Evaluation of Performance Based Design

Code Official's Role

Presented by: Dave Gramlich & Steven Dannaway
Provided for: Washington State Association of Fire Marshals (WSAFM)

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Introductions

Presenters

Dave Gramlich, PE

Engineer, Fire Protection – Seattle

- Over 7 years experience in Fire Protection Consulting
- B.S. in Mechanical Engineering from the University of Texas in Austin
- M.S. in Fire Protection Engineering from California Polytechnic State University
- Currently a member of the Society of Fire Protection Engineers, the National Fire Protection Association and Design/Build Institute of America.

Steven Dannaway, PE

Engineer, Fire Protection – Los Angeles

- Over 7 years experience in Fire Protection Consulting
- B.A. in Physics from Claremont McKenna College
- M.S. in Mechanical Engineering from UCLA.
- Currently a member of the Society of Fire Protection Engineers, Asian American Architects and Engineers Association, and Design/Build Institute of America.

Agenda

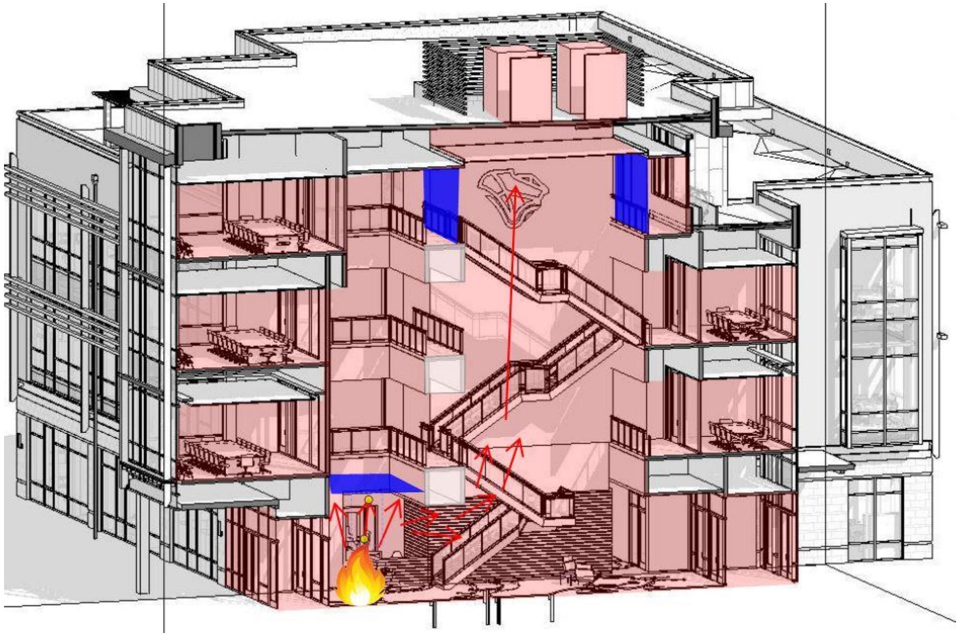
- Part 1: What is Performance-Based Design?
  - Prescriptive vs. Performance-Based Design
  - What is Performance-Based Design?
  - Role of Code Official in PBD
- Part 2: How can PBD be accomplished?
  - Defining Objectives and Requirements
  - Design Fire Scenarios
  - Methods, Models and Strategies
  - Documentation
  - Construction & Managing Building Changes
- Part 3: Case Studies

Part 1: What is Performance Based Design?

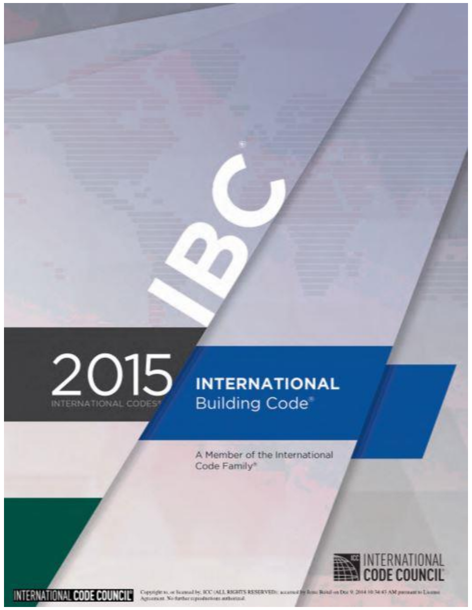
- Performance vs. Prescriptive?

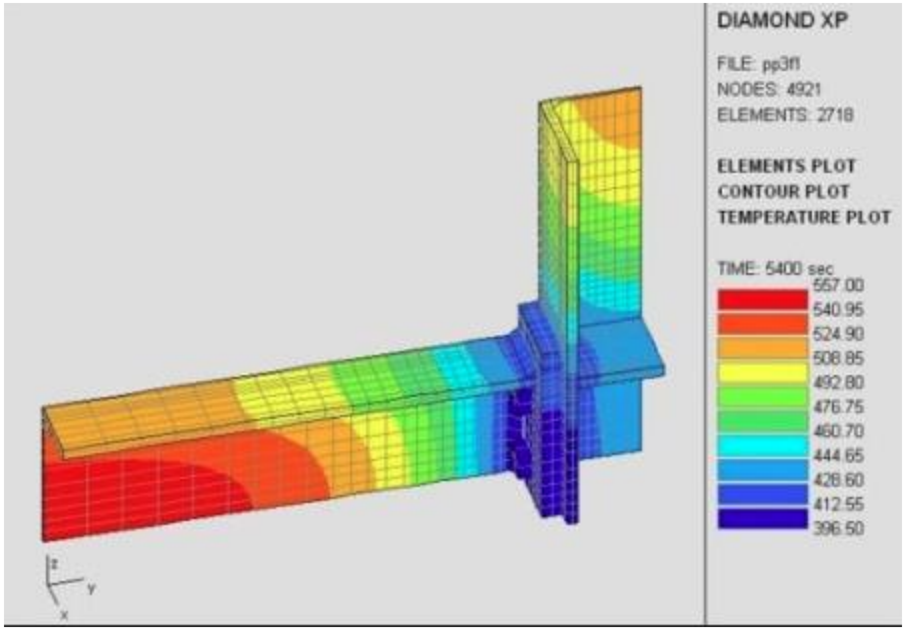
- What is performance-based design (PBD)?

- Code official's role?



Prescriptive vs. Performance-Based Design

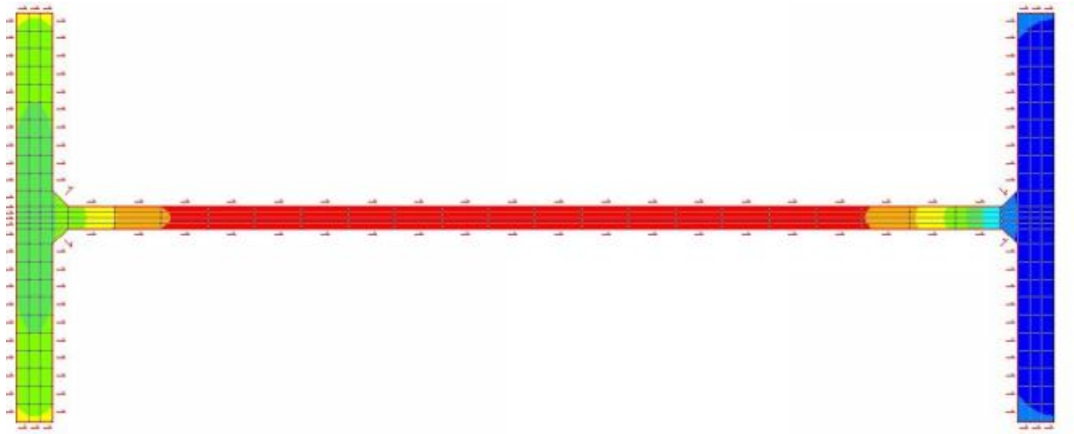


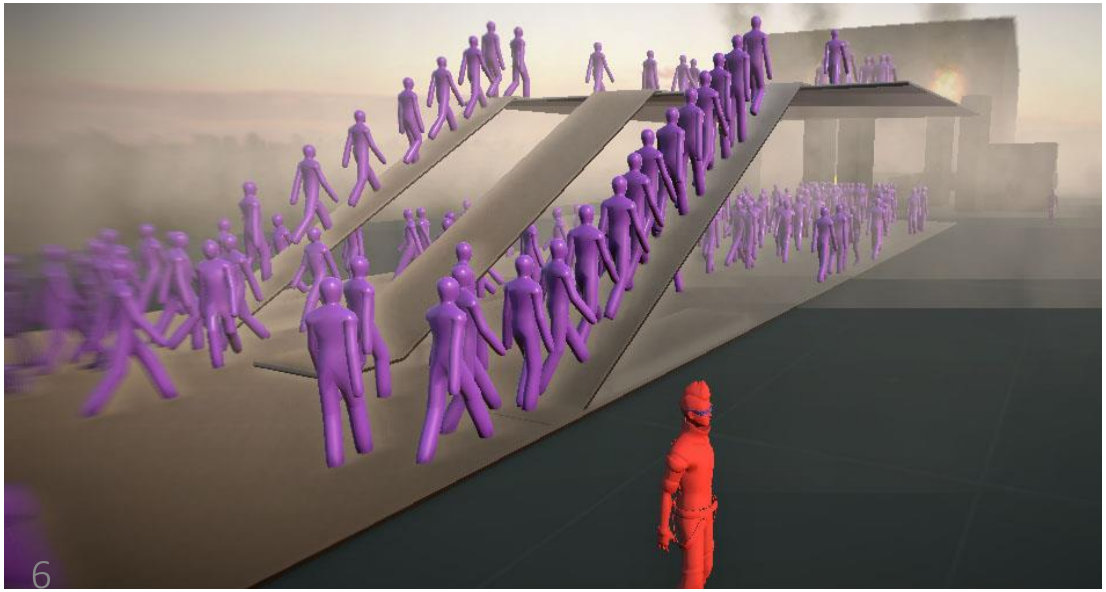


- Requirements developed from previous accidents or manufacturers
- Safety levels not quantifiable
- Stifle innovation

- Integrates science & engineering into design process
- Safety levels quantifiable

Performance-Based Design Applications





- Evacuation/Tenability
- Structural Fire Protection
- Fire Protection Systems
- Product/material assessment
- Smoke control systems

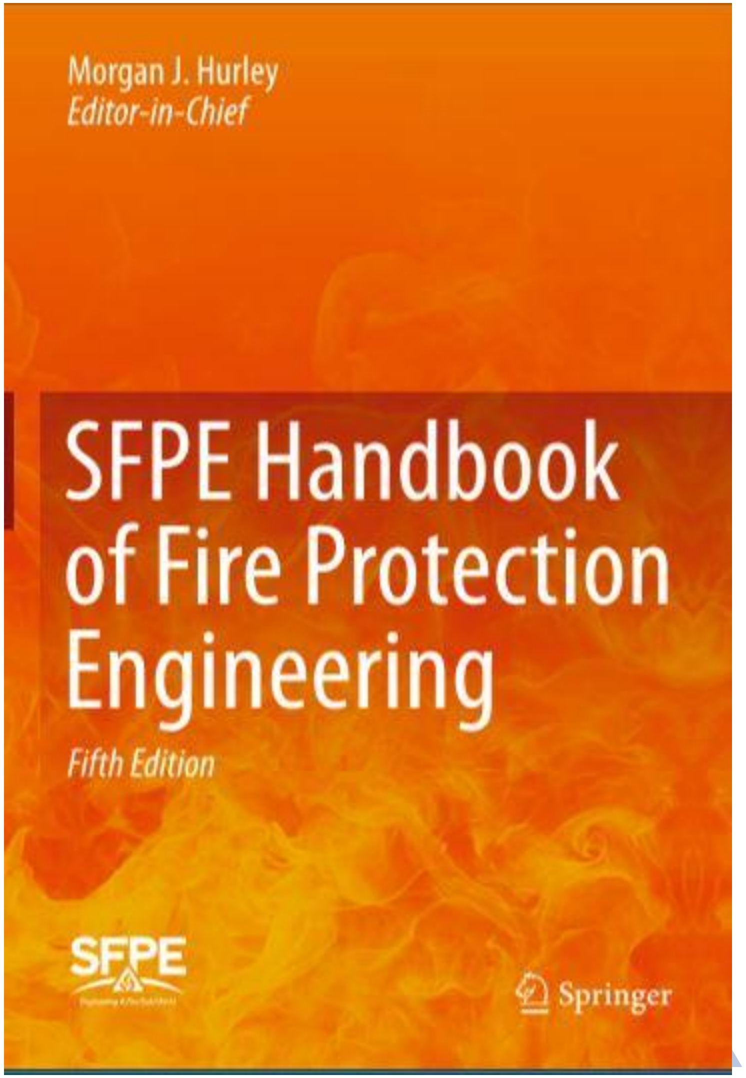
What is Performance-Based Design?

An engineering approach to fire protection based on:

(1) Agreed upon fire safety goals & objectives

(2) Deterministic and/or probabilistic analysis of fire scenarios

(3) Quantitative assessment of design alternatives against the fire safety goals and objectives using accepted engineering tools, methodologies, and performance criteria



What is Performance-Based Design?

- Most prescriptive-based codes contain an “alternative methods and materials” or “equivalency” clause that permits the use of alternative means to meet the intent of the prescribed code provisions. This provides an opportunity for a performance-based design approach.
- Two Methods:
  - Determine equivalency to prescriptive codes or standards
  - Achieve broadly defined fire safety goals & objectives
- Complexity and Scope will vary. Does not automatically mean extremely broad & complex design.

Why Might Designers or Code Officials Recommend PBD?

- To address unique building, occupant and fire related characteristics. Performance-based design helps quantify performance in these scenarios.
- Alternative fire protection options
- Allows level of safety to be measured and compared
- Increased engineering rigor
- Increased cohesion between fire protection systems
- Better understanding of loss or damage

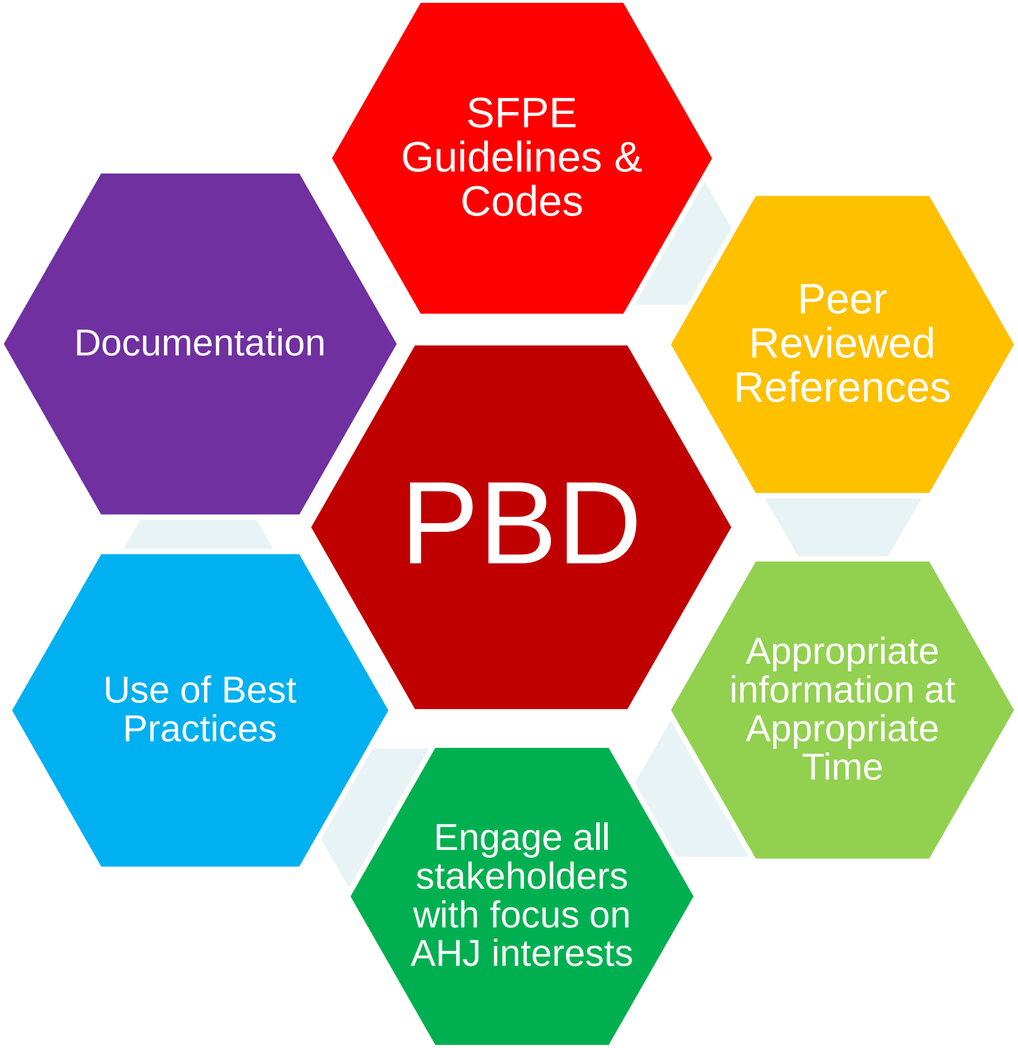
Limitations of PBD

- Required greater engineering skill on the part of designer and enforcement team than prescriptive-based design
- Requires greater engineering effort
- Change in occupancy or combustible loading may require reanalysis and/or modifications to protection
- Bounded by limits of engineering science used to develop design (e.g. modeling & testing).
- Liability on the part of the design professional and code officials using performance-based design.
  - Designer is responsible for documenting the basis of design
  - Code official responsible for requiring and understanding documentation. <u>If Unsure, Request Peer Reviewer!</u>

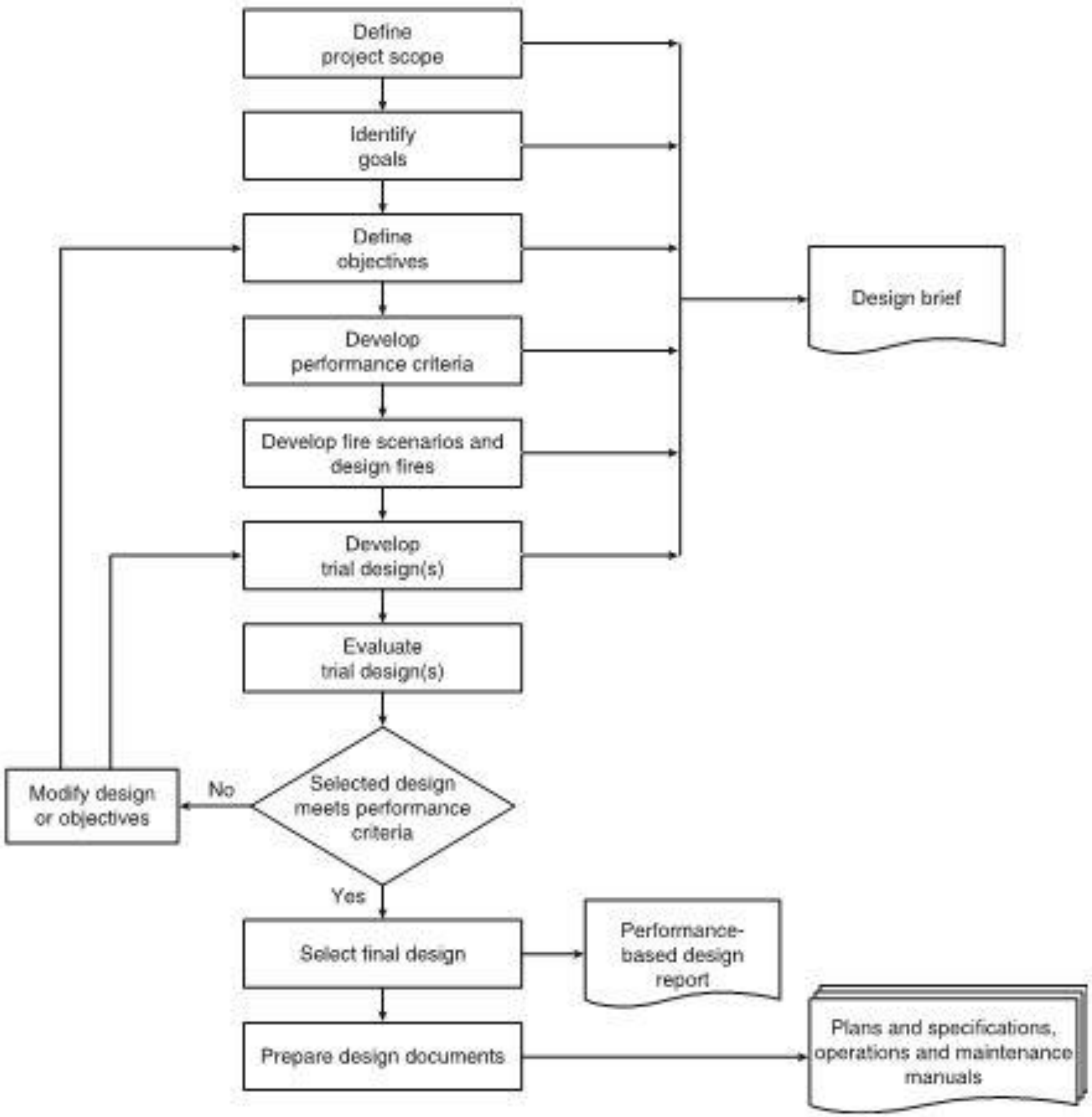
Who are the Stakeholders?

- Responsible for developing fire safety goals & objectives
- Stakeholders
  - Owners
  - Building Management & Operations
  - Design Team
  - Authorities Having Jurisdiction (AHJ, Building Official or Fire Marshal)
  - Contractor
  - Tenants
  - Emergency Responders
  - Peer Reviewer
- Different goals, objectives, and levels of influence.

Principles Behind Performance-Based Design Process



SFPE Performance Based Design Process



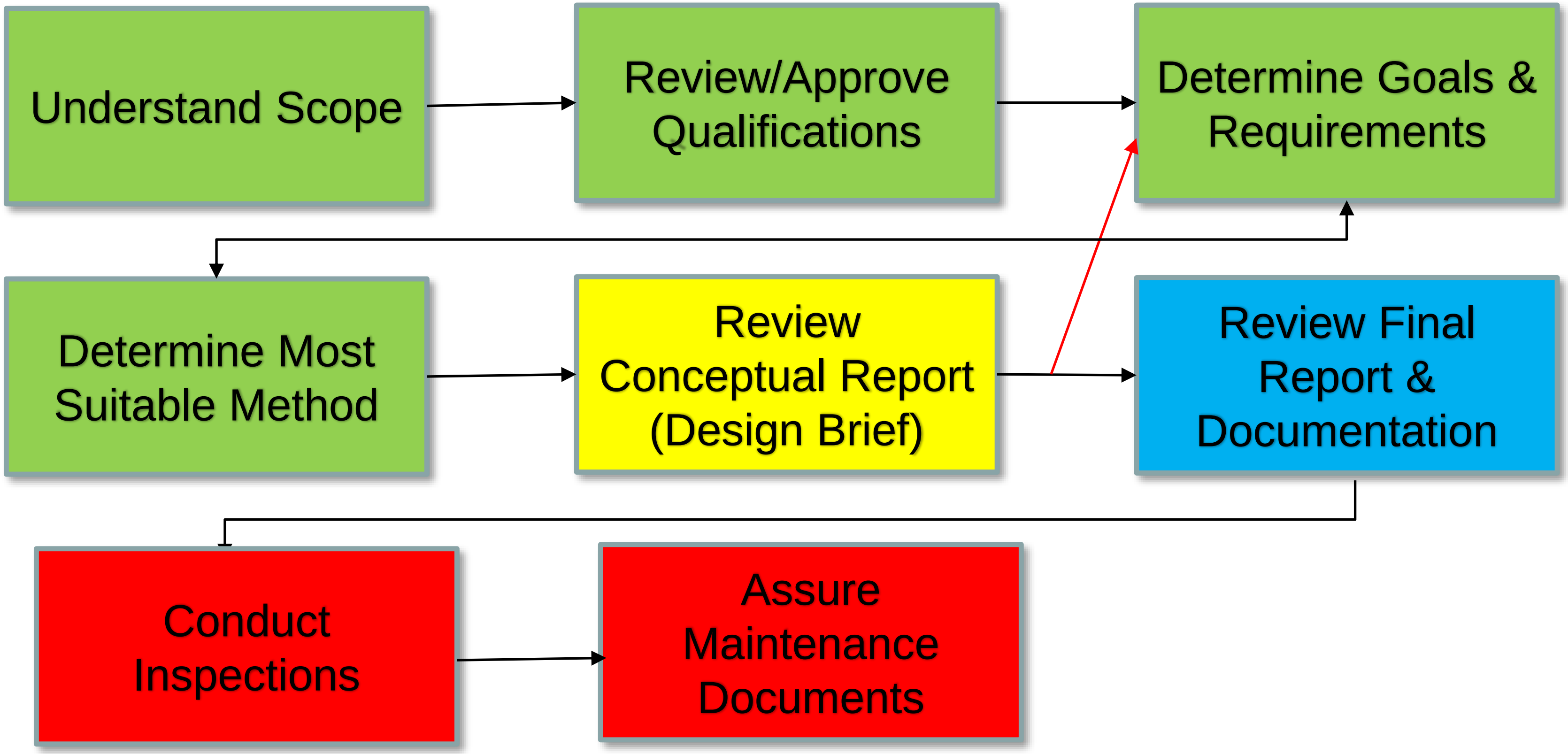
Source: SFPE Handbook 5th Edition

Role of Code Official in Both Design Approaches	
Prescriptive Design	Performance Design (Typically Performance Requirement Analysis)
	Review Designer Qualifications
	Attend Stakeholder's Meeting
Preliminary Meetings	**Review, Comment on Design Brief**
Plan Review	**Final Report &** Plan Review (Possible Peer Review)
Permit	Permit
Inspections	Inspections
Testing	Testing
Certificate of Occupancy (CofO)	CofO & **Establish Terms & Conditions of Occupancy**
Periodic Inspection	Periodic Inspection **(Boundary Conditions & Critical Systems)**

Source: Enforcer's Guide to Performance Based Design

Part 2: Performance-Based Design Steps

Steps for Performance Based Design



Establishing Goals & Expectations

- Source of goals are code requirements and consultation with stake holders
- 4 Fundamental Goals:
  - Life Safety
  - Property Protection
  - Mission Continuity (e.g. hospital)
  - Environmental Protection
- Primary Fire Safety Goals:
  - Safeguard occupants from injury due to fire until they reach a safe place
  - Safeguard fire fighters while performing rescue operations or attacking fire

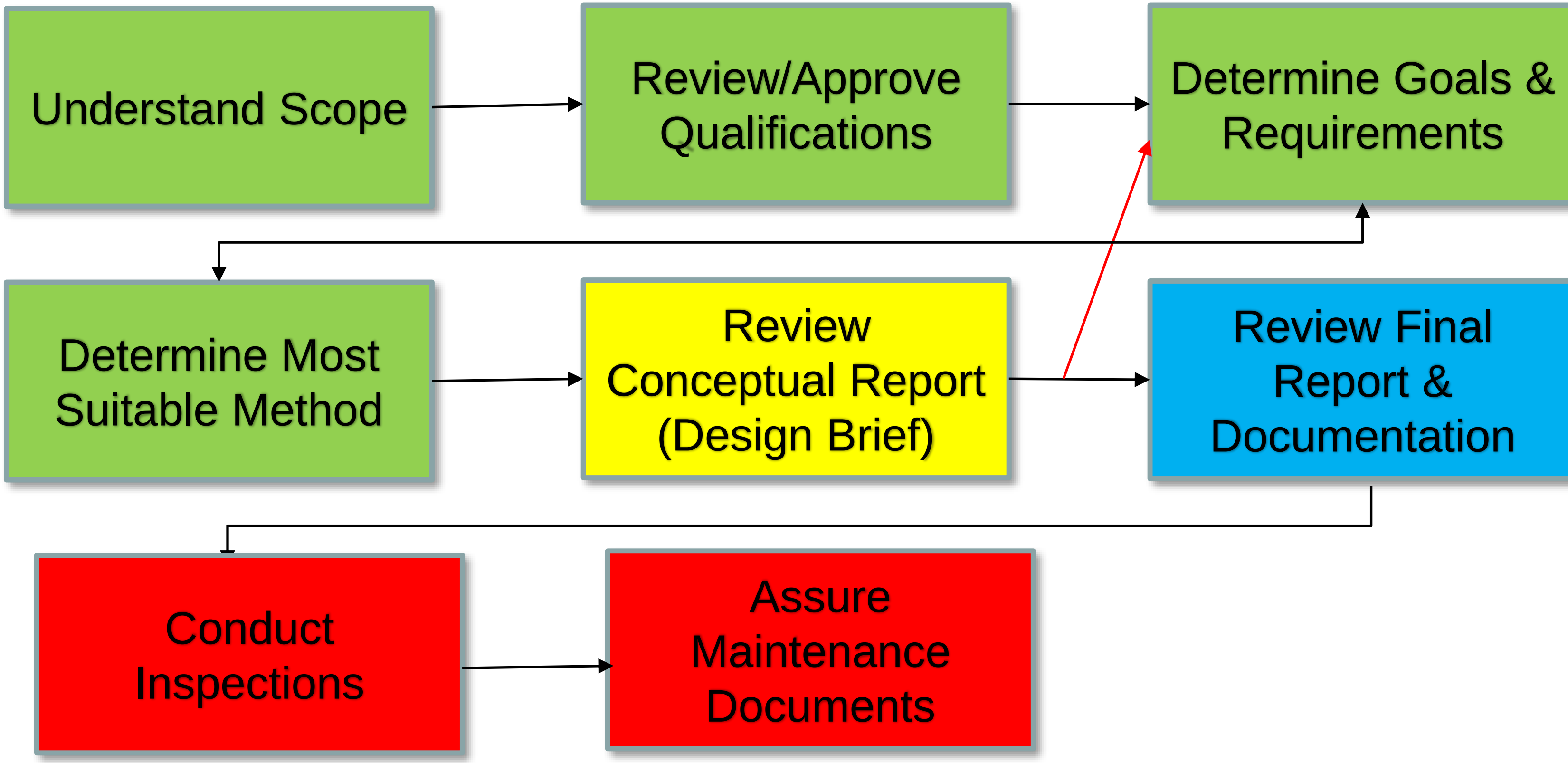
Establishing Goals & Expectations

- Specific Performance Requirements:
  - Temperature
  - CO Levels
  - Visibility
- Compliance with intent of Prescriptive Requirements
  - Adopted code language
  - Utilize available appendices & code commentary
  - Review available documents and comments from code committee meetings at the time the requirement was instituted

Fire Protection Goals → Performance Criteria

Fire Protection Goal	Stakeholder Objective	Design Objective	Performance Criteria
Allow occupants to egress safely	No Loss of Life Outside of the Room of Fire Origin	Maintain tenable conditions in remainder of compartment below 6 ft. for specified time of egress	• 33 ft. of visibility • Maximum 140F temperature • CO toxicity limited to 1000ppm

Steps for Performance Based Design



Deterministic vs. Probabilistic Methods

- Deterministic Approach: Addresses a single set of input data independent of likelihood of occurrence. Usually based upon worst case or compilation of various single scenarios. Most common approach for commercial buildings.

- Risk or Probabilistic Approach: Also available however much more time consuming and finding probabilities associated with fire scenarios and equipment failure does not exist in many cases. Some risk is utilized in establishing fire design scenarios. More common in insurance, oil and gas, etc.

Determining Appropriate Level of Detail

- Level of Analysis (Comparative vs. Performance Requirement Analysis):
  - Subsystem
  - System
  - Whole Building

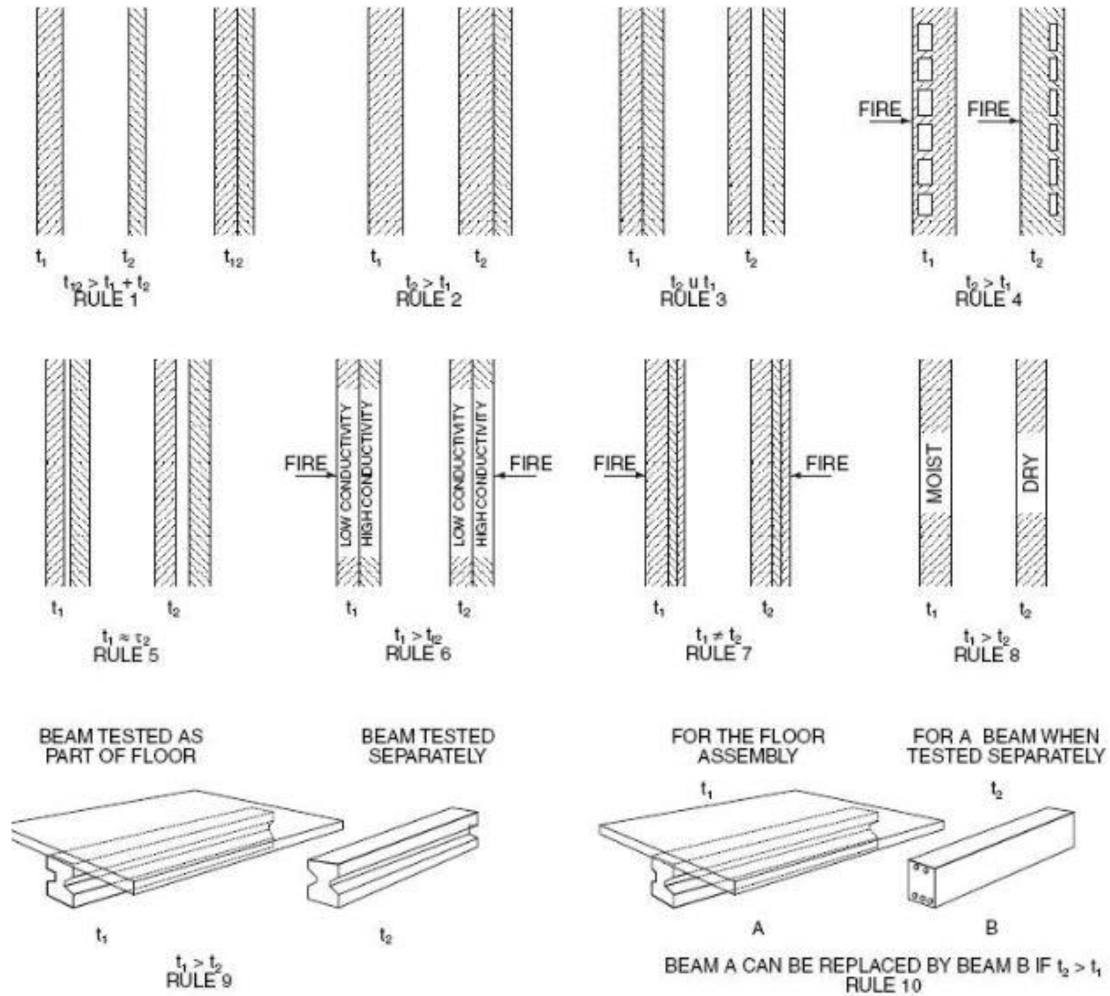
- Level of Documentation:
  - Engineering Judgment? Equivalency? Or Alternate Means and Method?
  - Design Brief & Rational Analysis?

Design Approach: Subsystem

- Simple comparative analysis to demonstrate subsystem provides equivalent level of performance to prescriptive codes:
  - Egress (e.g. travel distance in large warehouse)
  - Detection & Notification (e.g. NFPA 72 visual appliances)
  - Alternate Extinguishing
  - Fire Resistance

Example of Subsystem Comparative Analysis

- Harmathy's Rules to Support Alternate Method



Diagrammatic illustration of ten rules.
t = fire endurance

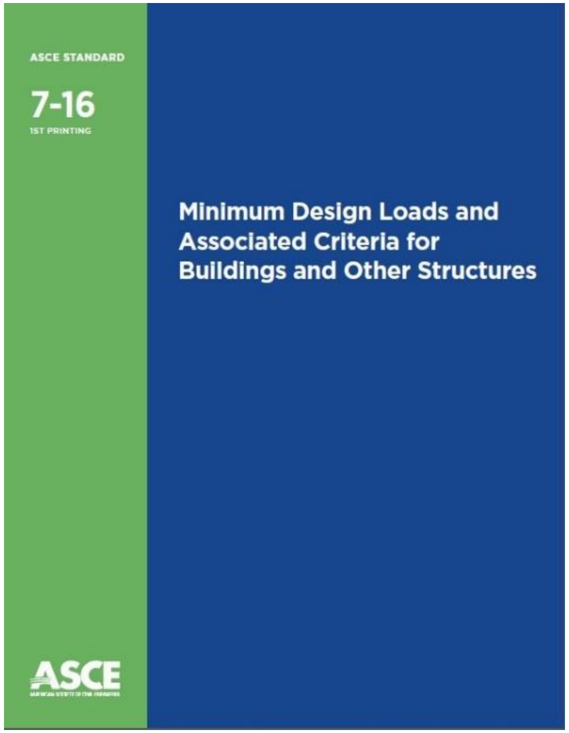
Source: SFPE Handbook 5th Edition

Design Approach: System

- Comparison to prescriptive requirements or analysis based on specific performance requirements. Must account for interaction between various subsystems.
  - Alternate means of egress
  - Structural fire resistance

    ASCE 7-16 Appendix E
  - Smoke control system

    (NFPA 92)



Example of System Design Approach

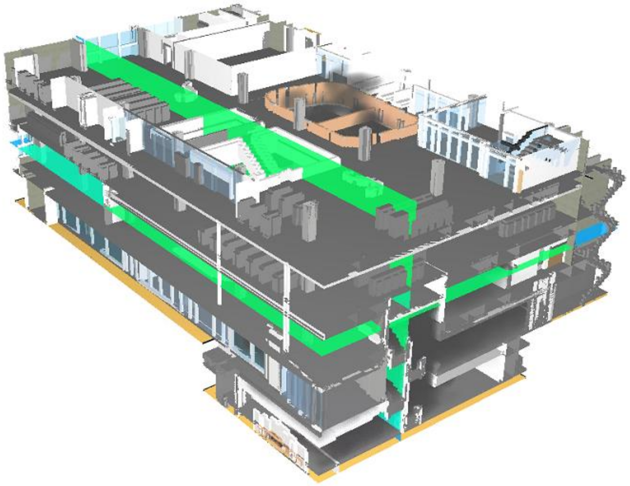
- Smoke Control System
  - Design Fire Selection
    - Fuel loads (size, combustion products, etc.)
    - Does the sprinkler system control the fire?
  - Alarm Configuration
    - How does this impact occupant notification egress?
    - Sequence of operations
  - Egress Modeling
    - Human Behavior
    - Tenability Conditions (Visibility, CO, Temperature)
    - 1.5 x Egress Time vs. 20 minutes
  - Smoke Control System Design

Design Approach: Whole Building

- All systems, subsystems and their interactions considered.
- As design gets closer to whole building it may be compared to specific performance requirements as the approach is typically different than presented in traditional methods.
  - Hazardous materials storage building
  - Structural fire resistance

Methods & Models

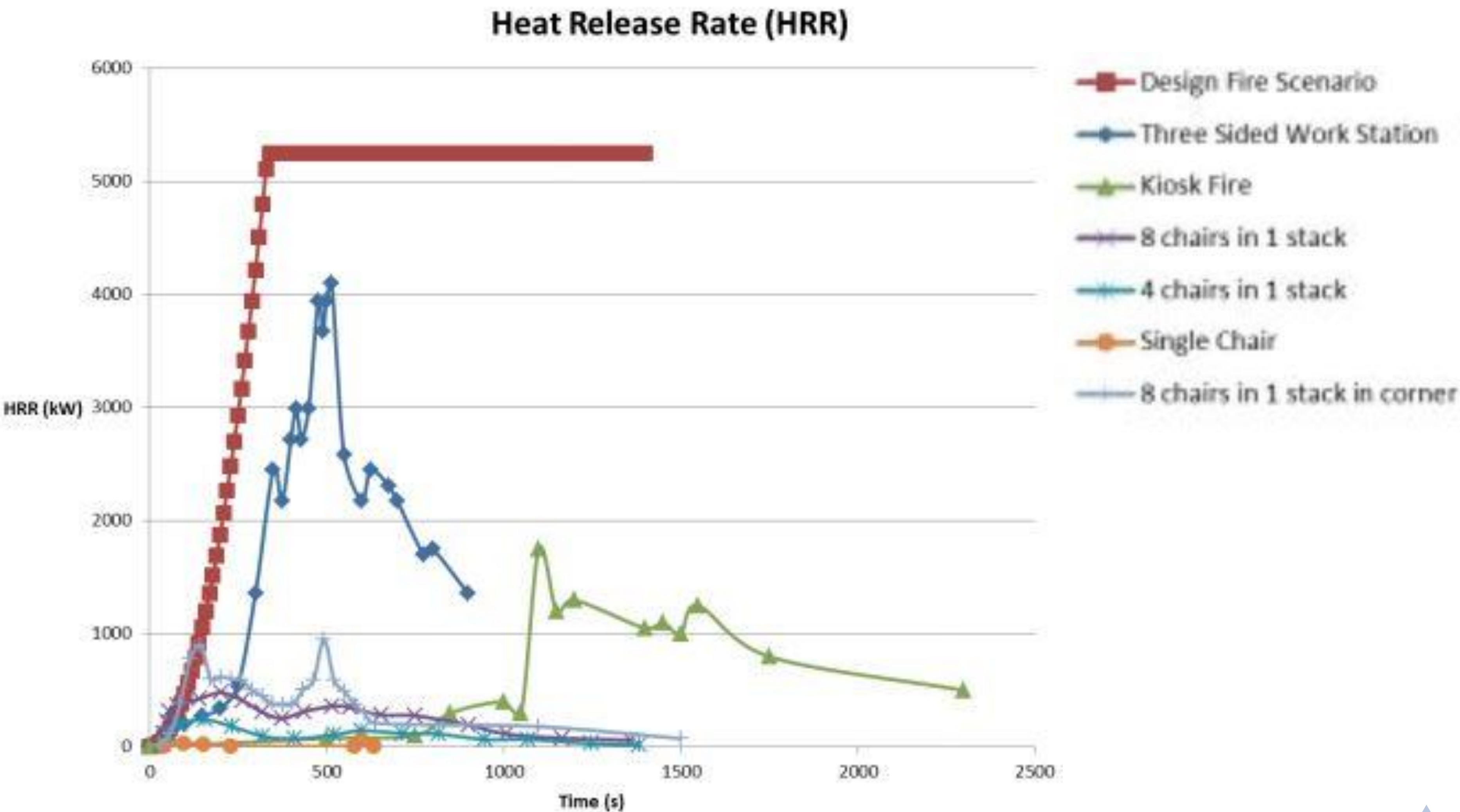
- Materials – Harmathy's Rules
- Fire Dynamic Simulator (FDS) – Smoke Control (Atrium)
- CONTAM – Smoke Control (Stair & Elevator Pressurization)
- SAFIR – Structural Fire Protection
- PATHFINDER – Egress Modeling
- Hand Calculations
  - SFPE Handbook
  - NFPA Standards
- Important to understand assumptions & limitations of each method or model



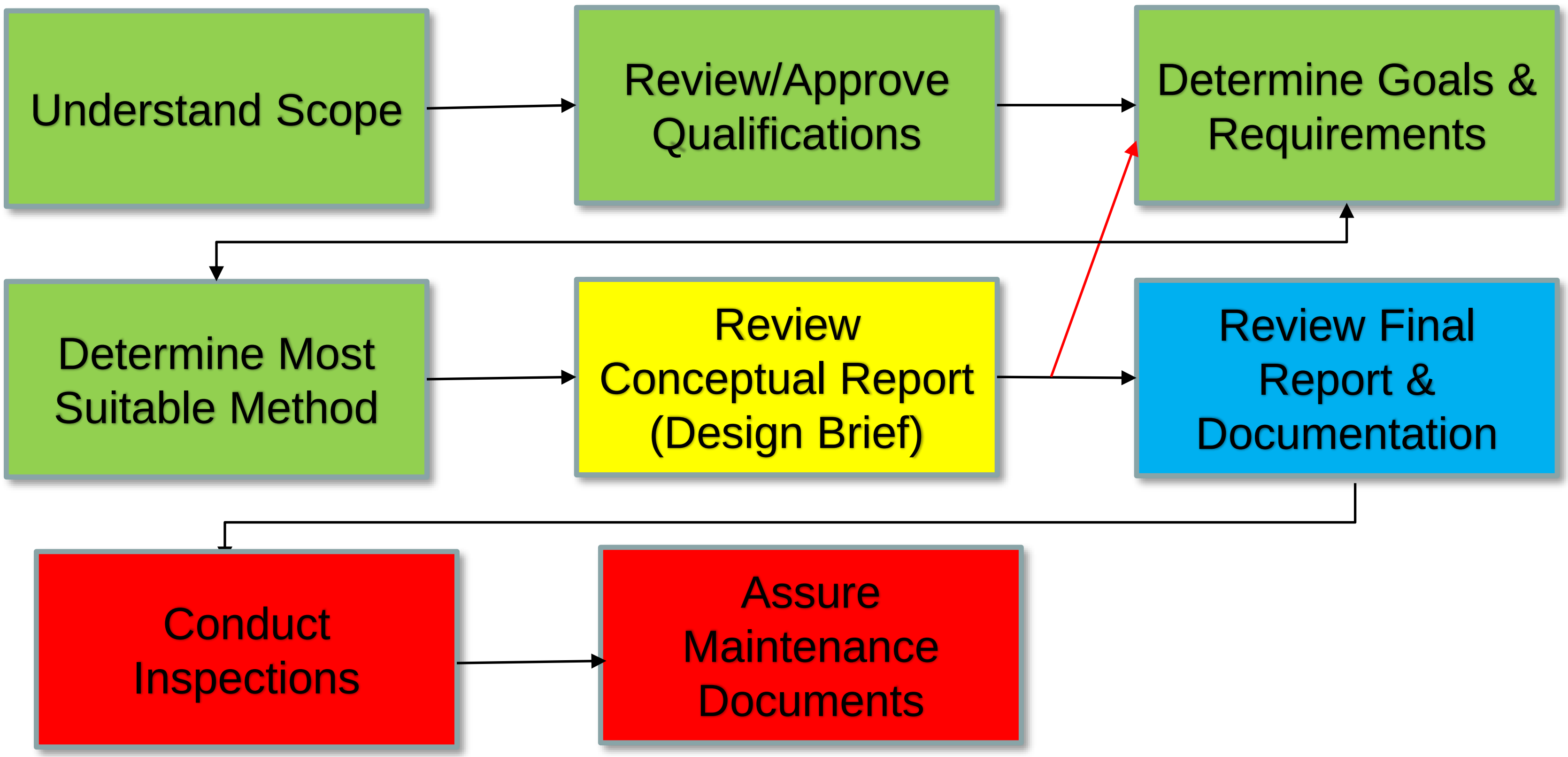
Does the PBD require a Design Fire?

- Possible vs. Design Fire
  - Design fire is a subset of possible fires (Meteor vs. Christmas tree)
  - Represents worst-case credible fire
- Evaluation of Building Characteristics
  - Fuel Loads, Occupants, Fire Suppression, etc.
  - Is it fire sprinkler controlled?
- Fuel composition matters (soot, CO, etc.)
- Location
- Safety factors
  - Steady vs. Unsteady

Design Fire Selection



Steps for Performance Based Design



Concept Report (Design Brief)

- Dynamic Document
- Define the following:
  - Project Scope
  - Stake Holders (Owner, architect, engineer, etc.)
- Documentation of Qualifications
- Description of Building/Occupants
- Applicable Codes
- Objectives
- Functional Statements/Performance Requirements
- Selected Event Scenarios
- Levels of Methods/Evaluations

Final Design Report

- … All information within Concept Report in addition to the following:

- Description of Final Design
- Engineering Evaluation
  - Methods, tools, analysis, safety factors, uncertainty & sensitivity analysis

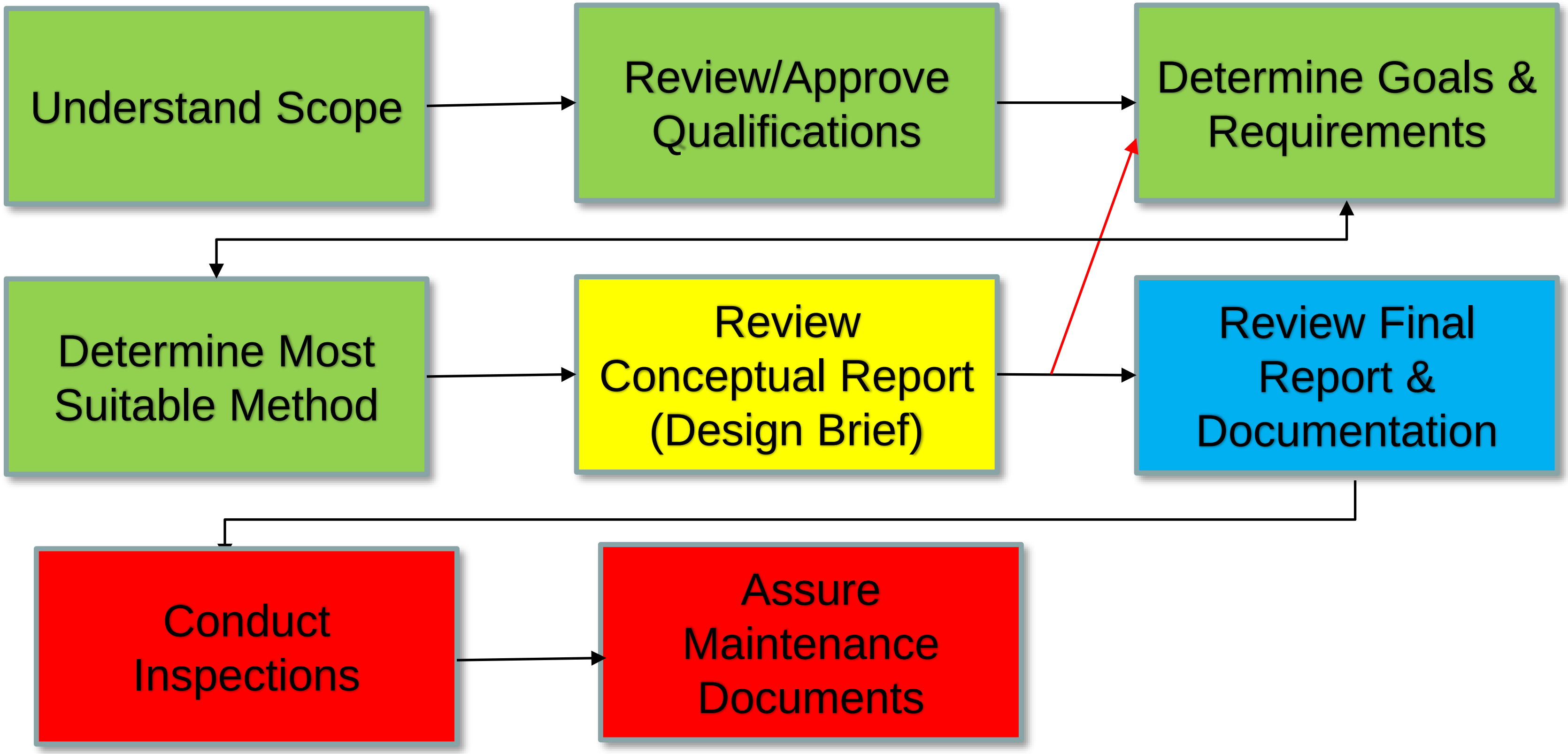
  Special testing procedures and bounding conditions if required.
- Special testing procedures and bounding conditions if required.

FINAL

Building Permit

- Building Permit:
  - Final Design Report
    - Possible Peer Review
    - *Design team signatures
  - Specifications & Drawings
  - *Deed Restrictions*
  - *Identification of areas requiring special inspections/testing*
  - *Product Data & Test Reports*

Steps for Performance Based Design

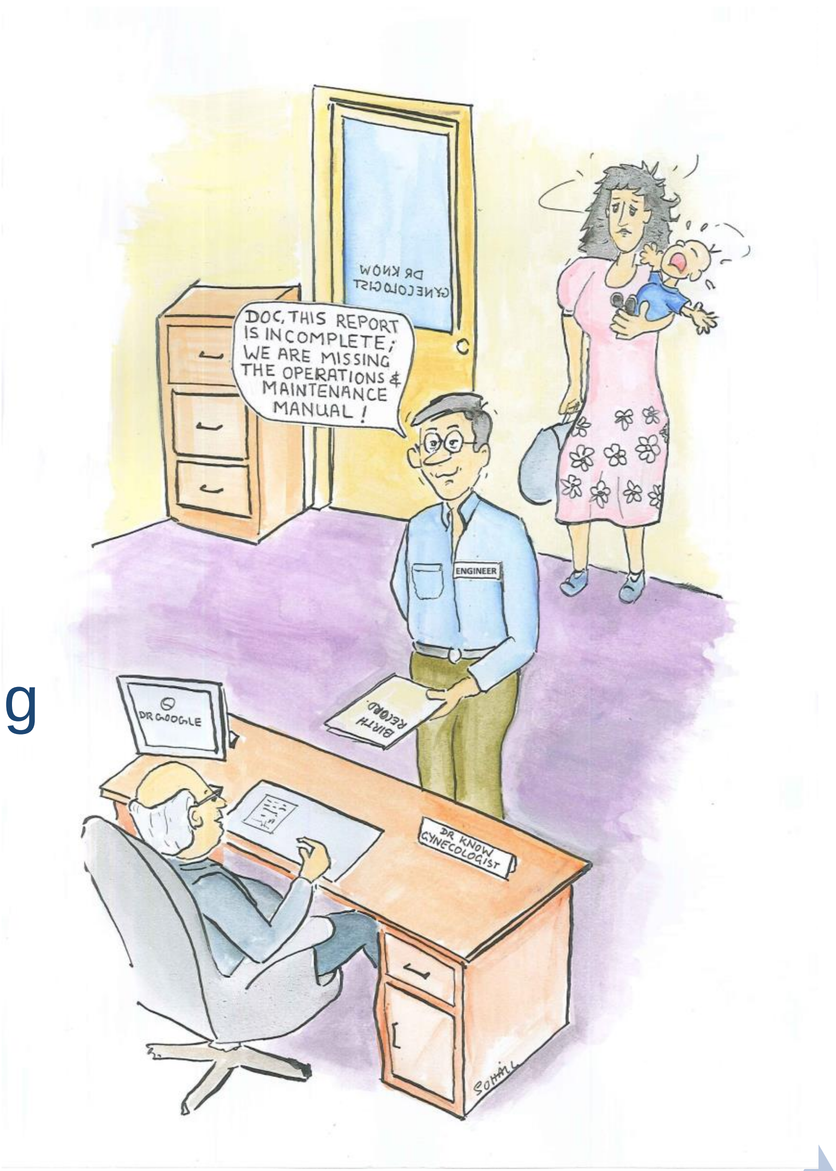


Construction & Testing

- Code Official & Design Team should be notified of any field changes
- Testing in accordance with Final Design Report. Are special inspections required?
- Should the code official witness testing?
- What happens if the acceptance testing results do not meet minimum requirements in Final Design Document?
  - System repair, alteration, design change, or even re-evaluation of the system/sub-system
- Documentation
- CofO
  - O&M Manuals
  - Special Inspections & Testing

O&M Manual

- As-built drawings
- Information on systems
- Limitations on use of building
- Testing & Maintenance Requirements
- Compensatory Measures
- Control of Combustible Loading
- Allowable Alterations
- Inspections by code official
  - Frequency
  - Scope & Procedures
  - Inspection Forms



Managing Building Changes

- Relatively minor changes (or cumulative small changes) might be significant for a PBD
  - O&M should be updated for cumulative changes, renovation work and any revisions that would effect PBD
- All proposed changes should be evaluated for their impact on PBD. Renovation does not necessarily invalidate design
- Renovations within scope of O&M vs. Outside scope of O&M
- Original Final Design Report may need to be revised or replaced with a new Report

Part 3: Case Studies

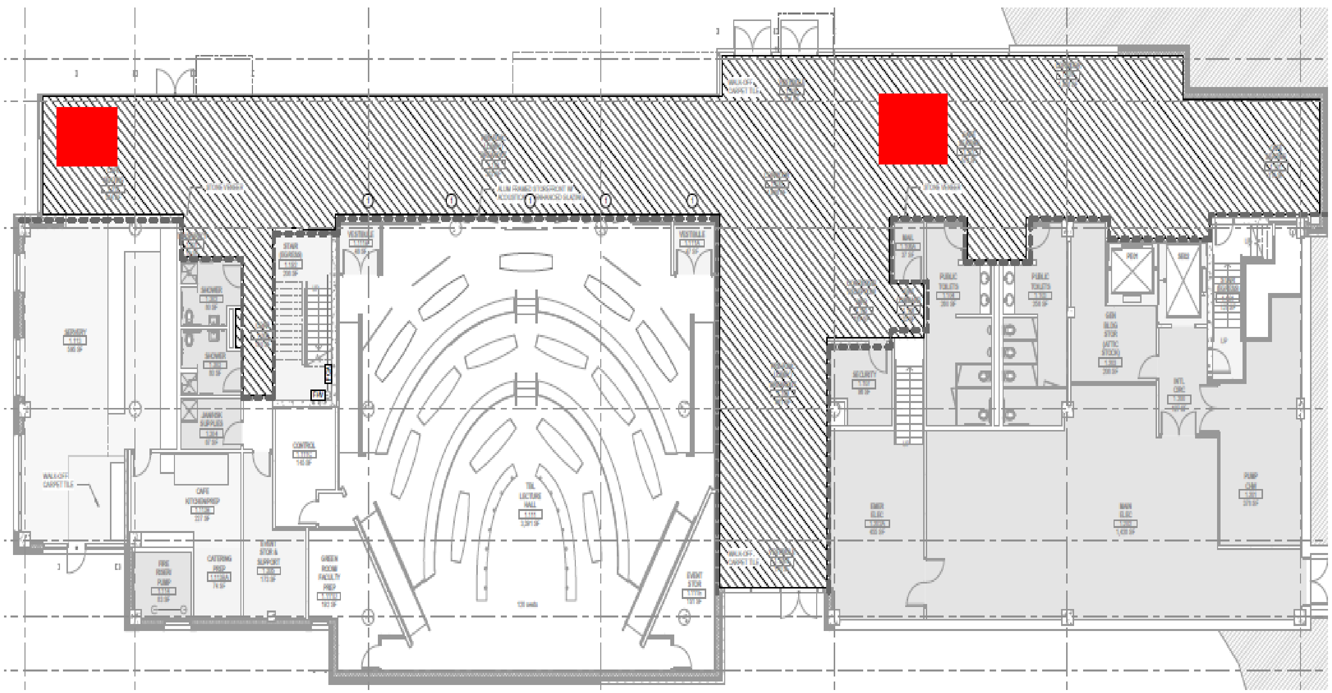
Case Study: University of Texas Dell Medical School – Health Learning Building

Building Description

- Higher-education classroom/office building
- 75,000 sq.ft. 5 story building
- Grand staircase spans Levels 1-5 creating a 5-story atrium
- Upper floors of atrium utilize staircase as exit access.

Evaluation of Mechanical Smoke Control System

- Draft design brief including fire scenarios and tenability criteria agreed to with stakeholders.



Tenability Criteria

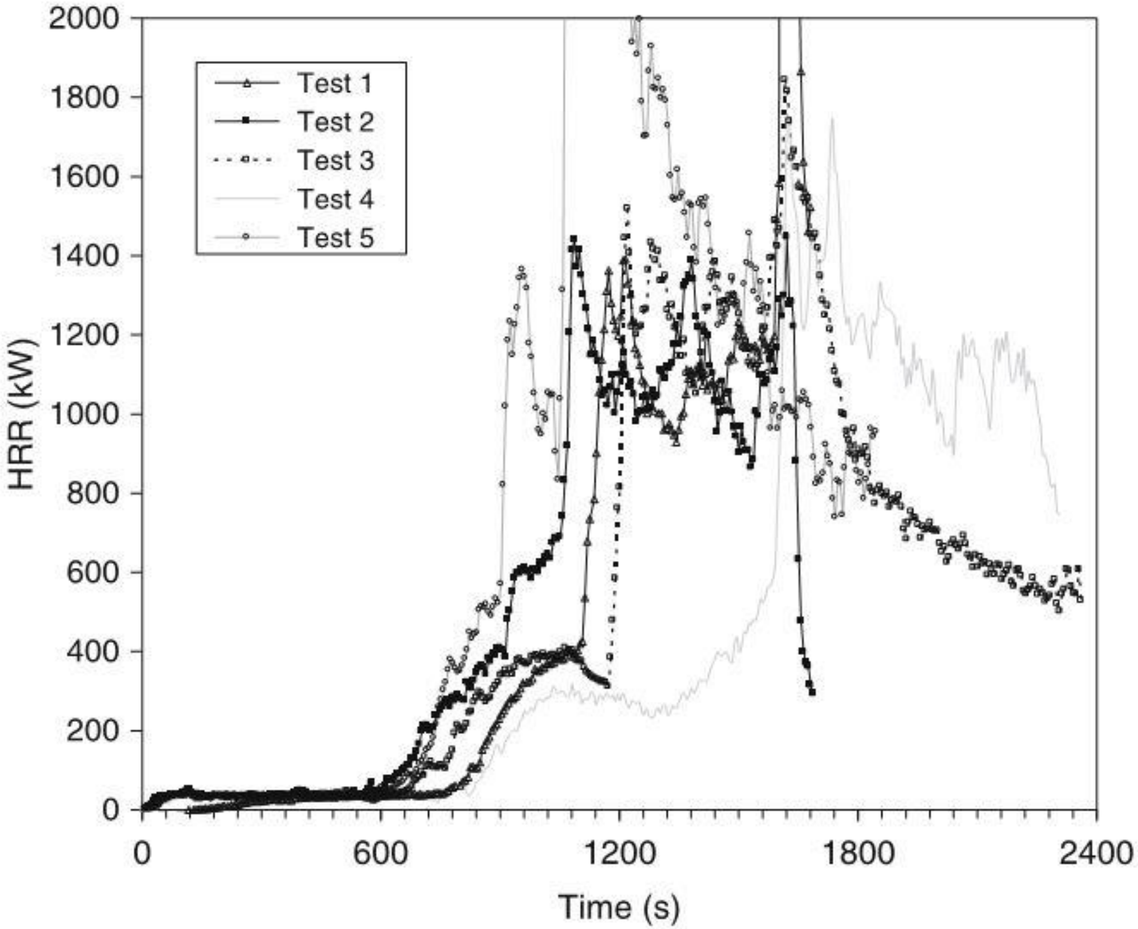
Tenability Criteria	Metric Units	English Units
Visibility	10 meters	33 feet
Temperature	60°C	140°F
Toxicity (CO)	1000 ppm	1000 ppm

Fire Design Scenario Axisymmetric

- 5.25 MW Axisymmetrical Fire (three kiosks)
- “fast” growing fire
- Maximum HRR to be maintained throughout duration of model
- Materials burned a conservative mixture of plastic, wood and foam with the following properties:

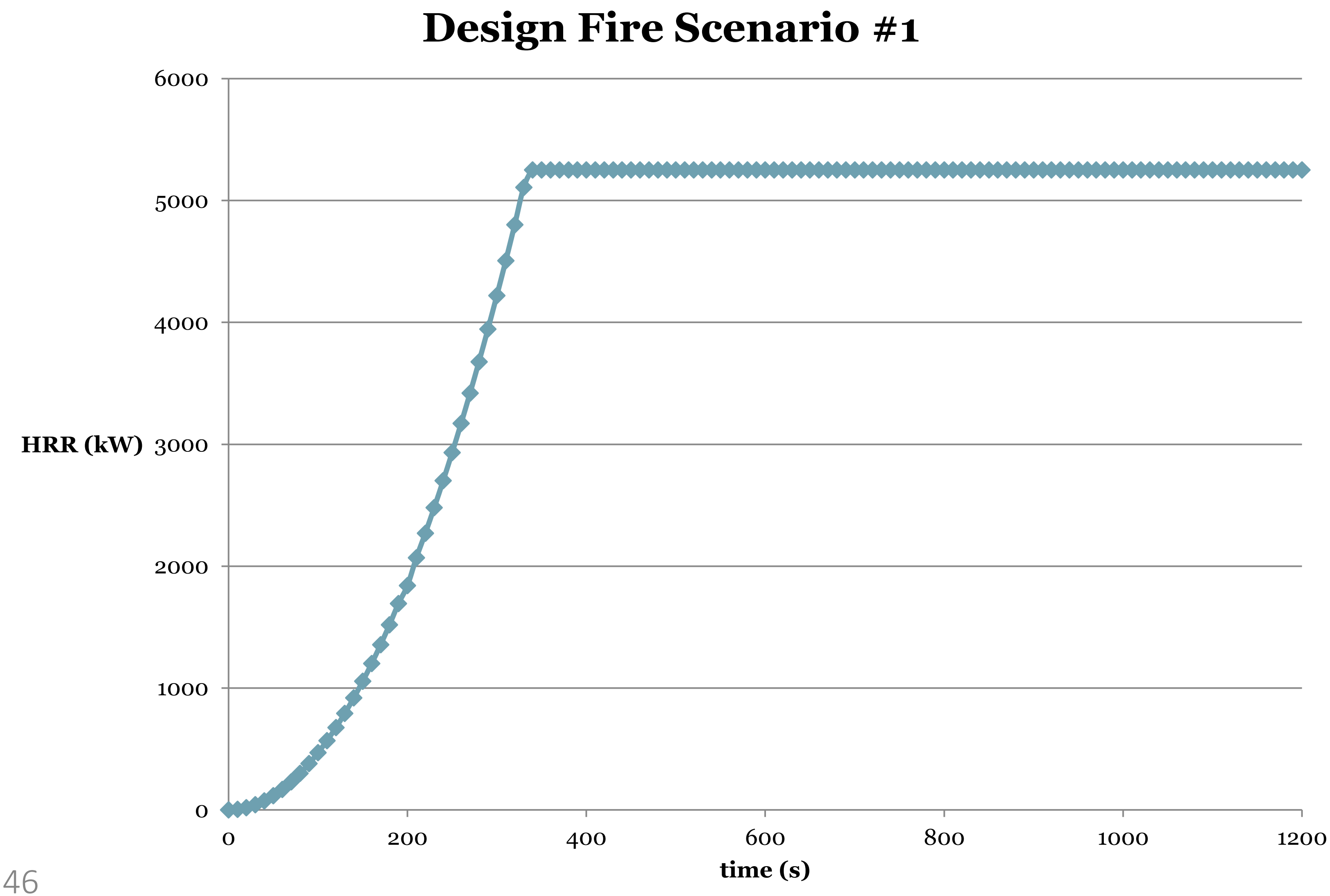
Property	Value
Heat of Combustion	20,000 kJ/kg
Soot Yield	.05 g/g
CO Yield	.05 g/g

HRR Curve Display Kiosk



SFPE Handbook 5th Edition Display Kiosk HRR Curve

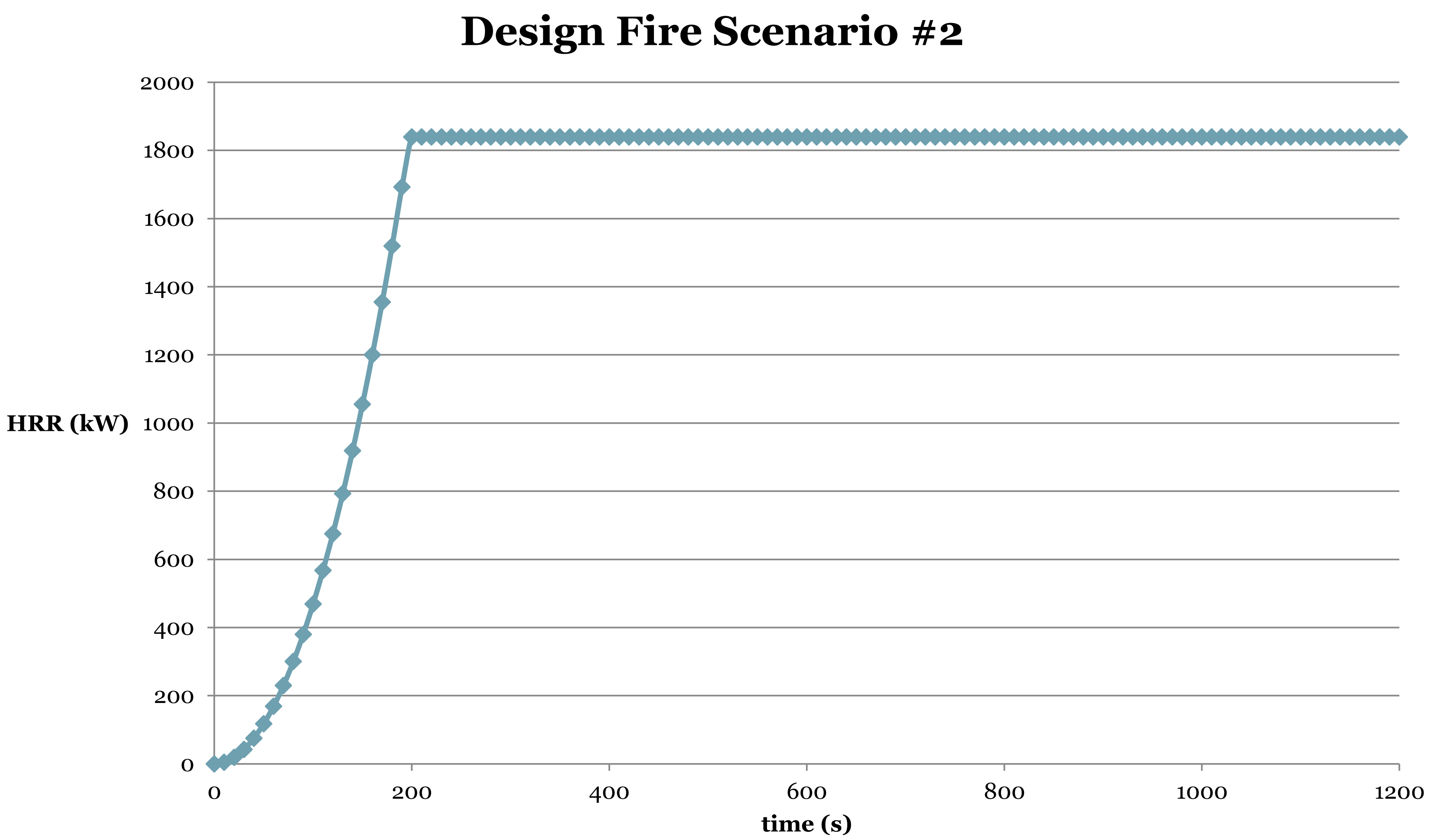
Axisymmetric HRR Curve



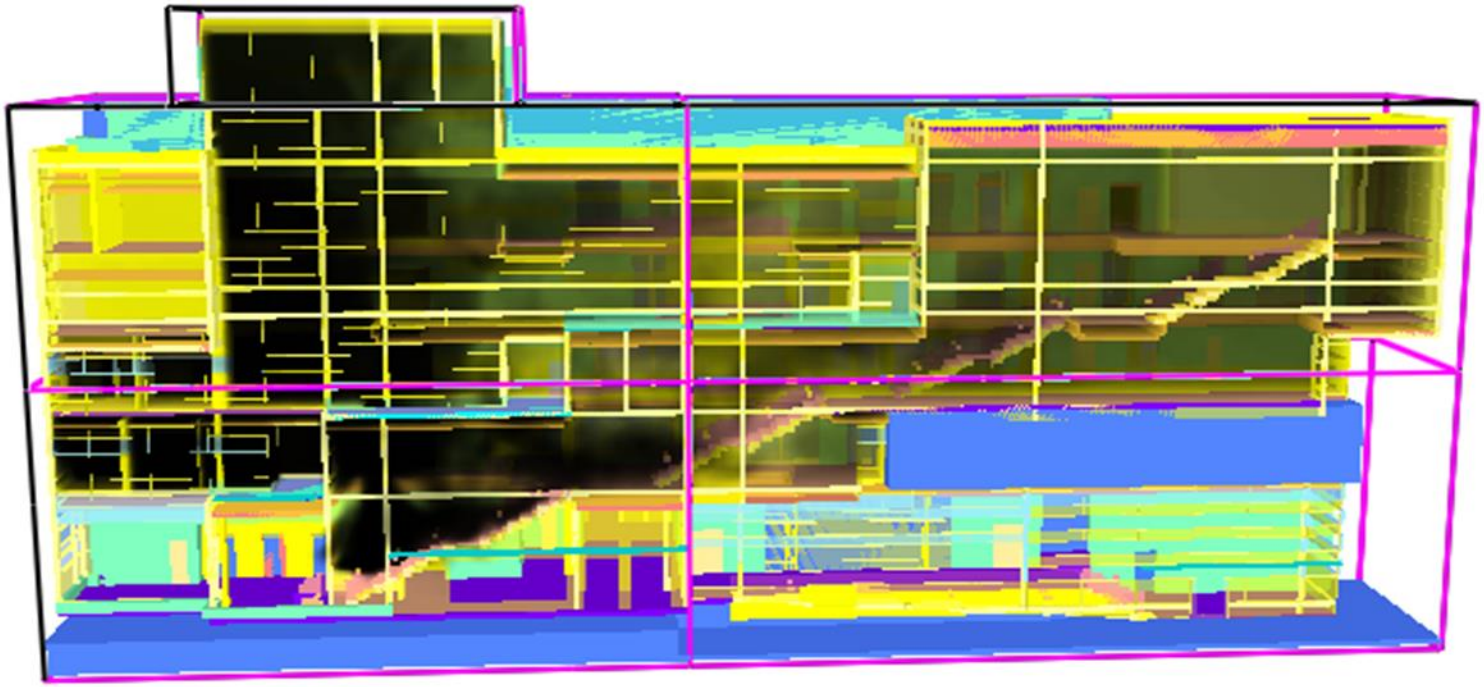
Fire Design Scenario Balcony Spill

- 5.25 MW Balcony Spill Plume Condition on Level 1
- DETACT Model showing sprinkler activation at 1,840 kW at 198 seconds.
- DETACT: Ceiling height was set to 24.6 feet for the first floor and RTI of the sprinkler was set at 50 $m^{½}s^{½}$.
- Assume sprinkler control but not extinguish.
- HRR at sprinkler activation is to be maintained throughout duration of model.
- Same fuel properties as Scenario #1

Balcony Spill HRR Fire Curve

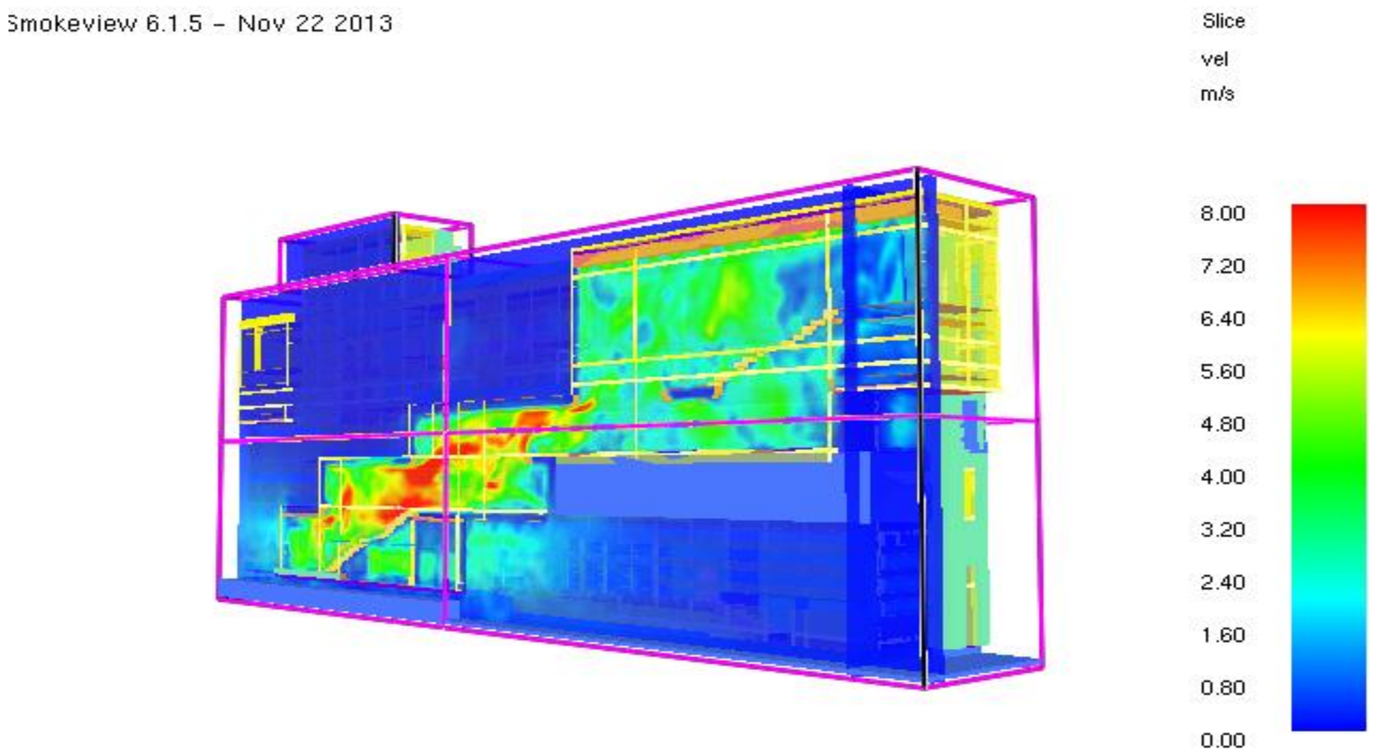


Mechanical Smoke Control Results



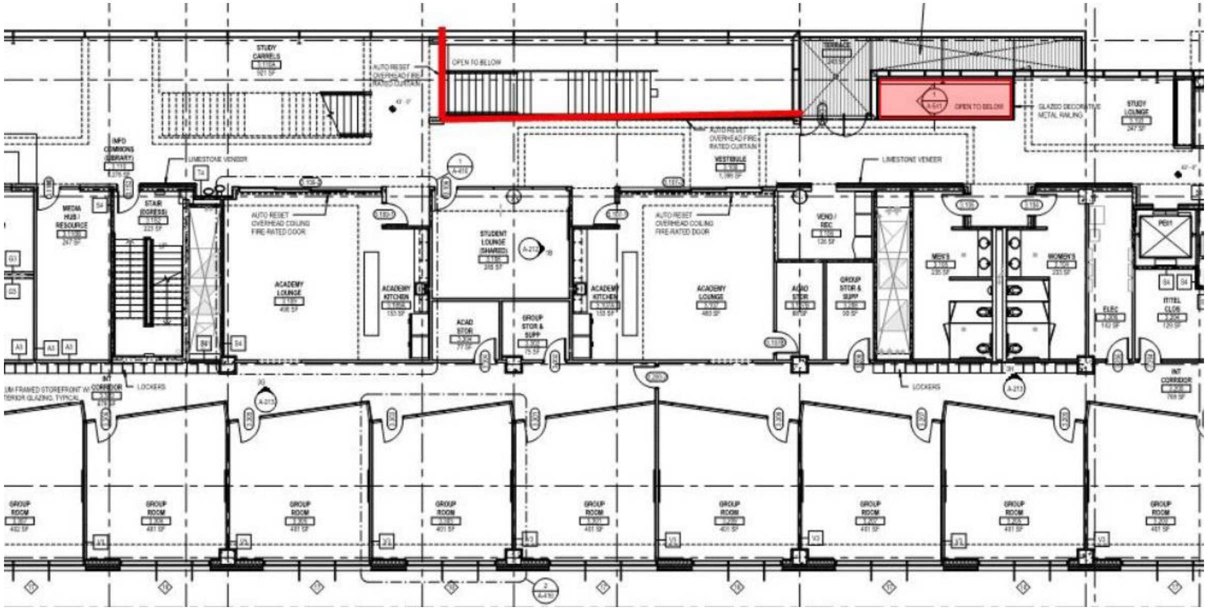
Mechanical Smoke Control Results

- In excess of 710,000 CFM would be required.
- Velocities along staircase untenable (1500 FPM)

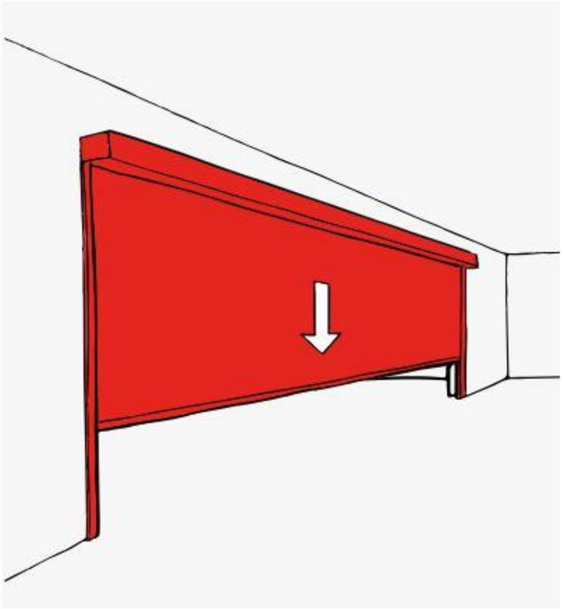


Revision in PBD Approach

- Mechanical smoke control deemed not practical
- Reconvene with stake holders and code officials
- Research design options for separating space while maintaining open design objective.



Vertical Fire Curtains



construction type	textile fire protection curtain
fire resistant	2 hours fire rating according to UL 10D, 20 minutes fire rating according to UL 10B, UL 10C, NFPA 252
fabric	Stoebich Fire & Smoke Fabric H • Fire & Smoke Fabric P
fire load free zone	Meet backface temperature 250°F with sprinkler as compensation
closing direction	from top to bottom
proof	Z-6.60-2127 • UB III/B-07-010-1 • LP-1216.2/02 • UB III/08-033 • UB III/B-04-045 • UB 3.1/ 09-018 • UB 3.3/09-202 • UU IV/00-39-1 • 08/32309876 • 2011-Efectis-R0495
closing cycle	10,000 cycles (drive unit)

Final Performance Based Design Approach

- Utilization of combination of smoke curtains and shutters to remove the need for smoke control.
- Smoke curtain fire resistance rating equivalent to fire resistance rating of floor (2 hours)
- Hose Stream & Backside Temperature required to be addressed
- Levels open to one another as convenience openings:
  - Levels 1 & 2 (Convenience Opening)
  - Levels 3-5 Atrium

New Results

- 310,000 CFM of Exhaust

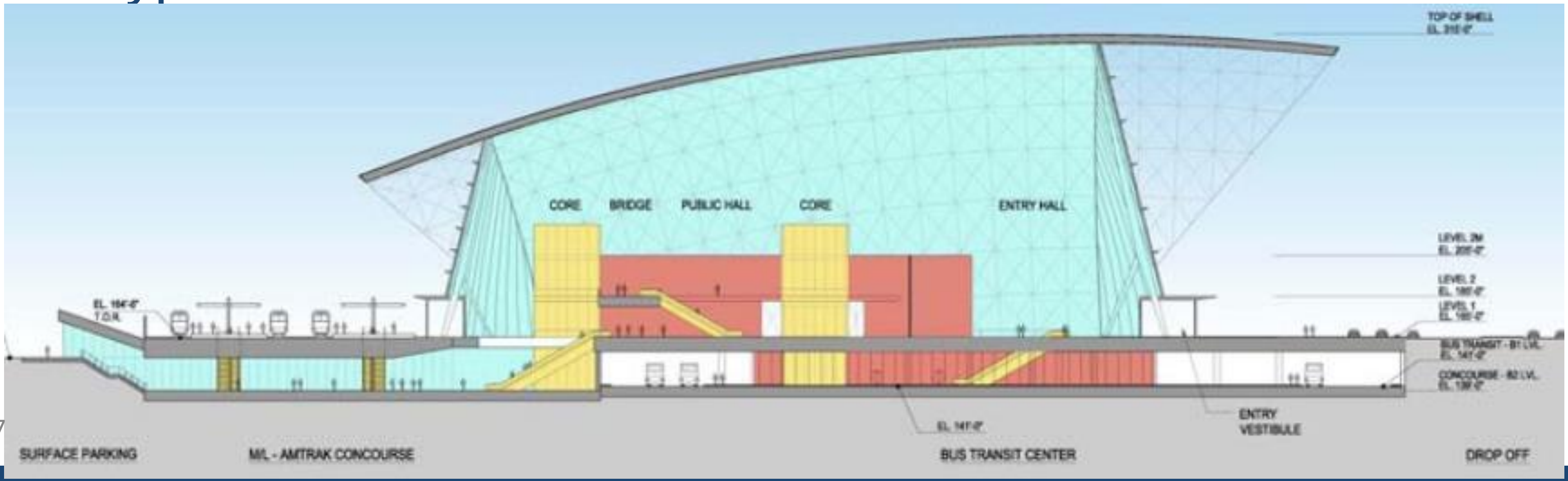
Performance Based Design Outcomes Met

- Original design intent is met
  - Space maintains “open” environment
- Cost savings on mechanical system
  - Code required smoke control system can be expensive, untenable and impractical
- Adequate level of safety and fire protection

Case Study: Anaheim Regional Transportation Intermodal Center

Building Description

- Integrated bus terminal and train station with space for retail and food vendors
  - – A-3 Assembly Occupancy with mixed uses including: retail shops (M) and restaurants (A2).
- 3 story, 150 feet high
- Type IB construction



Code requirements

- Type IB required due to Chapter 5 height allowances
  - Building Codes require a non-combustible roof membrane for Type IB
  - Two-hour fire-resistance rating of the primary structural of the primary structural frame required for Type IB
    - Codes allow a reduction to one-hour fire-resistance rating where supporting only the roof

Performance Based Design Solutions

- Goals: Meet the client’s needs while also providing a level of safety equivalent or greater than required by code.
  - Use of limited combustible Ethylene Tetrafluoroethylene roof membrane
  - Reduction of structural fire-resistance

Limited Combustibility Roof Membrane

- Various code-referenced standard fire tests of Ethylene Tetrafluoroethylene (ETFE) were analyzed and demonstrate that ETFE:
  - Does not allow sustained flaming
  - Does not produce continuously flaming droplets
  - Self extinguishes
  - Has low extent of burning
  - Does not permit rapid flame spread
  - Has a low probability of self-ignition

Limited Combustibility Roof Membrane

- Interior fire scenarios considered for hazard assessment
  - 5,275 kW design fire
    - Retail fire
    - Cleaning cart fire
    - Kiosk fire
    - Restaurant kitchen fire
- The plume centerline temperature was calculated to determine if the ETFE membrane will remain intact or reach its melting point at 267 °C
  - Worst case scenario reaches 153.2 °C and the membrane stays intact

Limited Combustibility Roof Membrane

- The fire scenario study and plume analysis show that any likely interior fire would not melt or ignite the ETFE membrane. This implies that there is not an increased fire hazard represented by the ETFE due to a large fire exposure from within the intermodal terminal.

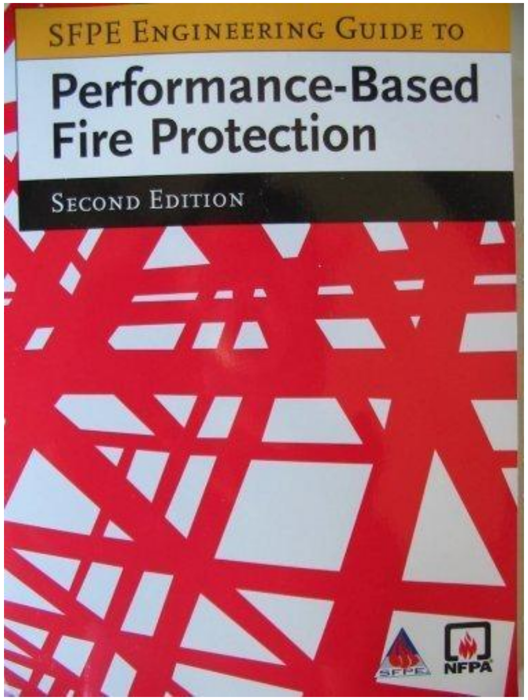
Reduction of Structural Fire-Resistance

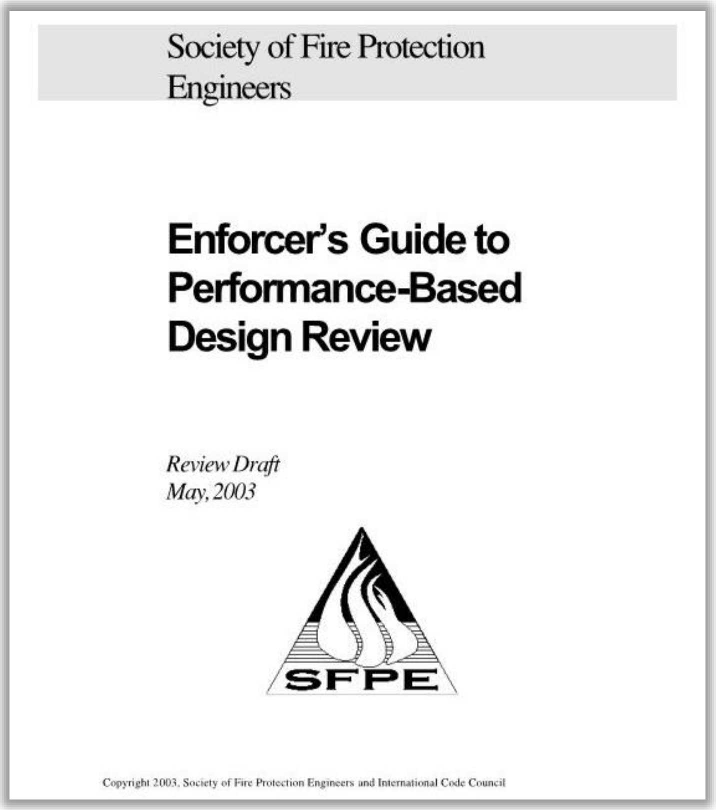
- Various building elements were analyzed using worst case scenario design fires (5,275 kW) to determine if structural failure occurs
- Calculations demonstrate:
  - Unprotected steel members are appropriate for grid shell elements more than 17 feet above usable floor areas
  - Bearing exterior walls do not require fire resistance
    - A reasonable level of individual failures will not cause overall failure
  - Concrete-filling provides the required fire-resistance for exterior columns

Performance Based Design Outcomes Met

- Original design intent is met
  - Code required fire-resistance is not aesthetically pleasing
- Cost savings on construction materials
  - Code required fire-resistance can be expensive
- Adequate level of safety and fire protection

Available Resources





“A theory (*model*) is something nobody believes, except the person who made it. An experiment is something everybody believes, except the person who made it.”

– Albert Einstein

This concludes the presentation. Questions?

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