A
## Fire Exposures

(exterior building-building propagation)

$$S = Z*G + N$$

Z = lesser of width or height

N = opening factor (5 ft)

G = guide number

- fire severity
- wall opening %
- exposure configuration

## NFPA 555
## Room Flashover

(interior package-package propagation)

$$q'' = F \times E$$

E = emissive power

F = view factor

- exposure dimensions
- fire height
- standoff distance

# Standoff Example – NFPA 555

- **Problem Specification**
  - Fuel Package: Industrial trailer
  - HRR: 10-50 MW
  - Heat flux ignition threshold: 12.5 $kW/m^2$

| NFPA 555 | | | |
|---|---|---|---|
| HRR (MW) | Fire Height (m) | Standoff w/o SF (m) | Standoff w/ SF (m) |
| 10 | 2.7 | 4.9 | 9.7 |
| 20 | 5.7 | 8.3 | 16.6 |
| 40 | 9.7 | 11.4 | 22.8 |

# Standoff Example – NFPA 80A Calculation

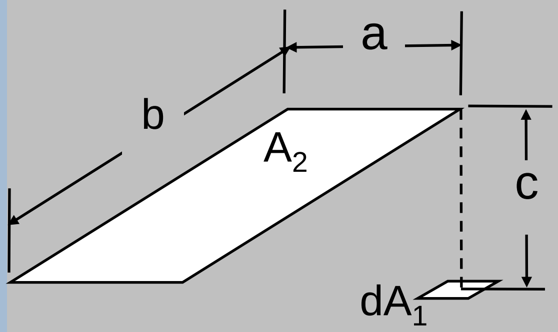
NFPA 80A

| Classification | Floor Area Loading (lb/ft$^2$) | Interior Surface Flame Spread Rating |
|---|---|---|
| Light | 0 – 7 | 0 - 2 |
| Moderate | 8 – 15 | 26 - 75 |
| Severe | ≥ 16 | ≥ 76 |

Example Results

| Classification | Z (ft) | G | Standoff (m) |
|---|---|---|---|
| Light | 12.8 | 2.44 | 36.3 |
| Moderate | 12.8 | 3.74 | 52.8 |
| Severe | 12.8 | 5.48 | 75.1 |

# Standoff Example – NFPA 555 Calculation




$$F = \frac{1}{2\pi}\left[\frac{X}{\sqrt{1+X^2}}\tan^{-1}\left(\frac{Y}{\sqrt{1+X^2}}\right)+\frac{Y}{\sqrt{1+Y^2}}\tan^{-1}\left(\frac{X}{\sqrt{1+Y^2}}\right)\right]$$

$$X = a/c, \quad Y = b/c$$

| HRR (MW) | Fire Height (m) | Best Estimate Standoff (m) | Standoff with Safety Factor of 2 (m) |
|---|---|---|---|
| 10 | 8.9 | 16.1 | 31.8 |
| 20 | 18.7 | 27.2 | 54.5 |
| 40 | 31.8 | 37.4 | 74.8 |

# Standoff Example – Result Comparison

| Severity | NFPA 80A Standoff (ft) | HRR (MW) | NFPA 555 Standoff (ft) |
|---|---|---|---|
| Light | 36.4 | 10 | 31.8 |
| Moderate | 52.8 | 20 | 54.5 |
| Severe | 75.1 | 40 | 74.8 |

# Summary – Fire Barriers

- Demonstrated a quantitative method to evaluate fire barrier response to specific fire demands
- Conclusions
  - Ventilation limited fires may produce a greater demand on a fire barrier than a well-ventilated fire
  - Manual intervention during severely ventilation limited fires may be very important



Washington Group International

# Summary – Physical Separation

- Compared two fire standoff models that produce similar results
- Conclusions
  - When using NFPA 555 provide a safety factor of 2
  - Use NFPA 80A to evaluate building to building propagation
  - Use NFPA 555 for interior package to package propagation