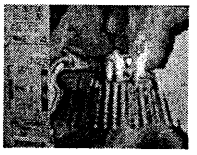
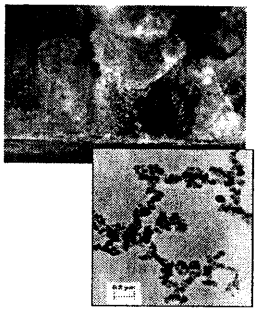
THE ROLE OF SCIENCE & ENGINEERING IN REDUCING FIRE RISK





William Grosshandler
Building and Fire Research Laboratory

FPRF Fire Risk and Hazard Assessment Research Application Symposium

9 July, 2003

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TARGETS FOR FIRE RISK REDUCTION IN THE UNITED STATES

- **Residential deaths (> 3000/yr) and injuries**

- **Firefighter line-of-duty deaths (> 100/yr) and burn injuries**
- **Wildland-urban interface and community-scale fires**
- **Life and property loss in public and commercial buildings (> $5 B/yr)**

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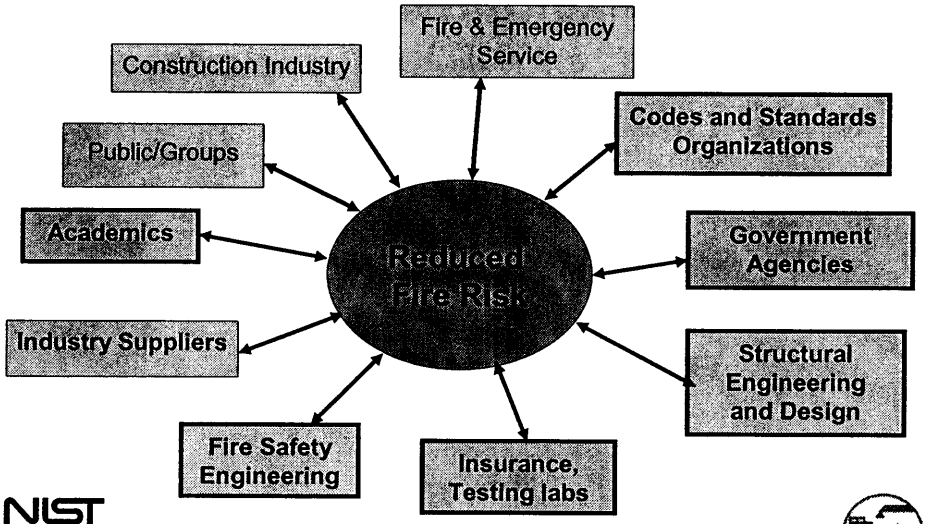
STAKEHOLDERS & CONTRIBTORS TO EFFECTIVE FIRE RISK REDUCTION



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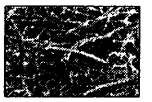
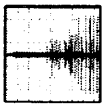
SCIENTIFIC AND ENGINEERING TOOLS FOR REDUCING RISK OF FIRE

- Fundamental data and theoretical constructs

- Innovative materials



- Controlled environments for real-scale testing



- Advanced sensing and instrumentation
- Advanced deterministic and probabilistic algorithms, and computational resources

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ELIMINATING RISK OF FLASHOVER IS KEY TO REDUCING DEATHS IN RESIDENTIAL FIRES

- Early and certain fire and environment sensing
- Cost-effective fire suppression technologies
- New/improved materials whose fire resistance does not negatively impact performance, cost, or the environment

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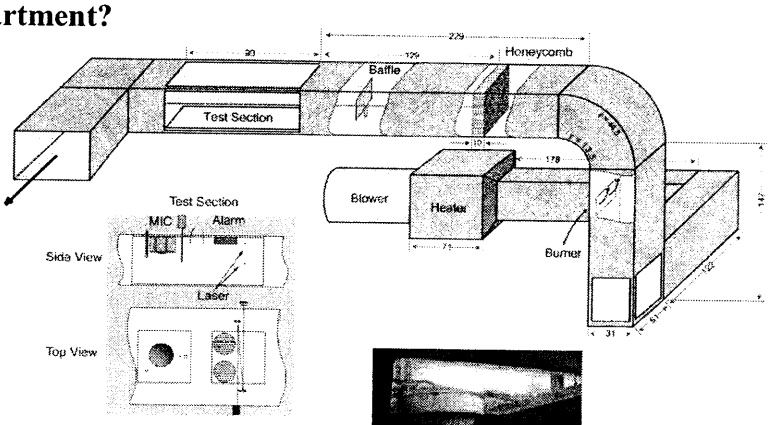
Early and Certain Fire and Environment Sensing

If we could ensure that one out of two fire alarms was a real threat, could we directly connect home alarms to the local fire department?



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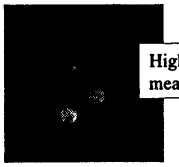
Cost-effective Fire Suppression Technologies

If we could predict the performance of low-cost alternative fire suppression technologies, how much could we reduce risk to society overall by accelerating the introduction and acceptance of alternative suppression technologies into housing markets?

Simultaneous sprinkler droplet size & velocity for input and validation of CFD fire models

200 μm drops



Highly magnified area of measurement region

Dual laser-induced fluorescence
- Particle tracking for velocity
- Non-intrusive, instantaneous
- Large area (1 m x 1 m)
- 2 Dim measurements.
- High resolution film camera

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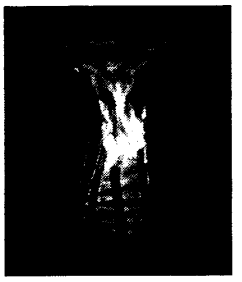
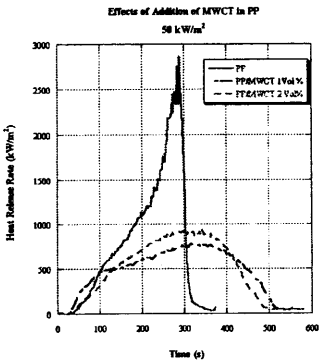
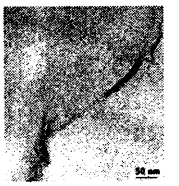
Less Flammable Materials

If we understood how alternative flame retardants impact flammability and performance of common materials, how much could we accelerate adoption by materials industry and acceptance by consumer of building products and furnishings with significantly lower heat release rates?







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KEYS TO REDUCING RISKS FOR FIRE SERVICE

- New technology and measurement standards
- Improved training tools
- Shift to an information-rich environment

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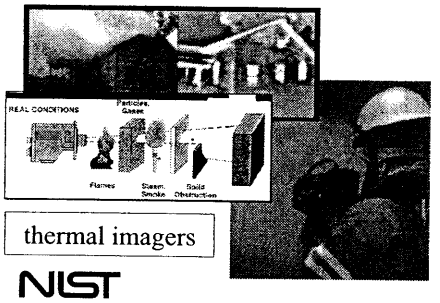
New Technology & Measurements Standards

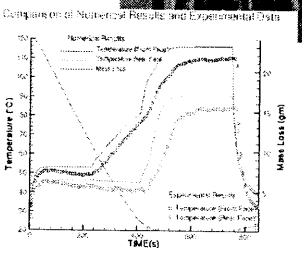
How can we make informed decisions on investments in new fire fighting technology without an unbiased assessment of the technology's performance in the field?

How can manufacturers convince customers of suitability of new products without scientifically sound industry standards?



thermal imagers

turnout gear



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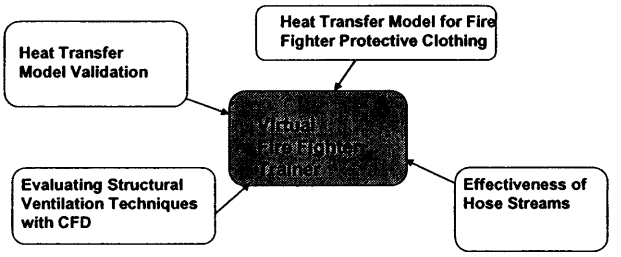
Improved Training Tools

What is potential for physics-based simulation tools to complement decreasing opportunities for live-fire training exercises, and supplement types of scenarios that firefighter is likely to encounter?



- Increased accuracy in display of smoke obscuration (prototype 3D smoke)
- Prototype version of virtual touring – basis for learning by decisions

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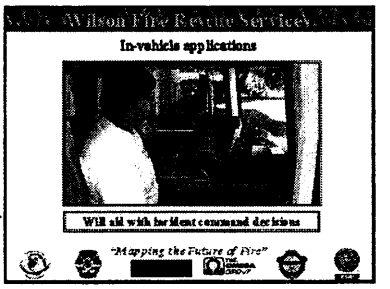
Information-rich Environment

If we could get the right information where it is needed, when it is needed, and in a form that is quickly understood, how much could we reduce risk and increase effectiveness of fire fighting operations?



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REDUCING FIRE RISK AT THE WILDLAND-URBAN INTERFACE AND COMMUNITY SCALE

- **Significant contribution of structure to fuel load**
- **Unique character of house-to-house and outside-in progression of flames**
- **Models for land-use planning decisions**
- **Simulations for emergency response drills**
- **Gross estimates for real-time fire fighting operations**

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Predictive Fire Spread Models

What do we need for reliable, usable, predictive models for assessing fire risk at the WUI and community scale?

- Focus on fire loads distributed evenly between structures and vegetation
- Collaboration across disciplines and organizations
- Data

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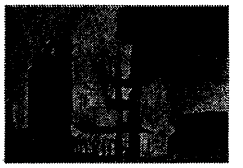
RISK TO LIFE AND PROPERTY FROM FIRES IN PUBLIC & COMMERCIAL BUILDINGS



- Traditional fire hazards
- Combined hazards
- Terrorist threats
- Performance envelope of structures

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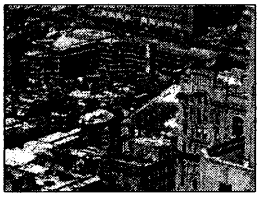
Paradigm-shifting Impact of 9/11 on Perceived and Real Risk for Buildings, Occupants & First Responders



- Lessons to be learned from World Trade Center (WTC) investigation
- The National Construction Safety Team (NCST) Act
- Dissemination and Technical Assistance Program (DTAP)
- Safety of Threatened Buildings R&D Program

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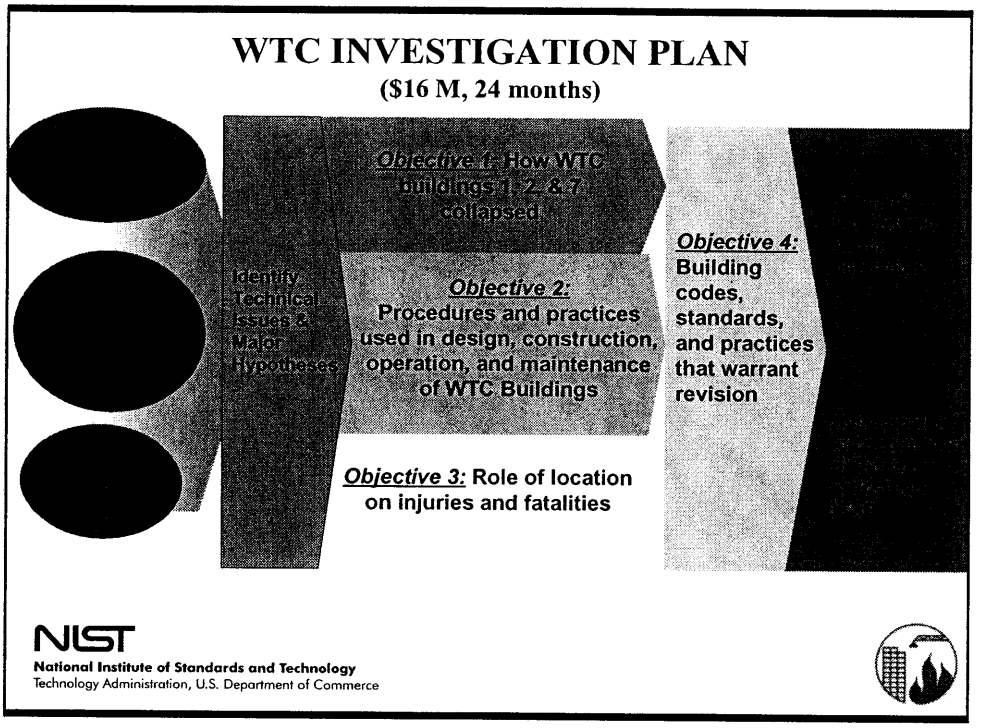

Lessons to Be Learned

Structural fire protection:

- *Dynamics of building fires, and collapse vulnerability of buildings to fires*
- *General methodologies for fire safety design and retrofit of structures*
- *Performance of fireproofing materials and connections used in steel structures*
- *Safety and performance of open-web steel trussed joists under fires*
- *Collapse mechanisms and role of pivotal components such as transfer girders and floor diaphragms*

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Lessons to Be Learned

Engineering practice:

- ***Process for innovative systems and systems requiring code variances***
- ***Margin of safety to accommodate abnormal loads***

Life safety:

- ***Firefighting and evacuation technologies and practices for tall buildings***
- ***Control of fire spread in buildings with potentially large open floor plans***
- ***Command, control, and communication systems for emergency response***

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Components of WTC Investigation

- **Analysis of Building and Fire Codes and Practices**
- **Analysis of Structural Steel**
- **Baseline Structural Performance and Aircraft Impact Damage Analysis**
- **Investigation of Active Fire Protection Systems**
- **Reconstruction of Thermal and Tenability Environment**
- **Structural Fire Response and Collapse**
- **Occupant Behavior, Egress, & Emergency Communications**
- **Fire Service Technologies and Guidelines**

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Analysis of Building and Fire Codes and Practices

- Design calculations, building construction, approval process
- Passive fire protection features
- Emergency access and evacuation systems, including firefighter lifts
- Code comparisons (city, state, national; then and now)
- Review maintenance records & modifications following 1993 bombing

Analysis of Structural Steel

- Catalog of available structural steel and relevant specifications
- Documentation of observed failure mechanisms and damage
- Metallurgical and mechanical properties of steel, weldments, connections
- Estimation of maximum temperatures reached by available steel
- Comparison of steel properties to applicable material specifications

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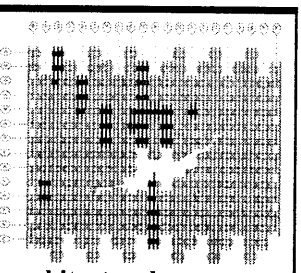
Baseline Structural Performance and Aircraft Impact Damage Analysis



- Reference structural, mechanical, and architectural models
- Baseline performance under design loads to estimate safety margins
- Aircraft impact damage to structural, mechanical, and architectural systems
- Comparison of responses to anticipated and actual abnormal loads
- Safety margin of towers immediately after aircraft impact

Investigation of Active Fire Protection Systems

- Analysis of design, operation and possible damage to of installed sprinkler, manual suppression, fire alarm, and smoke management systems
- Review of maintenance, modification, and inspection records and modifications made after 1993 bombing

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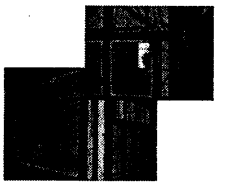
Reconstruction of Thermal and Tenability Environment

- Analysis of photographic/video images, witness accounts of damage

- Data on construction materials/systems, furnishings/contents, fuel loads



- Pathways for fire ventilation and compartment-to-compartment fire spread
- Performance of structural fireproofing and effects of vibration, impact, and shock
- Reconstruction of temperature/smoke movement due to fully involved fires, with and without initial damage from aircraft or incident debris

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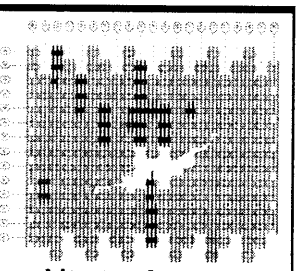
Baseline Structural Performance and Aircraft Impact Damage Analysis



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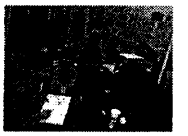

- Data on construction materials/systems, furnishings/contents, fuel loads

- Pathways for fire ventilation and compartment-to-compartment fire spread
- Performance of structural fireproofing and effects of vibration, impact, and shock
- Reconstruction of temperature/smoke movement due to fully involved fires, with and without initial damage from aircraft or incident debris

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Structural Fire Response and Collapse

- Response of floor and column systems under fire (standard and real fires, unprotected and protected steel)
- Response of WTC towers without and with aircraft impact damage under fire
- Identification of most probable collapse initiation and propagation mechanisms
- Performance of open-web steel trussed joists in fire
- Response of WTC 7 under fire conditions

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Occupant Behavior, Egress, and Emergency Communications

- Interviews, surveys of people affected by WTC disaster, and archival records from prior WTC evacuation incidents
- Evaluation of evacuation designs and protocols and comparison with code requirements and practices, and comparison of observations with predictions of alternate egress models and experience

Fire Service Technologies and Guidelines

- Analysis of data on first responder fatalities, command/control procedures, communication systems, on-site emergency information systems, fire alarm panels, elevator control panels, standpipes, fire hoses, etc.
- Effects of key factors on responder success including barriers to efficient performance and the ability to fight fires in upper floors of tall buildings
- Emergency response practices/technologies that could be used to improve effectiveness during extreme emergency incidents

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NATIONAL CONSTRUCTION SAFETY TEAM ACT (PL 107-231)

Purpose of Act:

"...to provide for the establishment of investigative teams to assess building performance and emergency response and evacuation procedures in the wake of any building failure that has resulted in substantial loss of life or that posed the potential for substantial loss of life."

Purpose of Investigations:

"...to improve the safety and structural integrity of buildings in the United States."

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NATIONAL CONSTRUCTION SAFETY TEAM ACT

NCST is an "NTSB-like" body...

- **Independent, objective, fact- (not fault-) finding**
- **Ability to collect, analyze, make public critical information**

Tasks NIST Director to establish teams, develop reports:

- **Launched within 48 hours**
- **Include at least one NIST employee**

Authorities:

- **Entry/Inspection**
- **Subpoena, Briefings, Hearings, Witnesses**
- **Priority (except for criminal act)**

First two investigations conducted under NCST Act:

- **World Trade Center collapse**
- **West Warwick, Rhode Island, Station Nightclub fire**

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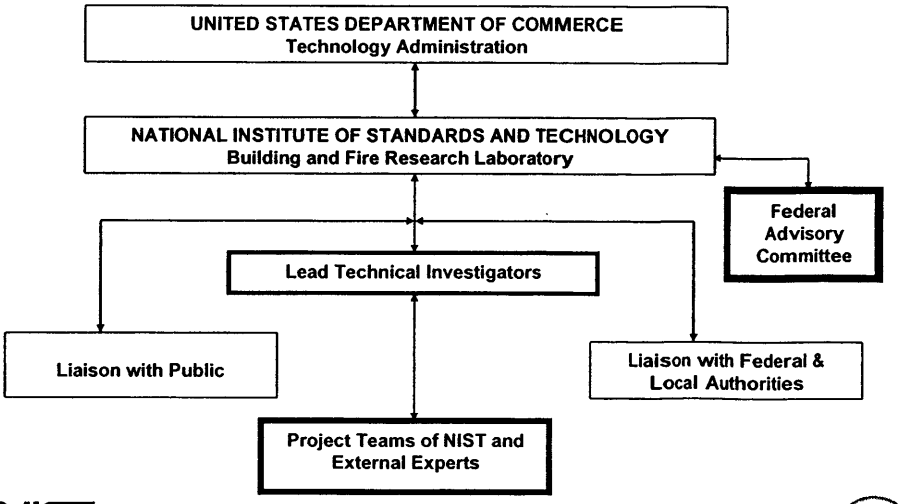
NCST Organization



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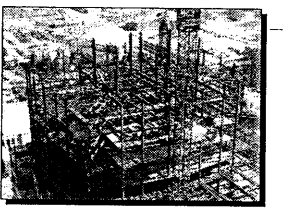
DISSEMINATION AND TECHNICAL ASSISTANCE PROGRAM (DTAP)

Concept:

- Forum through which facility owners and contractors deliver and disseminate results of research into ongoing projects and practice.
- Draw on top management, chief scientists/technology officers to motivate needed change.
- Complement and support parallel efforts of engineering societies to improve technology, codes, and standards.

Functions:

- Provide advice on best practices, guidance on vulnerability assessment, guidance on standards and codes needs.
- Disseminate and implement R&D outputs.
- Benchmark results
- Act as clearinghouse
  (Q&As, industry inputs, needs/priorities)



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SAFETY OF THREATENED BUILDINGS R&D PROGRAM

Objective:

- Provide a technical foundation that supports improvements to building and fire codes, standards, and practices which *reduce the risk of extreme threats* to the safety of buildings, their occupants and emergency responders.

Outcomes/Products:

- Increased structural integrity
- Enhanced fire resistance
- Improved emergency egress and access
- Building and emergency equipment standards and guidelines

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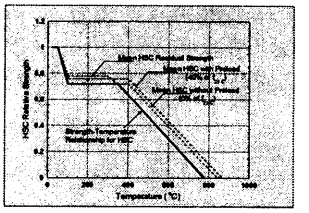
Increased Structural Integrity

Prevention of Progressive Collapse: To develop and implement performance criteria for codes and standards, tools, and practical guidance for prevention of progressive structural collapse.

- **No progressive collapse provisions in current U.S. building codes**
- **Lack of design tools**

Fire Safety Design and Retrofit of Structures: To develop and implement verified and improved standards, tools, methodology and guidance for the fire safety design and retrofit of concrete and steel structures.

- **Workshop to develop National R&D Roadmap**
  (with SFPE, Oct. 2003).



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Increased Structural Integrity

National Structural Fire Resistance Laboratory:

- **Concept - To enable structural fire resistance to be rigorously evaluated so that safety benefit of improvements to related building fire codes and standards can be demonstrated to all major stakeholders.**
- **Provide Quantitative Basis for Scaling Rules**
- **Measure Thermal and Mechanical Properties of structural and non-structural materials up to point of failure**
- **Measure Behavior of Connections and Assemblies**
  Experimental methods and protocols for measuring the response of structural connections (including welds, bolts, rivets and adhesives) when exposed to severe fire conditions and loads
- **Standard Test Methods, Computational Models and Codes**
  Establish ability to predict performance of coupled building systems to the point of impending failure in a fire.

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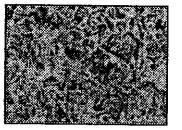
Enhanced Fire Resistance

Fire Protective Materials for Structural Steel: To develop and implement performance-based standards, tools, and practical guidance for design and selection of fire-protective materials for structural steel.

- Microstructural and materials science approach to adhesive, mechanical, and thermal properties.



Standard Test Method for Evaluating the Fire Resistance of Structural Steel: To develop efficient test method for evaluating fire resistance of structural steel.

- Benefits of FR steel not adequately tested under ASTM E119

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Enhanced Fire Resistance

Methodology for Fire Resistance Determination and Simulation of Building Partitions: Provide technical basis for accurate measurement and simulation methodology for inclusion of fire resistance properties of non-load-bearing, gypsum-based walls and ceilings in performance-based fire safety design

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Improved Emergency Egress and Access

Emergency Use of Elevators: To develop technical and procedural means to allow use of elevators during emergencies to supplement occupant egress by stairs, for evacuation of occupants with disabilities, and for first responder access

Occupant Behavior and Egress: To provide underlying phenomena and data to support best practices for design and performance prediction of egress in large buildings

- **Produce egress model classification**
- **Identify sources of uncertainty and variability**

Sub-lethal Toxicity: Develop a strategic list of elements needed for use in including smoke toxic potency in fire risk and hazard assessment.

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Building and Emergency Equipment Standards and Guidelines

- **Establish facilities and science-based exposures for measurement of firefighter equipment performance attributes essential to support informed fire service procurement decisions.**
- **Develop analysis tools and guidance for the assessment and subsequent reductions in the vulnerability of buildings to CBR attacks.**
- **Obtain understanding of properties and mechanisms controlling effectiveness of photocatalytic air cleaners in eliminating harmful CB agents.**
- **Develop standard building information models facilitating simulation of building system behavior during adverse events.**
- **Develop tool for building owners and managers to aid in selection of cost-effective strategies for management of terrorist and environmental risks.**

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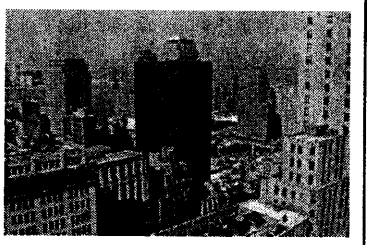
Desired Outcome of WTC Investigation, Research, and Dissemination Programs



- Enhanced safety of emergency responders
- Better protection for occupants and property
- Improved emergency procedures and capabilities during future disasters
- Safer high-rise buildings constructed and operated in a cost-effective manner

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Parting Thoughts

The power of deterministic approaches for fire risk assessments is being realized by broader segments of the fire protection and building industries.

The limitations to these approaches, especially for performance-based codes and design practices, need to be kept in mind by all stakeholders.

The challenges for the scientific and engineering professions are

- to quantify the uncertainty in these assessment methods;
- to extend them to the performance of whole building systems;
- to allow predictions beyond the requirements of the code to the point of failure; and
- to somehow incorporate human behavior into the mix

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