

NIST Response to the World Trade Center Disaster

World Trade Center Investigation Progress

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Progress Outline

- Status of Data Collection Efforts
- Interim Report on Fireproofing of WTC Floor System
- Fire Model Validation Experiments and Plans for Fire Testing of WTC Floor System
- Approach for Assessing the Most Probable Structural Collapse Sequence
- Status of Steel and its Analysis
- Photographic and Videographic Image Collection and Analysis
- First-Person Data on Occupant Behavior, Evacuation, and Emergency Response
- Selection of External Experts and Contractors

1. Status of Data Collection Efforts

- Solid foundation of technical evidence for review, analysis, modeling, and testing work
 - Building documents, video and photographic records, emergency response records, oral histories, recovered WTC steel
- NIST has received considerable cooperation and large volumes of information from a variety of organizations and agencies
 - Building designers, owners, leaseholders, suppliers, contractors, insurers
 - Local NYC authorities (FDNY, NYPD, DDC, DOB, OEM)
 - OSHA (correspondence on evacuation experience of WTC occupants)

Pending Information Requests/Needs

- NIST requests for materials that are currently pending with, or not yet located and/or provided by, several organizations
 - 9-1-1 tapes and logs, transcripts of about 500 first responder interviews
 - Supporting documents for McKinsey & Company's FDNY study
 - FDNY communication system and radio repeater network
 - Complete set of NYPD records identified in request lists submitted by NIST to NYPD
 - Contents of aircraft (cabin furnishings, cargo, etc.) that contributed to fires
 - Descriptions of the most recent partitions and furnishings in most of the tenant spaces of WTC 1, 2, & 7
 - Reports of critical UL tests performed for the supplier of fireproofing materials
- **It is vital that this information be made available to NIST**

Status of Project Specifications

- Complete set of project specifications not located:
 - Original contract specifications for WTC towers
 - Complete set of tenant alterations, construction logs, maintenance logs for WTC 1, 2, & 7
- Specifications provided to NIST
 - Procurement of materials (steel, concrete) from individual suppliers
- May be possible to reconstruct project specification partially from
 - Individual subcontract and purchase specifications
 - Individual reports for design and fire protection etc.
- NIST is working to locate the complete set of project specifications

Status of As-Built Drawings

- Complete set of as-built drawings not available (WTC 1, 2, 7)
- NIST has original contract drawings for WTC tower *structure*, including revisions made during bid and construction
- NIST has supplementary drawings for majority of WTC tower tenant *structural* modifications:
 - Mostly openings to floor framing systems (WTC 1, 2, 7) to meet tenant needs
 - Strengthening of core columns in upper stories of WTC towers to accommodate additional gravity loads
 - Repairs made to restore structural integrity of inadvertently damaged steel straps that were used to brace floor system to columns

2. Interim Report: WTC Floor Fireproofing

- Documents procedures and practices used in fireproofing of WTC floor system
- Based on review of factual data in the documents reviewed by NIST
 - Few instances of conflicting data or data that need some interpretation
 - Facts presented without interpretation to maximum extent possible
- **Nothing in report should be taken to imply floor trusses played a critical role in collapse of WTC towers**
 - **Issue is a key component of ongoing investigation**
- NIST continues to seek, receive, and review additional data on the subject
 - Maintenance and inspection records for WTC towers from different sources
 - Reports of critical UL tests performed for the fireproofing materials supplier
 - Information on ability of fireproofing material to withstand shock, impact, and vibration
 - NIST welcomes additional factual information from organizations or individuals
- NIST will review all information and update report as needed

Major Findings of Interim Report (1)

- Port Authority instructed its consulting engineers and architects to comply with NYC Building Code early in design phase (May 1963)
 - The 1961-1962 revision to 1938 edition of NYC Building Code was in effect
 - In 9/1965, PA instructed designers to revise plans to comply with second and third drafts of what became 1968 edition of the NYC Building Code
 - MOUs established in 1993 with DOB and FDNY
- Per 1968 NYC Building Code:
 - Construction Class IB
 - Columns 3-hour rating; floors 2-hour rating
- Fireproofing Material and Thickness Requirements:
 - No thickness information on project specifications or drawings
 - PA directed contractor to apply 1/2 in. of fireproofing to bar joists
 - Bar joists fireproofed with Cafco Blaze-Shield Type D, an asbestos-based spray-on material
 - After fireproofing 38 floors of WTC 1, material changed to Cafco Blaze-Shield Type D C/F, a non-asbestos product

Major Findings of Interim Report (2)

- Fireproofing Thickness Measurements (all from first 38 floors of WTC 1)
 - A few sample area data sheets, from surveys in 1990s as part of asbestos litigation, report fireproofing thickness was consistently about 1/2 in.
 - Measurements in 1993 on 16 random bar joists from two (out of 220) floors:
 - Average thickness for all 16 joists: 0.74 in.
 - Range of average thickness per joist: 0.52 in. (minimum), 1.17 in. (maximum)
 - Minimum thickness exceeded 1/2 in.
- WTC towers retrofitted with sprinklers by 1990s (per NYC Local Law No. 5, effective 1973)
 - Towers remained classified as Class IB, while it was possible to lower fire rating requirements to Class IC

Major Findings of Interim Report (3)

- Fireproofing requirements and guidelines upgraded in the 1990s:
 - Study performed by Port Authority in 1995 concluded that 1-1/2 in. of fireproofing was required for chords and web members
 - Port Authority issued guidelines in 1999 for fireproofing repairs, replacement, and upgrades adopting the 1-1/2 in. thickness
- Status of fireproofing upgrade in 2000:
 - Fireproofing upgraded in about 30 floors of aircraft impacted region
 - WTC 1: Floors 92-100
 - WTC 2: Floors 77-78, 88-89, 92, 96-97
 - Construction audit reports suggest thickness requirements were met
 - Blaze-Shield II used for upgrade, not Blaze-Shield D C/F

Major Findings of Interim Report (4)

- Adhesion of spray-on fireproofing:
 - Adhesion problems reported with Cafco D during construction
 - A 2000 report also indicates that “existing fireproofing required so much patching that it was more effective to replace it with new fireproofing material”
 - Construction audit reports associated with fireproofing upgrade to 1-1/2 in suggest that the minimum bond strength requirement for spray-on fireproofing was met
- Fire endurance testing of WTC floor system
 - Architect of Record and Structural Engineer of Record stated in 1966 and 1975, respectively, stated that the fire rating of the floor system could not be determined without testing
 - NIST has been unable to locate any fire endurance tests conducted on the specific WTC floor system
 - NIST intends to carry out testing to assess the fire rating and behavior of a typical fire-protected floor assembly under the fire conditions prescribed in ASTM E 119
- Property condition assessment in 2000 based on existing fireproofing conditions:
 - “The rating of the structural fireproofing in the Towers and subgrade has been judged to be an adequate 1 hour rating considering the fact that all Tower floors are now sprinklered”
 - Noted ongoing program to upgrade the fireproofing thickness to 1-1/2 in, in order to achieve a 2 hour rating

Major Findings of Interim Report (5)

- From documents reviewed, NIST has not been able to determine the technical basis for the selection of fireproofing material for the joists, and the determination of the thickness of fireproofing to achieve a 2-hour rating
- A key NIST investigation objective is to determine what procedures and practices were used in the design, construction, operation, maintenance of the WTC towers and WTC 7; specifically acceptance procedures and practices for:
 - innovative systems, technologies, and materials
 - variances from requirements of building and fire code provisions
- **This historical information is expected to be of value to the professional community in identifying and adopting changes to procedures and practices that may be warranted**

3. Fire Model Validation Experiments and Fire Testing of WTC Floor System

- NIST is using a combination of analytical, experimental, and numerical tools to analyze alternative collapse hypotheses
- NIST is conducting experiments to provide input to its analytical and numerical work, including the validation of those results
- Fire performance of open-web bar joist systems
 - NIST is reviewing previously completed tests on open-web bar joist systems
 - NIST is documenting past performance using available fire incident and insurance investigation reports

Model Validation Experiments (2)

- Fire tests to validate fire dynamics and thermal-structural analyses
 - Large compartment fires: heat release and transfer rate to compartment gases (two different fuels)
 - Heat release rate to and temperature of steel
 - Truss and column specimens (geometry, cross-section)
 - Fireproofing: two thicknesses, no fireproofing
- Series of office work station fire tests to provide input to fire dynamics simulation tool:
 - Based on descriptions of furnishings used in WTC office space
 - Generate database of thermo-physical properties of the materials
- Fire tests to validate model predictions of sensitivity of fire intensity, duration, and spread to the distribution and nature of combustibles

Progress on Fire Model Validation Experiments (2)



Figure 2. Insulated steel components in place prior to Test 5. In the foreground are two steel trusses and a steel rod, supported across the lower chord panel points, positioned near the ceiling above the fire pan. The steel column is located between the air inlet and the fire pan.

Progress on Fire Model Validation Experiments (3)

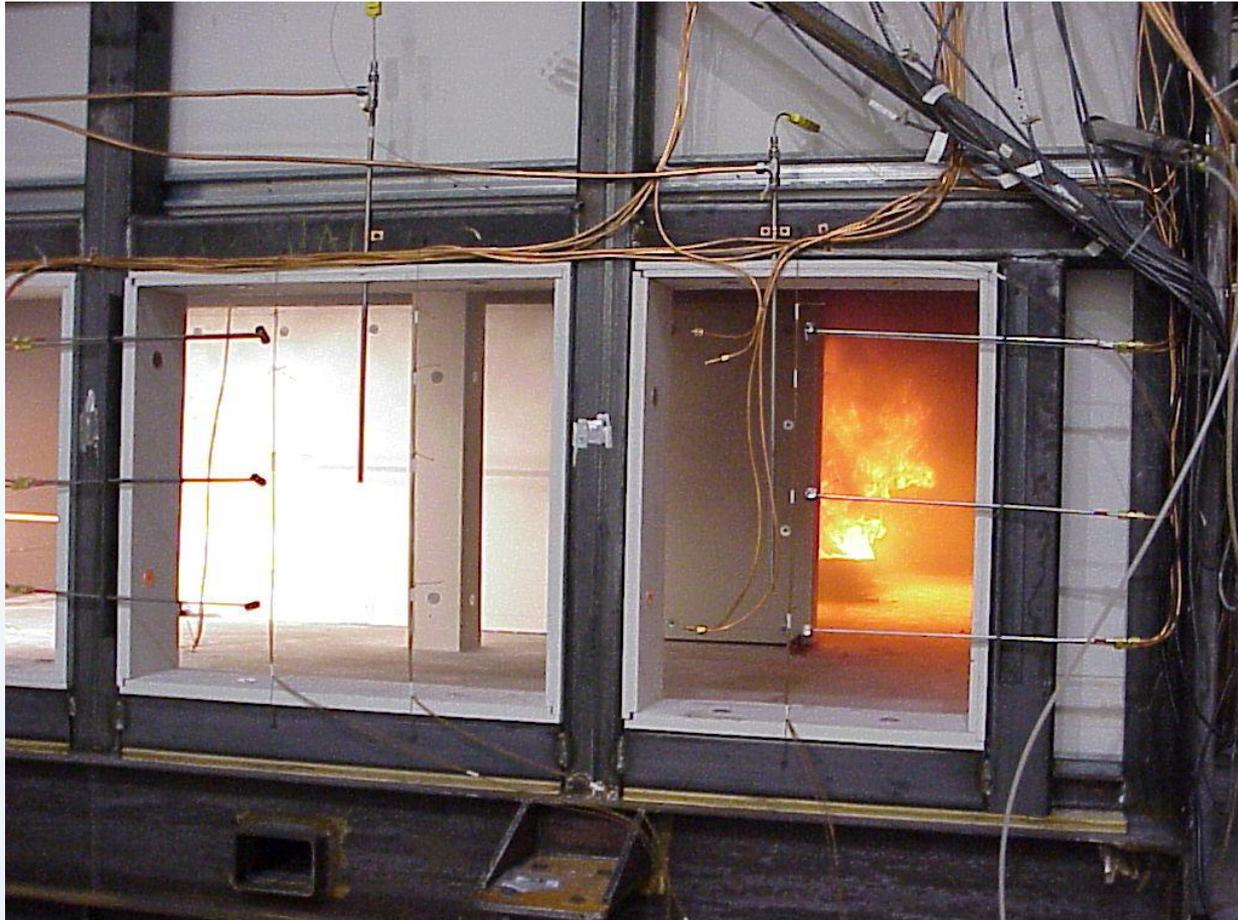


Figure 3. Inlet side of the compartment 5 minutes after ignition in Test 2. The fire is in the background. The foreground shows instrumentation for characterizing the air flow at the inlet. A baffle is located in front of the fire.

Progress on Fire Model Validation Experiments (5)



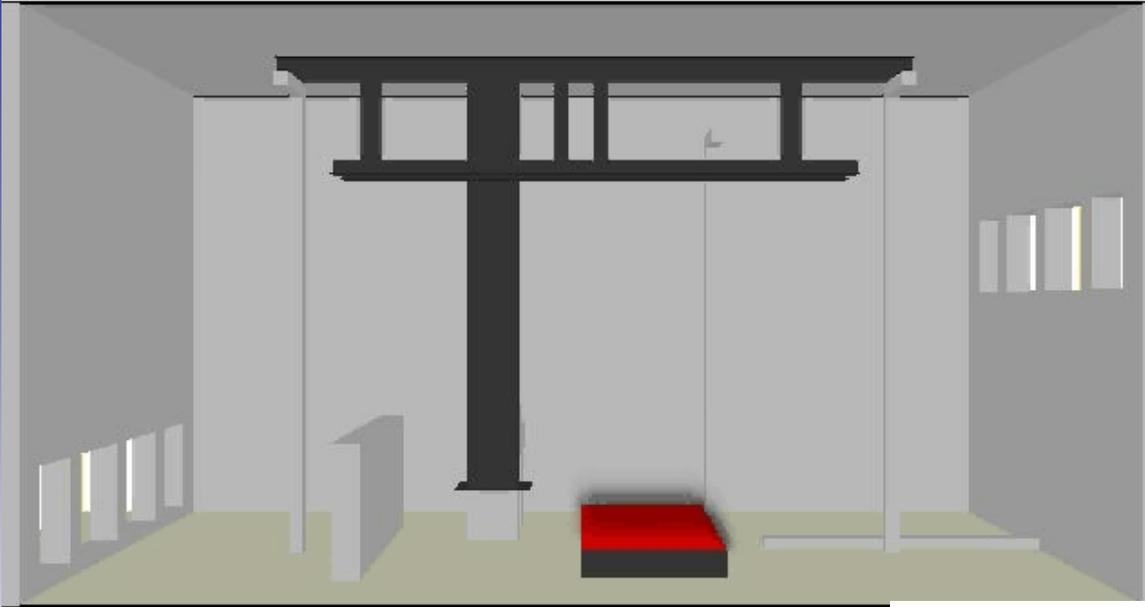
Figure 5. View of compartment from air exhaust outlet several minutes after the start of test 6. Note the flame impingement on the steel trusses and bar.

Progress on Fire Model Validation Experiments (6)

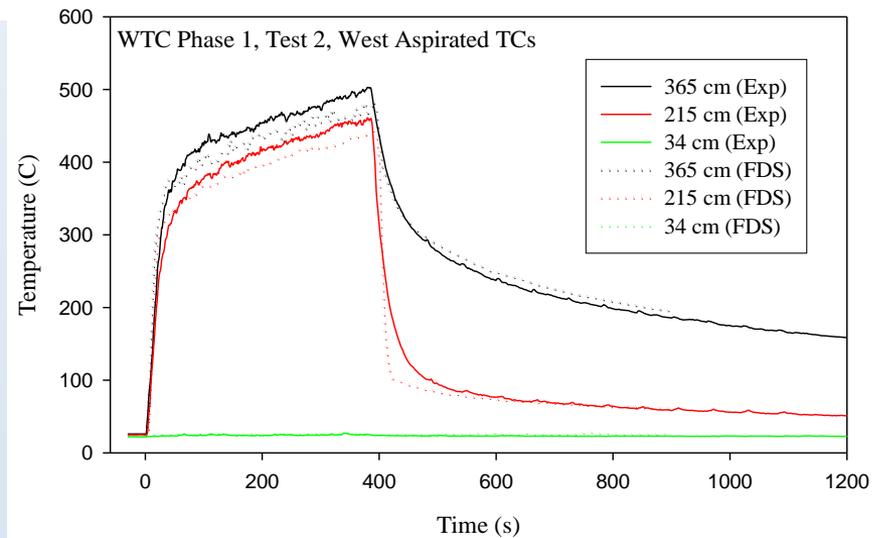


No Picture

WTC fire test1.mpg



Progress on Fire Model Validation Experiments (8)



4. Assessing the Most Probable Structural Collapse Sequence

- Several leading hypotheses postulated publicly by experts for the structural collapse sequence between aircraft impact and collapse of WTC 1 and 2
- Little information on initial damage and source of fire ignition in WTC 7
- **NIST considers it premature to exclude any of the postulated hypotheses; NIST is analyzing these and other possible collapse sequences**
- Objectives of formal approach to analyzing complex failure sequences failure in WTC 1, 2, and 7:
 - What is the most probable collapse sequence?
 - What confidence levels are associated with it?
 - What is the probability of other collapse sequences?
 - What parameters influence on the most probable collapse sequence?

Key Analysis Components to Assess Most Probable Structural Collapse Sequence

- **Impact damage analysis**
 - Determines probable damage states in aircraft impacted region
 - Provides initial building conditions for fire dynamics and thermal-structural response
- **Fire dynamics analysis**
 - Determines probable paths of fire spread from impact region up until time of collapse initiation
 - Determines probable time-histories of heat flux and temperature on the structure
- **Thermal-structural analysis**
 - Determines probable structural response to the identified fire paths
 - Identifies the probable sequences of component damage or failure
 - Provides initial conditions for analyzing the stability of the structural system
- **Collapse initiation analysis**
 - Determines most probable collapse sequence from identified component failure sequences
 - Stability analysis of the structural system for each identified component failure sequences
- **Develop, validate, and use simplified models to extent possible**

5. Status of Steel and its Analysis

- NIST has nearly 250 pieces of WTC steel in its possession
 - Vast majority of significant size (exterior column-spandrel panels, box beams, wide flange, truss, channels); several smaller pieces such as bolts
 - Cataloged 235 pieces as of March 28, 2003; includes database with photographic records and member markings
 - Small fraction of WTC steel examined at several salvage yards in cooperation with SEAoNY
- NIST has examined additional steel stored by Port Authority at JFK airport; 12 specimens transported to NIST
- Steel in NIST's possession represents roughly 1/4 to 1/2 percent by weight of the approximately 200,000 tons of steel used in WTC towers

Steel from WTC Towers



Clean weld fracture of Interior columns



Failure at
connection
between floor
system and
exterior
columns

Dr. John Fisher (Lehigh) and Robert Duvall (NFA)



WTC steel columns



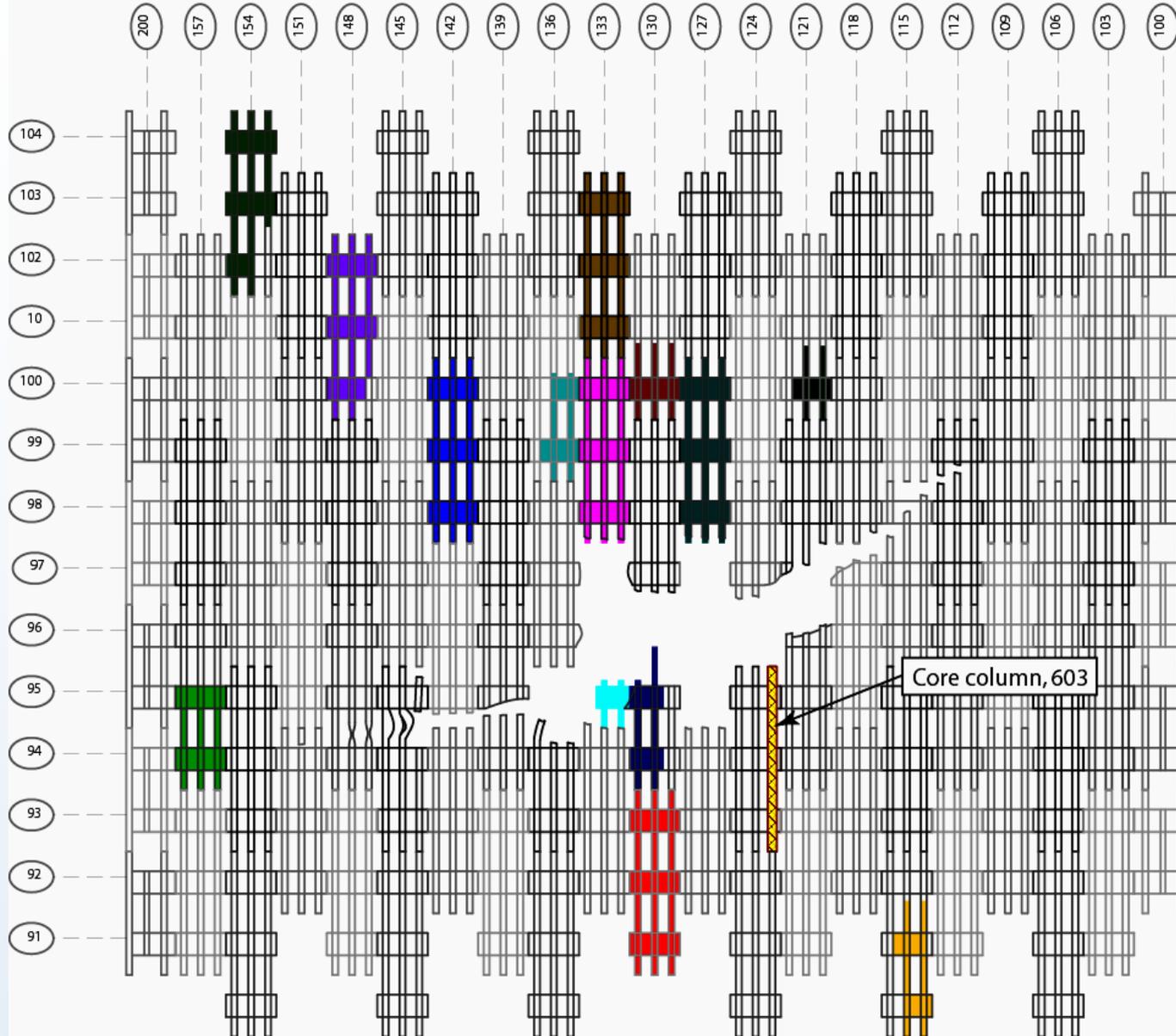
Dr. John Gross (NIST)

WTC Steel at NIST



Sections Identified as of February 6, 2003

As determined by the NIST Metallurgy Division



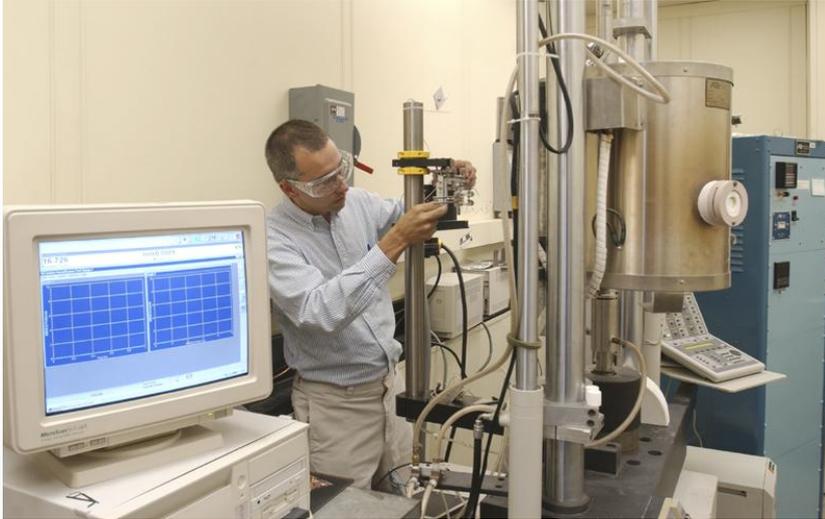
Collection of Steel in NIST's Possession

- Identified locations:
 - Exterior panels: 28 with identified locations; several from impact zone
 - Core columns: 11 with identified locations; two from impact zone
- Identified grades:
 - Exterior panels: All 14 specified strengths; 10/14 columns; 10/12 spandrels
 - Core columns: 2 specified strengths; represent 99 percent of columns
 - Floor trusses: Both specified strengths; 2/2 for rods; 2/2 for angles
- **NIST believes the collection of steel from the WTC towers is adequate for purposes of its investigation**

Preliminary Results from Tests on WTC Steel

- Majority of perimeter steels were higher strength steels (50 to 100 ksi)
 - Micro-alloyed steels (similar to modern pipeline steels)
 - CrMo steel that would meet U.S. specifications for heat resisting steels
- Room temperature mechanical properties (for analyzing baseline structural performance and evaluating if the steel met specifications)
 - Compared measured yield strength with yield strength specified on drawings
 - Samples: columns (82), spandrels (5), trusses (6 rods, 7 angles), truss seats (6)
 - **All yield strengths were found to satisfy applicable specifications, with most well in excess of specified minimum values**
 - All-weld-metal samples (2): yield strengths (85 ksi)
 - significantly greater than base metals (65 ksi measured; 55 ksi specified)
 - heat affected zone yield value (68 ksi measured, 55 ksi specified)

Experiments to Determine Properties of Steel (2)



Checking the calibration of the contact extensometer used in the high-temperature mechanical testing system



Adjusting a dial gauge on one of several creep testers that will be used to evaluate the high-temperature, time-dependent properties of WTC steel

Burn Tests on Primer Paint



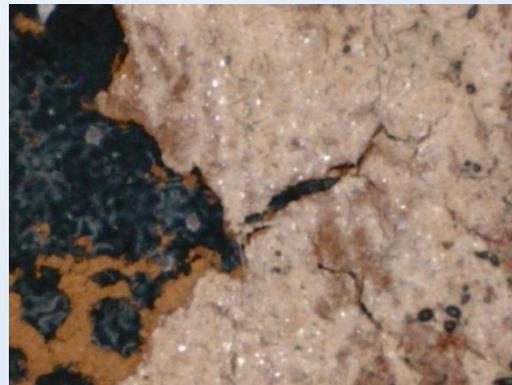
No burn
faint cracks from drying of paint 1 mm



250 deg C for an hour
mud cracks much more visible



700 deg C for an hour
mud cracks partially obscured by formation of
whiteish "sandy" phase on surface
delamination easy with finger



1000 deg C for an hour
wholesale spalling of paint, falls off
thick scale forms between paint and steel

Observations of condition of primer paint could be used to detect pieces that did not exceed 250 °C, and those that exceeded 250 °C but did not exceed 750 °C

6. Photographic and Video Image Collection and Analysis

- Photographic and video images of damage and fires to WTC 1, 2, & 7
 - Initial conditions for modeling fires
 - Rates of fire spread through the building
 - Floors on which structural collapse may have initiated
- Many individuals contacted NIST based on news coverage of December 2002 update. Large number of important photos and videos provided to NIST
- **NIST continues to seek images, especially interested in:**
 - close-up details of fire conditions in all three buildings
 - images of airplane approaching and entering
 - images of WTC 7, particularly on the south face
 - views from south and west faces of WTC towers

Collection of Visual Material

- Assembling collection into a searchable computerized database
- Database now contains:
 - Over 3,100 photographs taken by 66 professional or amateur photographers
 - Over 3,400 video clips from publicly available news coverage, news agencies, and 25 individual videographers
- NIST has received significant visual material from Associated Press, New York 1 News, WNBC New York
- NIST has reviewed similar materials from NYPD and FDNY; arrangements being made to transfer materials of interest to NIST

7. First-Person Data on Occupant Behavior, Evacuation, and Emergency Response

- NIST's study of WTC evacuation and emergency response requires a systematic collection of first-person data from:
 - Survivors (occupants, first responders, others with safety responsibilities)
 - Families of victims who were in touch with victims after aircraft impact
 - Individuals with operational and command authority
- **NIST believes that:**
 - **it is possible to learn from the WTC disaster, and to improve public safety through the collection and analysis of first-person accounts, but**
 - **this is an ambitious undertaking and will need active participation of WTC employers and survivors in its interviews, surveys, and focus groups**
- NIST is cooperating with complementary evacuation studies being conducted by CDC, Columbia University, NYC Department of Health and Mental Hygiene
 - NIST developed list of tenants using information provided by Port Authority and Silverstein Properties, and identified their locations within the buildings
 - April 8, 2003 public meeting in New York City to present study plans to the public and elicit active participation of WTC employers and occupants

Purpose: To determine behavior and fate of occupants and responders

- **Occupant behavior and evacuation technologies and practices for tall buildings**
 - Decision-making and situation awareness
 - Time-constrained evacuation strategies (e.g., defend-in-place)
 - Role of floors wardens and fire safety directors
 - Issues concerning people with disabilities
 - Human factors issues and design of egress system
- **Firefighting technologies and practices for tall buildings**
 - Means for emergency access, time to reach affected floors
 - Firefighting versus evacuation
 - Physical condition of firefighter under high-rise work conditions
- **Command, control, and communication systems for emergency response**
 - Content and timing, among occupants and authorities, within and outside buildings, intra and inter group communications
- **Observations of fire and smoke conditions, structural damage, water flow, liquid fuel from aircraft**

Methodology for First-Person Accounts

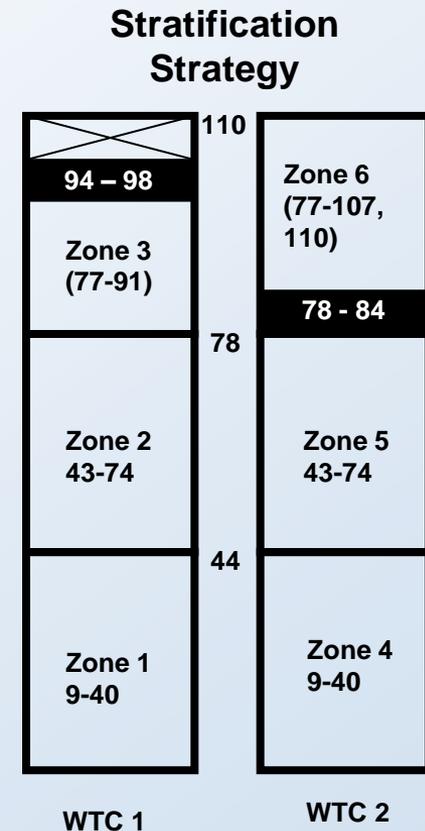
- Face-to-Face Interviews (~750):
 - Designed to maximize accuracy, recall, & detail
- Telephone Interviews (~800):
 - Designed for statistical representativeness
- Focus Groups (~15):
 - Designed for in-depth study of specific issues

Face-to-Face Interviews

- Three-Step Process
 - Uninterrupted description of the event
 - Structured discussion to elicit sequence of actions
 - Follow-up questions
- Participants: Occupants, First Responders, and Families

Telephone Interviews

- Standardized Set of Questions
- Statistically representative population of occupants from WTC 1 and WTC 2
- Stratification Variables:
 - **WTC 1 or WTC 2**
 - **Floor Location (three zones each)**
 - **Tenant Size:**
 - Large tenant floor: single tenant occupies more than 40 percent of usable space on a floor
 - Small tenant floor: all other tenant-occupied floors



Focus Groups

- Detailed Recall of Specific Group Experiences
 - **5 Groups of ~10 Occupants of WTC 1, 2, or 7**
 - **10 groups of ~5 first responders (a company or other similar group)**

Thank You