FIRE SAFETY RESEARCH AT NIST

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The Fire Research Division is one of four Divisions in the Building and Fire Research Laboratory (BFRL) at the National Institute of Standards and Technology (NIST). The Division is composed of approximately 58 full time employees, 25 Guest Scientists and several post-doctoral associates. The technical background of the staff includes engineering, mathematics, chemistry, and physics. The Fire Research Division Budget in 2002 was approximately $13 M, with half of the support coming from government agencies and private industry. The goal of Fire Loss Reduction is one of four technical research areas in BFRL. The intent of this research is to provide engineered fire safety for people, products, facilities and enhanced firefighter effectiveness. The goal is broken into the four component programs described below.

The objective of the first component program is to eliminate the risk of flashover cost-effectively by enabling 1) new/improved materials whose fire resistance does not negatively impact performance, cost, or the environment; 2) early and certain fire and environment sensing; and 3) automatic fire suppression technologies compatible with occupants and the environment. Flashover is the dramatic and sudden transition from a relatively small, slowly developing fire to a much larger and dangerous fire in which all flammable surfaces within the enclosure are involved. Flashover is generally accompanied by a significant increase in the heat release rate, extension of flames out open doors and windows, and a dramatic increase in the production of toxic fire products.

Fire statistics do not report directly the occurrence of flashover. Estimates based on the extent of fire damage indicate that roughly 30 % of reported fires transition to flashover and that these were responsible for 80 % of fires deaths and property damage in buildings in 1999. Reducing the risk of flashover offers an opportunity to significantly reduce the high human and property costs of fire. Means exist to prevent flashover: e.g., by having a fire fighter always on the scene, by installing sprinklers, or by limiting the contents of the room.

The problem is that these means of prevention lack public acceptance because they are not affordable, reliable, flexible, and/or predictable. Standard test methods are generally not applicable to new technologies, and models for fire growth on realistic objects do not yet exist. The lack of effective fire spread and growth models is recognized as a major obstacle to the implementation of performance-based codes. A major impediment to efforts to reduce the risk of flashover is insufficient understanding of fire growth and spread on room contents. The unavailability of appropriate fire growth and spread models is a serious roadblock to the implementation of performance-based fire standards. A substantial effort is being undertaken to improve the experimental and theoretical understanding of fire growth and spread within enclosures, with the goal of developing a modeling capability for real-world room contents that can be reliably used for fire safety engineering, product design, and materials assessment. BFRL has made significant progress in cost-effective approaches that reduce the flammability of polymers while improving or maintaining physical characteristics. Introduction of these materials into the market will accelerate fire safety. Active measures to limit fire growth require reliable early fire detection and effective suppression approaches. As an example, elimination of false alarms would allow detector systems to be wired directly to the fire fighting service, which, in turn, would reduce the response time to a fire. Directed research designed to enhance fire detector sensitivity while reducing the number of false alarms and to improve suppression effectiveness are being carried out. Component projects include:

- Real-scale specification and testing
- Flame radiation
- Early, fault-free detection
- Flammability measures for electronic equipment
- Micro-scale high throughput optimization of flame retarded polymers
- Bench-scale high throughput flame retardancy measures

The objective of the second component program is to enhance fire fighter safety and effectiveness through research and help achieve a 50% reduction in line-of-duty fatalities and burn injuries in the United States by 2012. Fire fighting operations proceed with very limited information about the extent of fire involvement, structure safety, hazards, and even the location of fire fighters. To be safer and more effective, incident commanders and fire fighters need access to reliable and timely information regarding fire conditions, developing hazards, and the location and condition of resources. Efforts are underway to explore new technology for protective clothing, wireless transfer of information from fire alarm systems, evaluation of performance of thermal imagers and exploring the use of thermal imagers for hazard sensing, acoustic sensing of weak roof structures, and capabilities of durable agents to protect structures from external fires. Component projects are:

- Developing a heat transfer model for fire fighter protective clothing under wet and dry conditions with associated material property database, which will be assembled into an effective training tool and software to assist in design.
- Working with a fire alarm manufacturers and the BFRL effort in Cybernetic Buildings, wireless means to deliver timely emergency information about conditions inside of buildings and predictions of developing hazards to first responders before they arrive at the scene is being demonstrated.
- The capabilities and limitations of the current generation of thermal imagers.
- A fundamentally based computational model is being developed to predict major features of the interaction of structures with wind-driven fires utilizing FDS.
- The capabilities of acoustic sensing to determine weakness in roof structures.
- Nano-particles added to polymer gels used to protect external structures against fire have been shown in laboratory scale experiments to greatly increase the durability of the gel. Based upon work completed last year in a grant, a standard method to determine the performance in full scale will be investigated to allow durable agents with different nano-particle formulations to be evaluated.
- To aid the fire services in keeping abreast of developments in research, information on fire service related research is being distributed electronically.

The objective of the third component program is to lead the world in fire measurement and predictive methods, enabling engineered fire safety for people, products, facilities, and first responders. Engineering correlations developed through fire testing over the past 25 years have improved fire codes and technologies in the U.S. and produced a slow decline in the number of deaths and injuries due to unwanted fires; however, the total economic burden of fire in the U.S. continues to rise. To counteract these losses, new fire safety technologies and performance-based codes are needed that can only be achieved by a higher level of understanding of the dynamics of fire, and more certain measurement methods. Component projects include:

- basic research on the physics of fire to improve our knowledge and capabilities in quantitative methods in heat release rate, heat flux (including spectral and total radiation), room flows, soot/smoke, and water sprays.
- advanced instrumentation with emphasis on measurement accuracy, precision, and interpretation of measurements through models and analysis
- mass and heat transport phenomena involving gas phase and condensed phase processes and their interaction
- gas phase model enhancement - radiation submodel, boundary layer submodel, water spray submodel, flow boundary sensitivity, experimental validation
- combustion submodel development - pyrolysis submodel, soot formation/destruction submodel, experimental validation
- building structure fire model enhancement - real-scale fire validating demonstrations, HVAC/smoke flows
- expanded numerical simulations and computational fluid dynamics models of transport processes to encompass higher accuracy radiation, droplet and sprays models and semi-empirical sub-models of phenomena at the fuel/flame interface
- a Large Fire Laboratory (LFL) with advanced measurement capabilities that promote the understanding of full and reduced-scale fire phenomena
- reference data for model input against which predictions can be compared and validated and made available electronically to the fire community
- tools and knowledge that enable the implementation of performance based fire codes, allow assessment of key test methods and address international barriers to standards and the role of uncertainty in regulations.
- transfer of BFRL research results to industry as well as to organizations that create fire standards and codes.
- guidance to U.S. fire testing laboratories to identify and address research needs.
- FRIS as the source of easily-accessible fire information and data.

The objective of the fourth component program is to investigate the building construction, the materials used, and the technical conditions that combined to cause the World Trade Center (WTC) disaster. This work is under planning and will serve as the basis for improvements in the way buildings are designed, constructed, and used; improved tools, guidance for industry and safety officials, revisions to codes and standards, and improved public safety.

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Anthony Hamins

May 2, 2002

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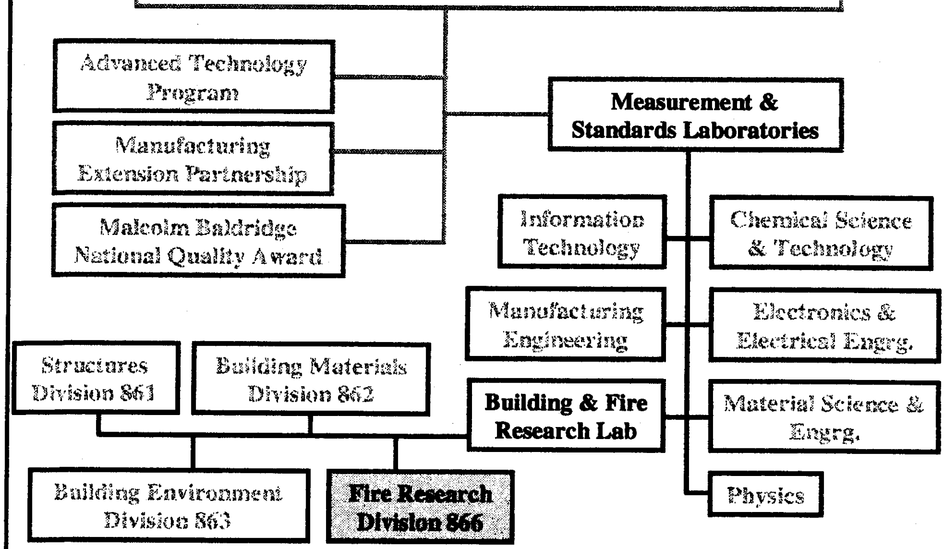
Where We are in NIST



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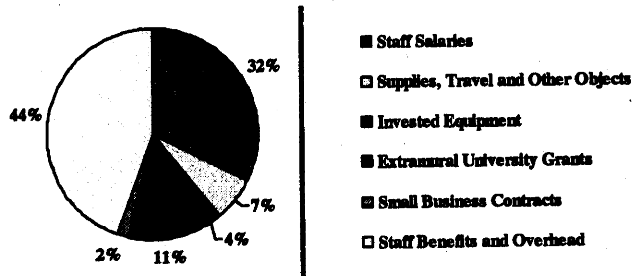
Fire Research Division



BFRL Fire Research Budget (FY02): STRS ($6 M); OA ($6 M)

Staff: 58 FTE (24 PhDs), 25 Guest Scientists (ATF, NRC, Univ.) & 3 post-docs

Background: engineers, mathematicians, chemists, physicists

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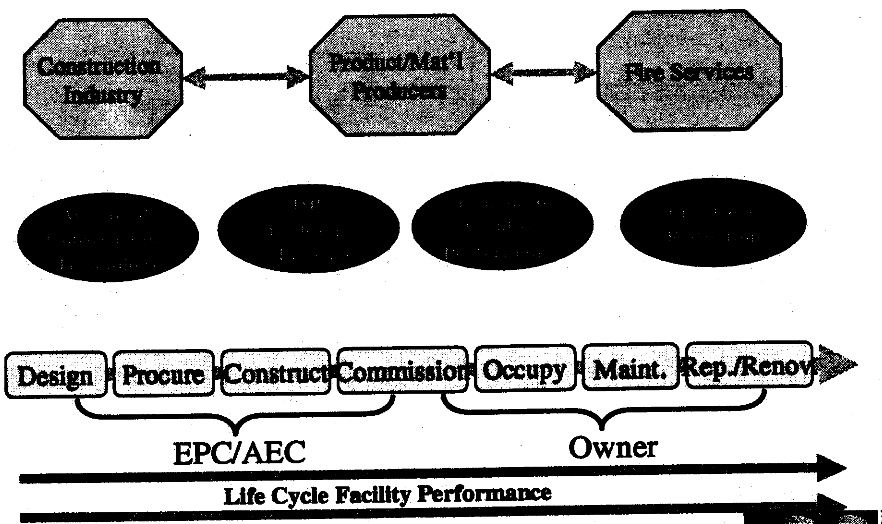
BFRL Focus: Four Technical Goals



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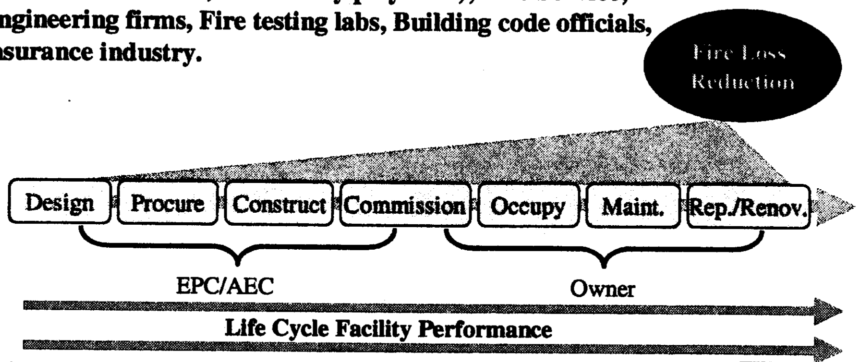
Fire Loss Reduction Goal

Goal: Enable engineered fire safety for people, products, facilities; and enhanced fire fighter effectiveness

Customers: Manufacturers (fire protection equipment, fire retardant chemicals, commodity polymers); Fire Service; Engineering firms, Fire testing labs, Building code officials, Insurance industry.



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Strategy to Reduce Fire Losses (1/2)

Reduce *residential fire deaths, injuries and property losses* by

- **adapting measurement and predictive methods to better understand conditions leading to *flashover*,**
- **enabling early and certain fire and environment sensing,**
- **advancing cost-effective fire suppression technologies; and**
- **enabling new/improved materials whose fire resistance does not negatively impact performance, cost, or the environment.**

Reduce *fire fighter line-of-service deaths and burn injuries* by

- **providing new *technology*, measurement standards, and training tools; and**
- **enabling shift to an information rich environment.**

Enable cost-effective *engineered fire safety* for people, products, facilities, and first responders by

- **advancing *fire measurement and prediction methods***
- **accumulating and archiving data, and**
- **accelerating their transfer to practice.**

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Strategy to Reduce Fire Losses (2/2)

Reduce fire fighter and occupant vulnerability in extreme fire events which threaten *homeland security* by

- **applying measurement and predictive methods to *identify role of fire in World Trade Center collapse*, and**
- **improving methods of *structural fire protection* and *protection of emergency responders*.**

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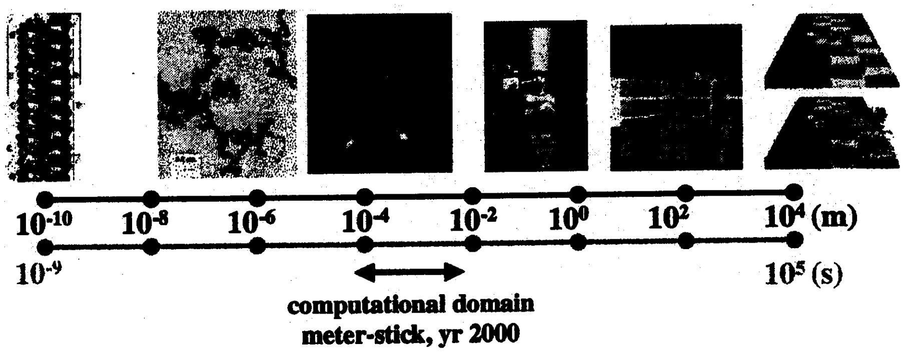
Technical Challenges to Fire Research



Challenge: Understand/predict fire behavior over 14 orders of magnitude in length (and time) scale

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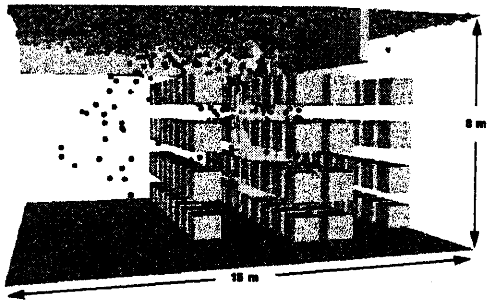
Fire Dynamic Simulator (McGrattan)



- fire protection applications
- performance based design
- fire investigations
- education/training

- runs on fast PC
- large eddy simulation (LES) of gas phase flow
- mixture fraction
- Finite volume method for radiation transport equation based on 100+ discrete angles

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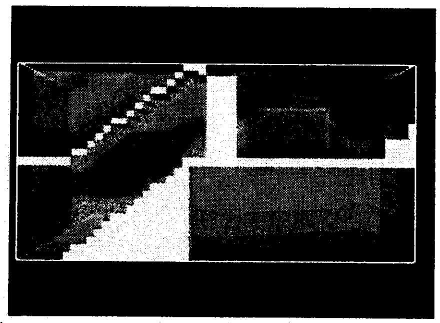
Fire Reconstruction Modeling Project (Madrzykowski)

- NYC – 3 fire fighters die inside apt. bldg. following flashover & wind driven fire
- DC – 2 fire fighters fatally burned in townhouse fire
- Keokuk, IA – 3 fire fighters die inside house following flashover



- New tool used to gain insight into fire events resulting in some fire fighter fatalities
- Continuing to improve model capabilities in response to needs and feedback from investigations

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COMMUNITY-SCALE FIRE SPREAD (R. Rehm)

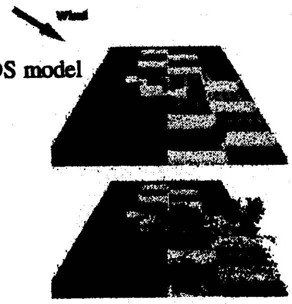
1993 Laguna Fire (Newsweek)

Site Specific Fire Model

- Fire spread between buildings and the natural environment
- Fire protection strategies
- Quantitative planning & training tool

- Full-scale performance data of building materials and assemblies.

- physics-based fire spread calculation using NIST FDS model



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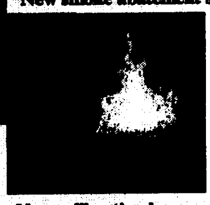
Large Fire Laboratory Operations (Mulholland)

- **renovated facility on-line ($ 7 M)**
- **implement advanced measurement capabilities ($1.5 M)**

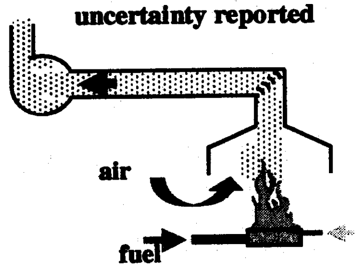
~10 MW heat release rate

New smoke abatement system



New calibration burner

- **Best-practices to ensure minimal, quantified uncertainty reported**



- **O_2-depletion calorimetry**
- **mass flow measurement in duct using He doping**

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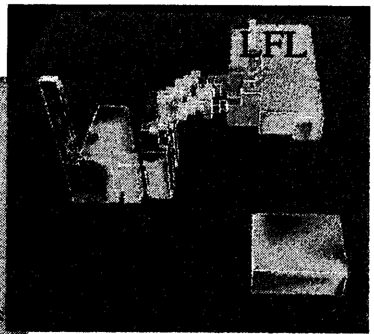
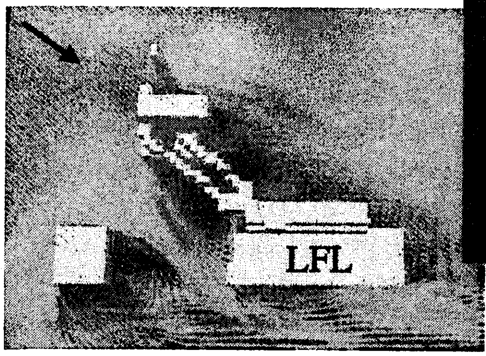
Wind Effects (Rehm)

- effects of topography & obstacles on wind fields
- effects of external winds on flows inside of the LFL



Simulated surface pressure on the LFL



Simulated flow vectors 4 m above the ground near the LFL

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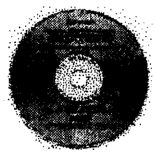
Information and Data (Reneke)

Fire Research Information System (FRIS)
- **unique fire library (60,000 holdings)**
- **Planning underway for transition to e-FRIS**



Fire Data Management System
- **create a centralized database of fire data and exchange format for use by researchers & testing laboratories**

Codes And Standards (Bukowski)

- **NFPA Standards Council (+15 other NFPA Technical Committees)**
- **CIB W14 (Fire, TG37 - Performance-based Bldg. Regulations)**
- **ISO (TAG8, TC92)**
- **ASTM (E5, Fire Standards,...)**
- **Korean test method used for measuring fire resistance of wood construction**
- **Cigarette ignitability test methods**
- **ICC Performance Code Development Com.**

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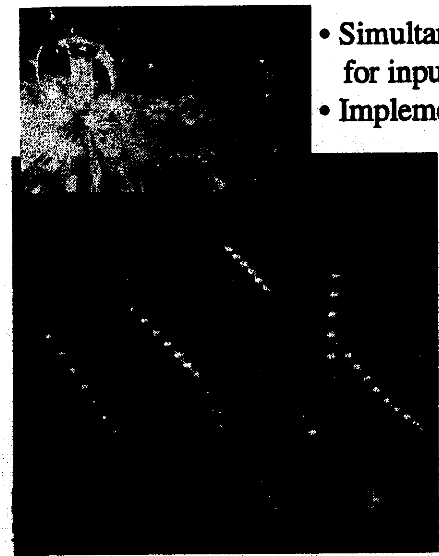
Planar laser measurements of Sprinkler Flows (Putorti)

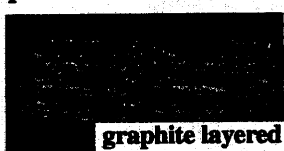


- Simultaneous sprinkler droplet size & velocity for input and validation of CFD fire models
- Implement in LFL

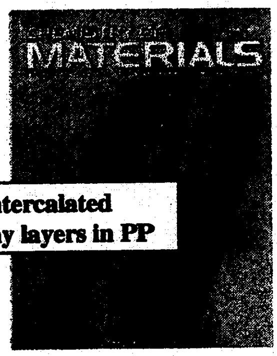
- Fluorescing droplets for sizing
- Particle tracking for velocity
- Non-intrusive, instantaneous
- Large area (1m by 1m)
- Laser sheet. 2D measurements.
- 2 lasers, 2 wavelengths, 2 pulses.
- High resolution film camera

Less Fire-prone Materials Project (Gilman)

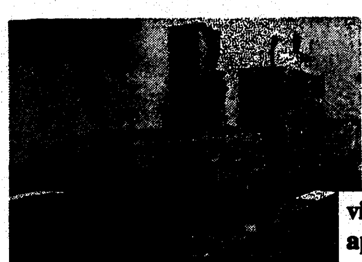
Commodity polymers with nm-sized inorganic layers interspersed can improve mechanical, thermal & flame resistant properties.



graphite layered PP nanocomposite simulation



TEM of intercalated silicate clay layers in PP



viability of high-throughput approaches to formulate/screen new flame retardants/fire resistant materials explored.

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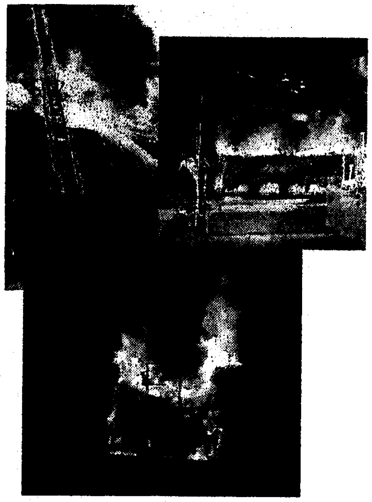
Prediction of Fire Growth and Spread (W. Pitts)



Predict detailed fire behavior:
- **effects of geometry (realistic items)**
- **materials (dripping, bubbling, chemical effects)**
- **charring**

Challenge: develop a physics-based pyrolysis model relating fuel flux to heat feedback

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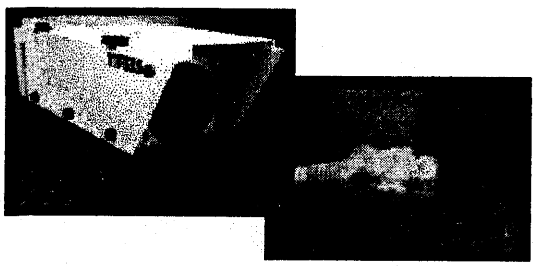
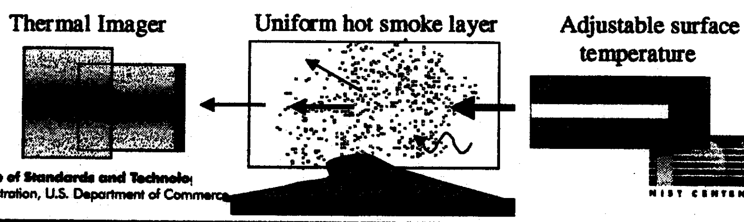
Characterization of Thermal Imagers (Widmann)

Develop an evaluation facility to test the capabilities and limitations of commercially available thermal imagers.



Infrared viewers see through smoke for fire fighting applications.



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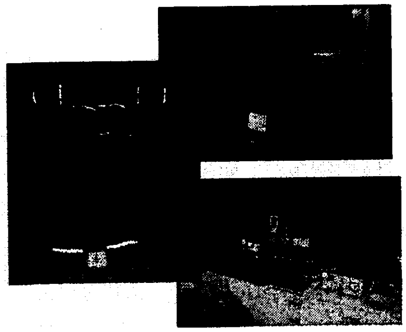
Protective Clothing Project (R. Lawson)

- Develop instruments & methods for measuring thermal environments for fire fighters' protective clothing and equipment - NIST, USFA, NIOSH & FDNY



Decision Aids Project (W. Jones)

- Develop a prototype advanced (smart) fire alarm panel that will
  - identify the location of a fire in a building
  - determine fire characteristics
  - operate as part of the cybernetic building systems
- Develop prototype fire service devices
  - standardized graphic/icons for information
  - scalable, prioritized communication
  - wireless transmission

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NIST Response to 9/11 Events

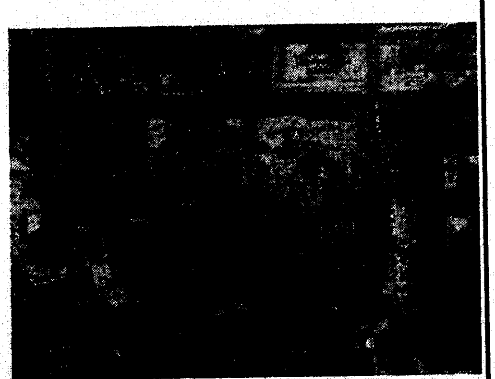
I. National Building and Fire Safety Investigation of the World Trade Center Disaster

II. Structural Fire Protection

III. Human Behavior, Emergency Response & Mobility

IV. Building Vulnerability Reduction

V. National Construction and Infrastructure Forum



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IRSN

Future Fire Research at IRSN

- IRSN strategy in Fire Research
- Experimental programs in progress
- Fire scenarios selected
- Fire research needs

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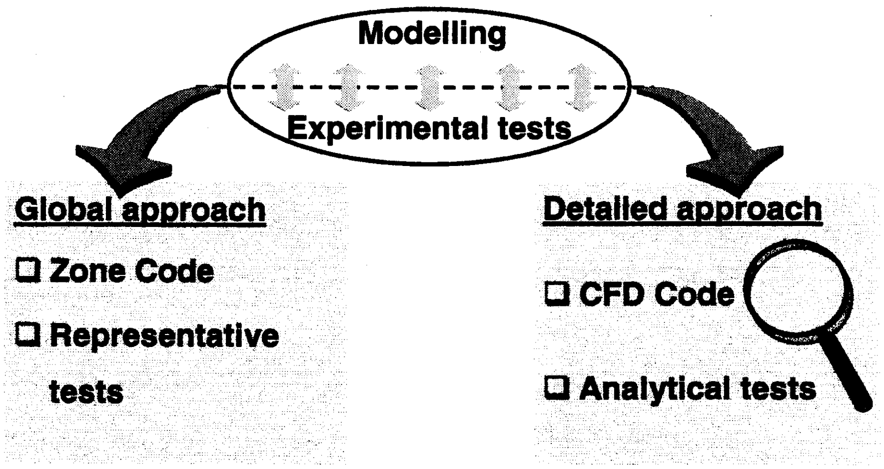
IRSN

IRSN Strategy in Fire Research

- Strategy of IPSN in fire safety research



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IRSN Strategy in Fire Research

- **Fire Modelling**
  - Approach of Modelling

Global Approach
FLAMME_S
Fast and global evaluation studies

Detailed Approach
ISIS
More precise evaluations in specific complex configurations

Two Zone & CFD Approaches
SYLVIA
To provide different modelling levels for various users

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Experimental program in progress

- **Representative tests**
  - FLIP: Fire scenario in a confined and forced ventilated enclosure
  - DIVA: Fire propagation through several rooms
- **Analytical tests**
  - CARMELA: Electrical cabinets

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Fire scenarios selected (1/2)

- **Fire scenarios ranking Approach**
  - Lists of fire scenarios of each IRSN team :
    - Emergency plans
    - Deterministic fire risk assessment
    - NPP fire PSA
  - First ranking by each team (ignition source frequency, dominant scenarios of fire PSA or importancy of releases)
  - Last ranking of all fire scenarios

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Fire scenarios selected (1/2)

Glove box fire	1st rank	Nuclear facility
TBP/TPH fire	2nd rank	Nuclear facility
Fire of solid waste drums	2nd rank	Nuclear facility
Electrical cable fire	4th rank	NPP
Relay room fire	5th rank	NPP
Pyrophoric metal fire	6th rank	Nuclear facility
Electrical cabinet fire	6th rank	NPP
Fire propagation to a compartment located above	6th rank	NPP
Fire in the Containment	9th rank	NPP
Fire in a benchboard of the control room	10th rank	NPP

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IRSN — Fire Research Needs

- **Topics selected**
  - ✗ Combustion parameters
  - ✗ Soot production
  - ✗ Improvement of the plume model in a confined and ventilated configuration
  - ✗ Explosion hazards due to the non-burnt residues
  - ✗ Fire propagation towards other fire sources
  - ✗ Damage criteria for equipment and electrical cables

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IRSN — Fire research needs: Combustion parameters

Objectives

- Caracterisation of the fire source (establishement models to estimate the combustion mass rate, the combustion efficacity, flamme spread velocity)

State of the Art

- Combustion parameters :

$HRR = m . S . \Delta H$

m : combustion mass rate
S : combustion area
ΔH : combustion heat
Vf : vitesse de flamme

$\Delta H = \chi . \Delta Ht$

χ : combustion efficiency
ΔHt : complete combustion heat

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Fire research needs
Combustion parameters

State of the art (cont')

- **Parameters taken into account**
  - ➾ *m, ΔHt et Vf are combustible caracteristics*
  - ➾ *m et Vf depends on size and geometry of the combustible, of its position vertical or horizontal and of its temperature*
  - ➾ *m, χ et Vf change during the fire scenario*
- **Tests**
  - ➾ *m can be measured in a cone calorimeter*
  - ➾ *During full scale fire test the mass loss rate can be measured continuously but it is not easy to measure the HRR, moreover during flame propagation or fire extinguishing the combustion surface changes strongly*
- **Usually existing data are for unconfined fire (fire over oxygened)**

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IRSN

Fire research needs
Combustion parameters

Objectives and approach

✗ **Models for computer zone codes**

- to estimate m according to the fire (combustible, geometry, position ...)
- Taking into account S evolution notably during the fire growth and extinguishing
- Impact of ambient confined (O_2 concentration, CO, CO_2, soots, Tgaz...) on m, Vf and χ

✗ **Approach**

- State of art report (in progress)
- In the first stage, study of fluid and solid combustible without radionuclid
- 3 steps
  - ➾ *Scale effect on m and χ*
  - ➾ *effect of ambient conditions on m and χ*
  - ➾ *Effect of scale and ambient conditions on Vf*
- Development and qualification of a model for a first combustible
- Adaptation of the model to the combustibles of selected fire scenarios

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