Risk Assessment for Cultural Institutions: Fire Testing vs Computer Modeling

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Introduction

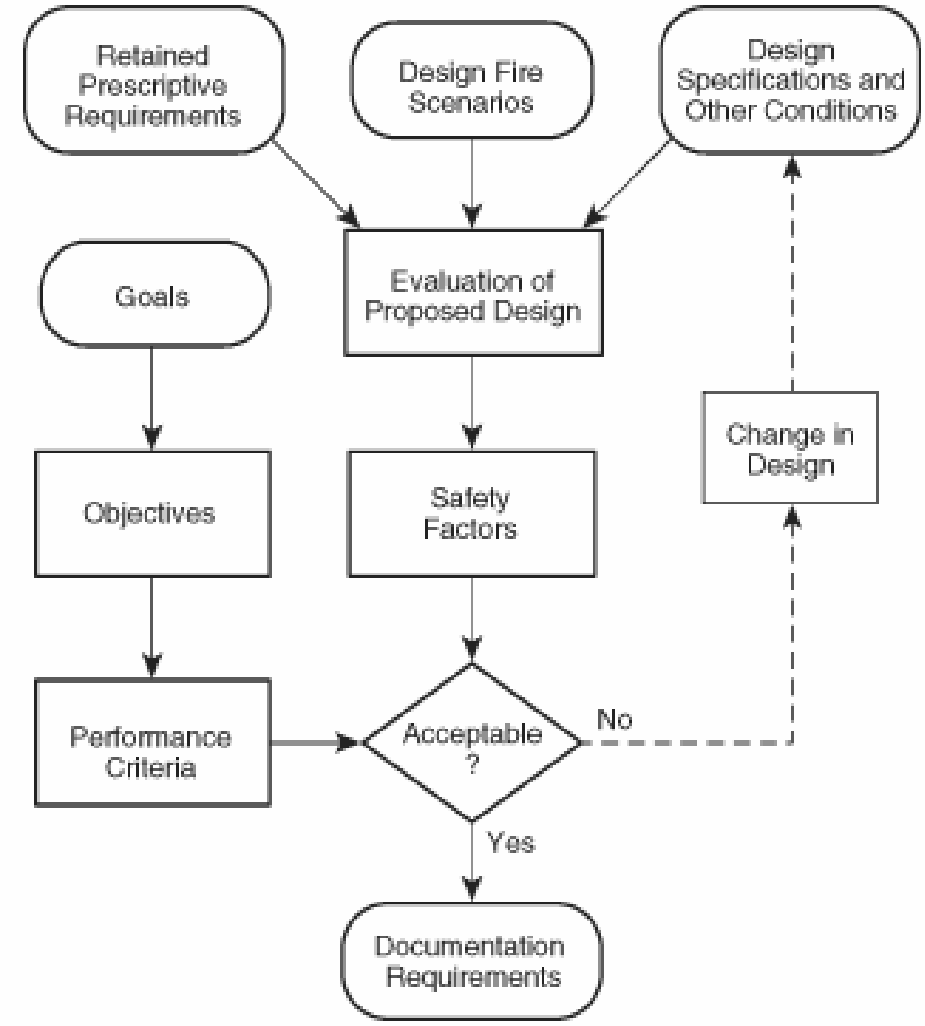
- A number of codes and standards address the fire protection of cultural institutions:
  - NFPA 909
    - Protection of Cultural Resource Properties – Museums, Libraries and Places of Worship
  - NFPA 914
    - Fire Protection of Historic Structures
- These documents identify two options to meet life safety and property conservation goals and objectives:
  - Prescriptive-based
  - Performance-based ... focus of this discussion

Compliance options

- Prescriptive option
  - Codes and standards address specific design requirements
  - Relationship between specified requirements and performance objectives is implicit (or nonexistent)
  - Easy to review and enforce
- Performance-based option
  - Goals and objectives are explicitly stated
  - Achievement of objectives demonstrated through engineering analysis of performance criteria
  - More difficult to review and evaluate

Performance-based design

- NFPA 909
  - Figure 7.1
- Goal
  - Conservation
- Objective
  - Protect artifacts
- Performance criteria
  - ?



Performance criteria

- "Culturally significant features, rooms, spaces, or contents shall not be exposed to instantaneous or cumulative fire effects that would cause irreversible damage."
  - 9.2.2.2 NFPA 909

- How can this performance criterion be achieved and demonstrated?
  - A.9.2.2.2 NFPA 909 addresses this issue

Performance criteria

- Demonstrate for each design fire scenario that
  - each space will be fully isolated from the fire before the smoke or thermal layer descends to a level where irreversible damage can occur
  - the smoke and thermal layer will not descend to a level where irreversible damage can occur in any room
  - no fire effects will reach any space beyond the room of origin

A.9.2.2.2 NFPA 909 recommendations

Performance criteria

- The recommendations in NFPA 909 (A.9.2.2.2) point toward the use of fire modeling to demonstrate compliance ...

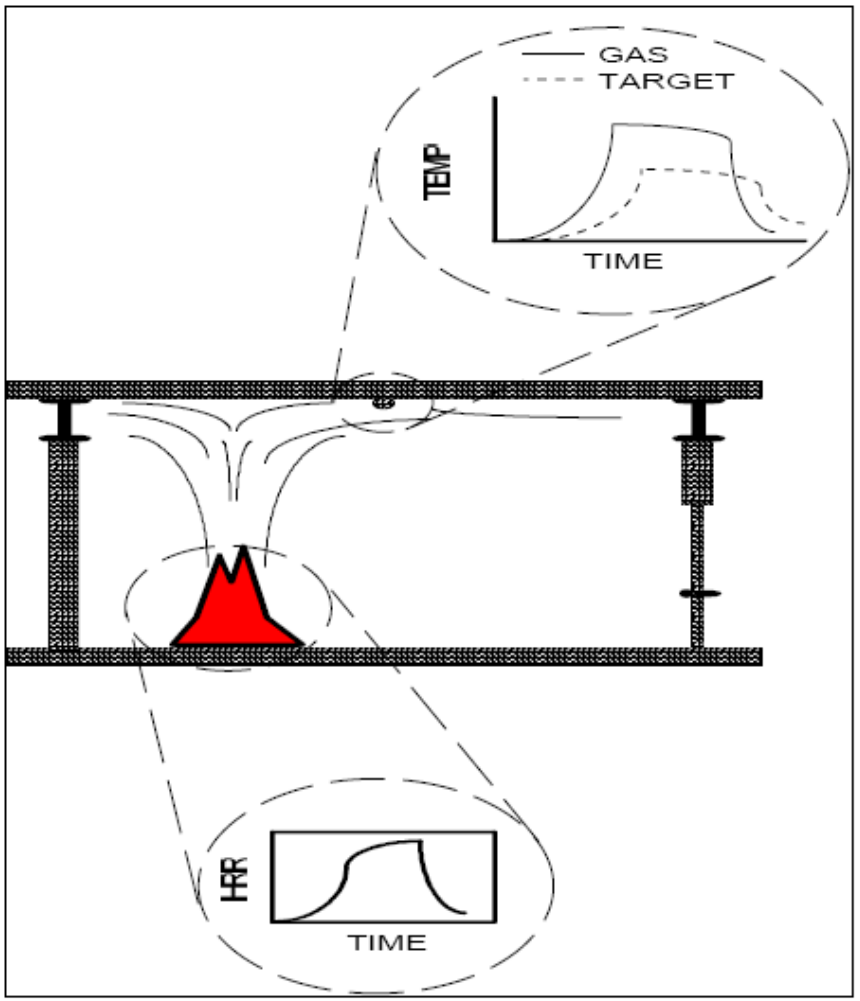
- ... but is fire modeling currently up to this challenge?

What is fire modeling?

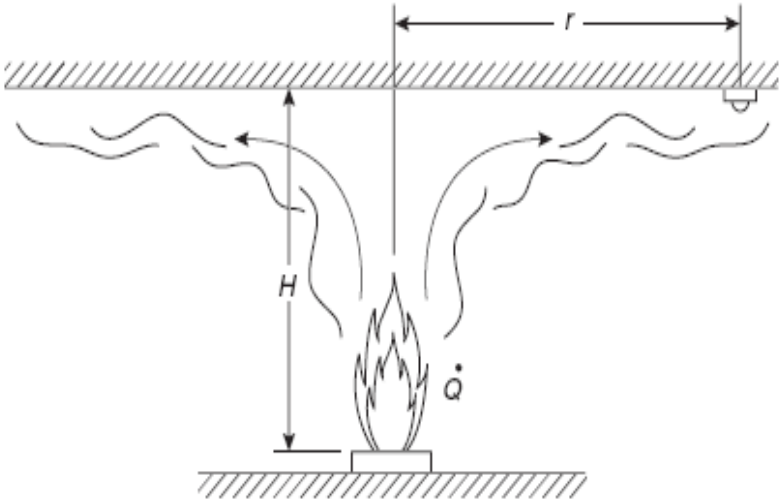
- A fire model is a mathematical prediction of fire growth, environmental conditions, and potential effects on structures, systems or components ...
  - (3.3.26 NFPA 909)

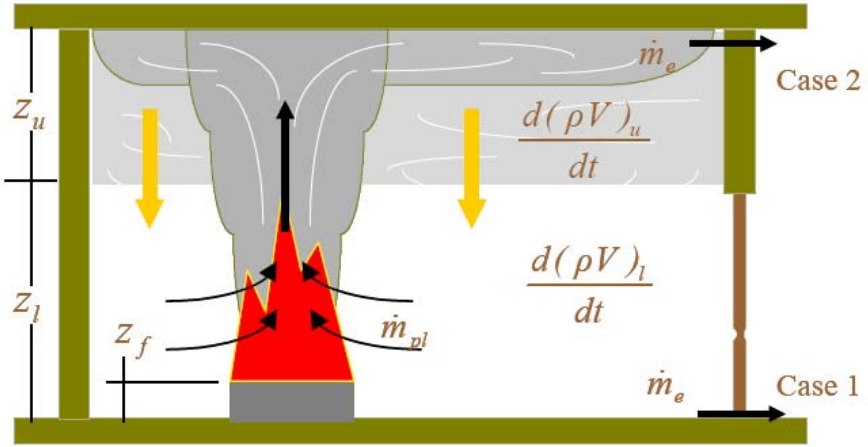
What is fire modeling?

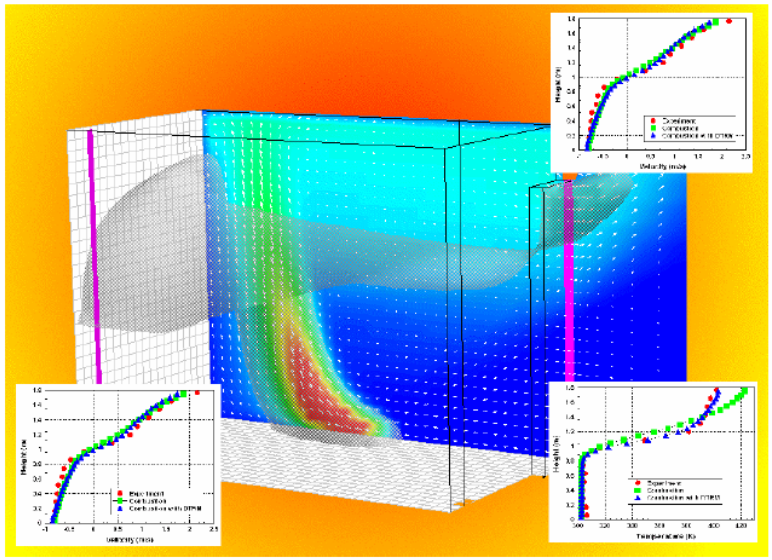
- Fire source
  - Specified
  - Predicted
- Smoke / heat transport
- Target response
  - Conditions at target
  - Target vulnerability



Types of fire models







- Correlations
- Zone models
- CFD models

How fire models are used

- Predict fire growth / fire suppression
  - Current capabilities are limited
- Calculate conditions resulting from specified fire
  - Current capabilities are relatively good
- Both methods require specification of design fire scenarios

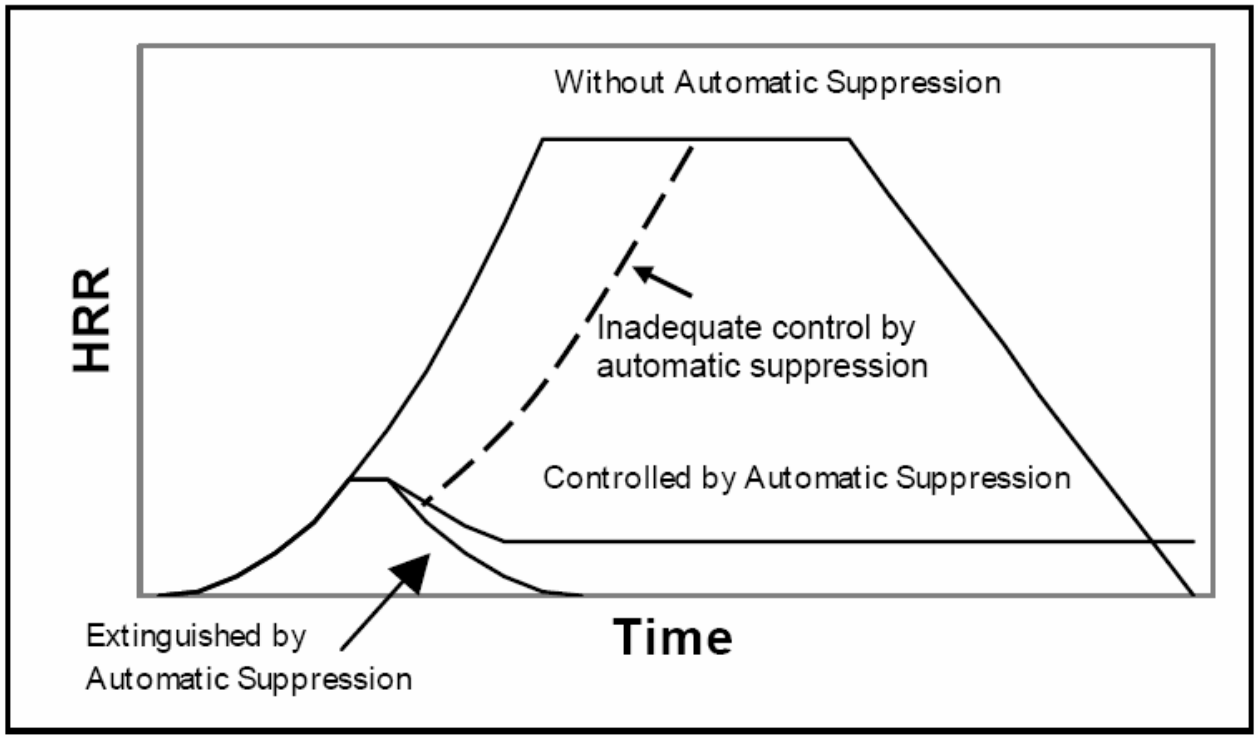
Design fire scenarios

- Fire Scenario (3.3.72.2 NFPA 909)
  - "A set of conditions that defines the development of fire, the spread of combustion products throughout a building or portion of a building, the reactions of people to fire, and the effects of combustion products."
- Design Fire Scenario (3.3.72.1 NFPA 909)
  - "A fire scenario used for evaluation of a proposed design."

Design fire scenarios

- Each fire scenario shall be challenging, but realistic, with respect to at least one of the following scenario specifications (9.5.2.2 NFPA 909):
  - Initial fire location
  - Early rate of growth in fire severity
  - Smoke generation
- What about fire suppression?

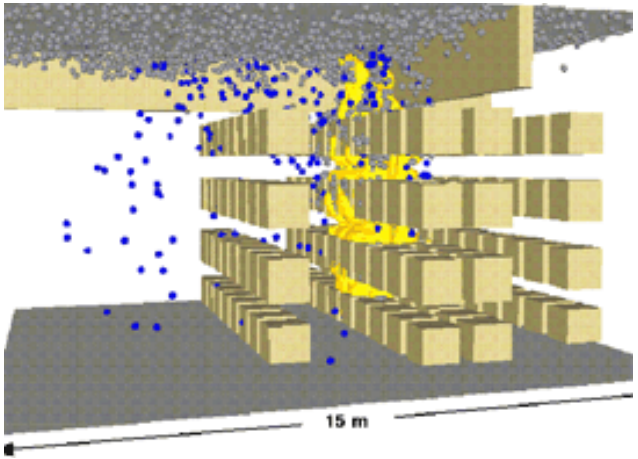
The role of suppression



As adapted from the SFPE performance-based design guide

The role of suppression

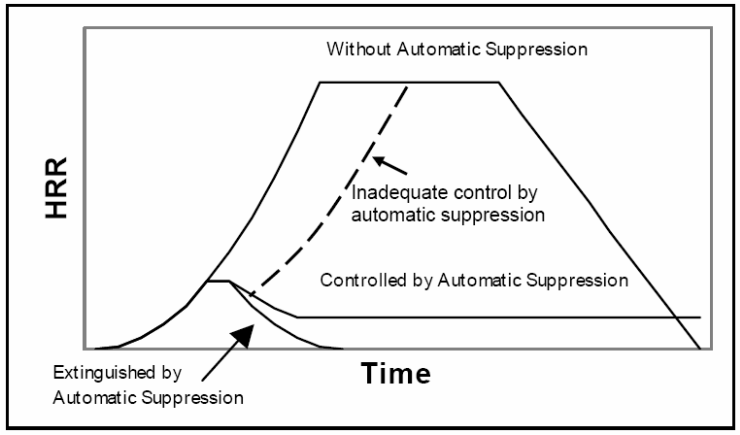
- The ability of current fire models to predict fire suppression is (very) limited
- Fire models that attempt to calculate fire suppression are based on empirical relations derived from limited large-scale fire test results



Credit: www.fire.nist.gov

The role of suppression

- Fire modelers typically specify the influence of fire suppression on a design fire scenario
  - Time of fire detection is modeled, then it is assumed the fire will be extinguished or controlled when the suppression system discharges
  - The impact of agent discharge on environmental conditions is typically ignored
    - e.g., effect of agent discharge on smoke layer stability



The role of fire testing

- Large-scale fire testing is still an essential part of fire suppression system design
  - Needed to prove suppression effectiveness for proposed configurations / designs
  - Needed to demonstrate that conservation objectives will be achieved
    - Successful suppression ≠ successful conservation

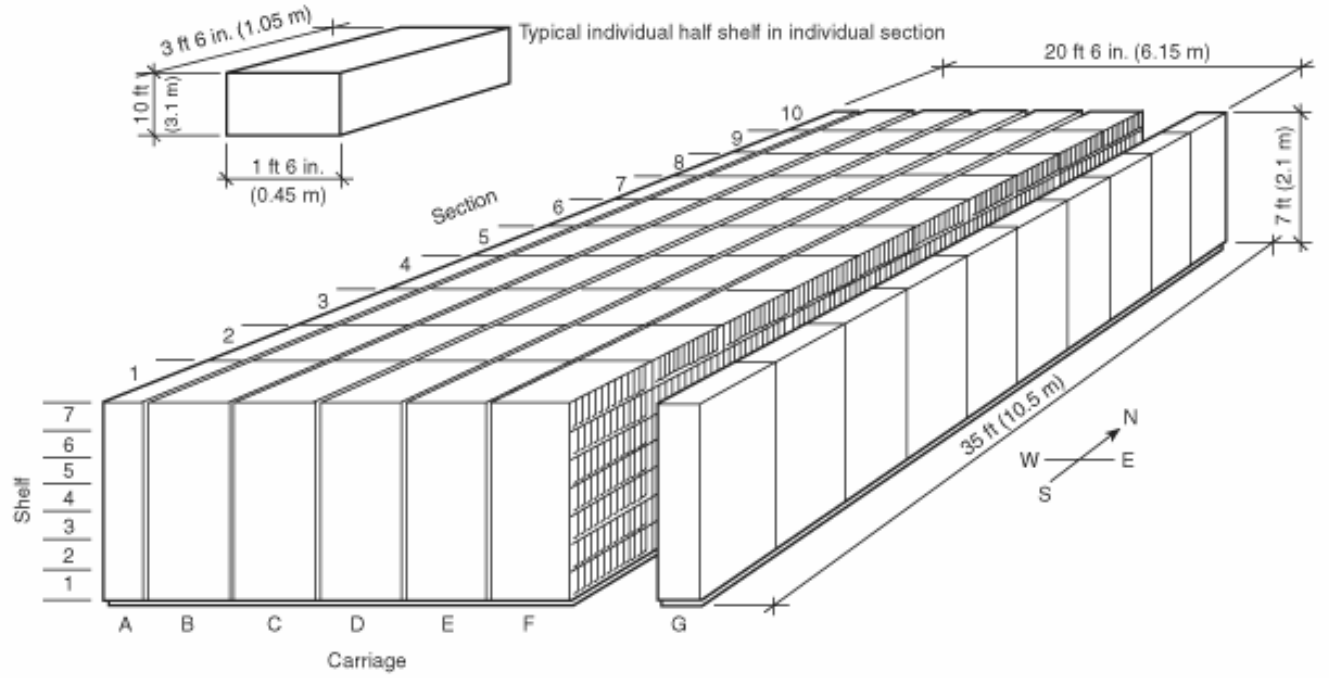
Limitations of fire testing

- Each test represents only one of many scenarios
  - Ignition source / location / fuel configuration / building geometry / ventilation ...
- Large-scale fire testing is very expensive
  - ~$50,000 per test for warehousing tests
- Conservation issues (i.e., artifact damage) are not typically assessed in fire suppression tests
  - Some exceptions

Example

- Compact mobile shelving fire research

FIGURE I.3 Mobile Shelving Array Terminology and Dimensions.



Example

- Compact mobile shelving fire research
  - 1978 – GSA sponsored fire tests at FM
  - 1989 – NARA sponsored fire tests at UL
  - 1991 – National Archives/Library of Canada sponsored tests at NRCC
  - Current – FPRF sponsored fire tests

Summary

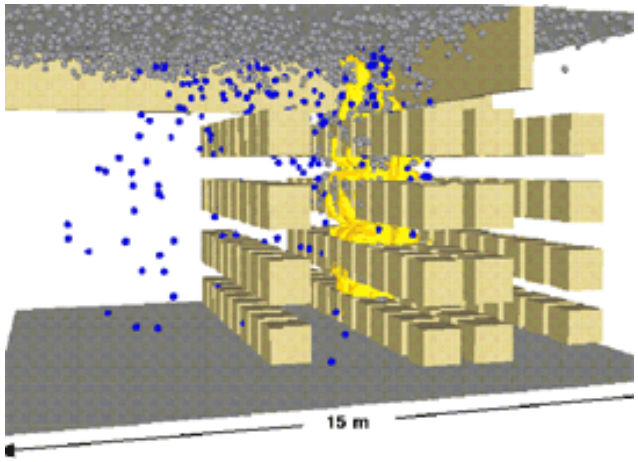
- Fire modeling is very useful for:
  - Parametric studies of different variables
    - What if … the fire is twice as big?
  - Fire hazard analyses of specified scenarios
  - Estimating times for detector activation
- Fire modeling is NOT YET reliable for:
  - Predicting fire growth / flame spread
  - Predicting suppression system effectiveness

Summary

- Fire testing is still necessary to:
  - Evaluate flame spread / fire growth potential
  - Evaluate fire suppression effectiveness
    - High challenge / unique storage arrangements
    - Complex storage / ventilation conditions
  - Evaluate damage potential to artifacts
    - Thermal and nonthermal damage from smoke
    - Fire suppression agent / decomposition product effects

Summary

- Fire testing should be augmented by modeling
  - Pre-test modeling
    - Help define fire test parameters / measurements
  - Post-test modeling
    - Help understand / extend fire test results
    - Help validate the fire model
- Example
  - FPRF project on sprinkler / vent / draft curtain interactions



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