NIST Response to the World Trade Center Disaster

World Trade Center Investigation Status

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Highlights

- Release of December 2003 Public Update
- Overall Investigation Status, Schedule, and Challenges
- Selection of External Experts and Contractors
- Update on Data Collection Efforts
- Original Aircraft Impact Studies
- Assessing the Most Probable Structural Collapse Sequence
- Update on Experimental/Field Work
- Collection and Analysis of Photographic and Video Images
- First-Person Data Collection on Evacuation and Emergency Response
- Analysis of Building and Fire Codes and Practices
- Investigation of Active Fire Protection Systems

Goals

- To investigate the building construction, the materials used, and the technical conditions that contributed to the outcome of the World Trade Center disaster

- To serve as the basis for national benefits:
  - Improvements in the way buildings are designed, constructed, maintained, and used
  - Improved tools and guidance for industry and safety officials
  - Revisions to codes, standards, and practices
  - Improved public safety

Objectives

- Determine:
  - why and how the WTC Towers collapsed following the initial impact of the aircraft, and
  - why and how the 47-story WTC 7 collapsed
- Determine why the numbers of injuries and fatalities were so low or high depending on location, including technical aspects of fire protection, occupant behavior, evacuation, and emergency response
- Determine what procedures and practices were used in the design, construction, operation, and maintenance of the WTC buildings
- Identify, as specifically as possible, areas in national building and fire codes, standards, and practices that warrant revision

NIST WTC Investigation Projects

BPAT Recommendations

Government, Industry, Professional, Academic Inputs

Public Inputs

Public Inputs

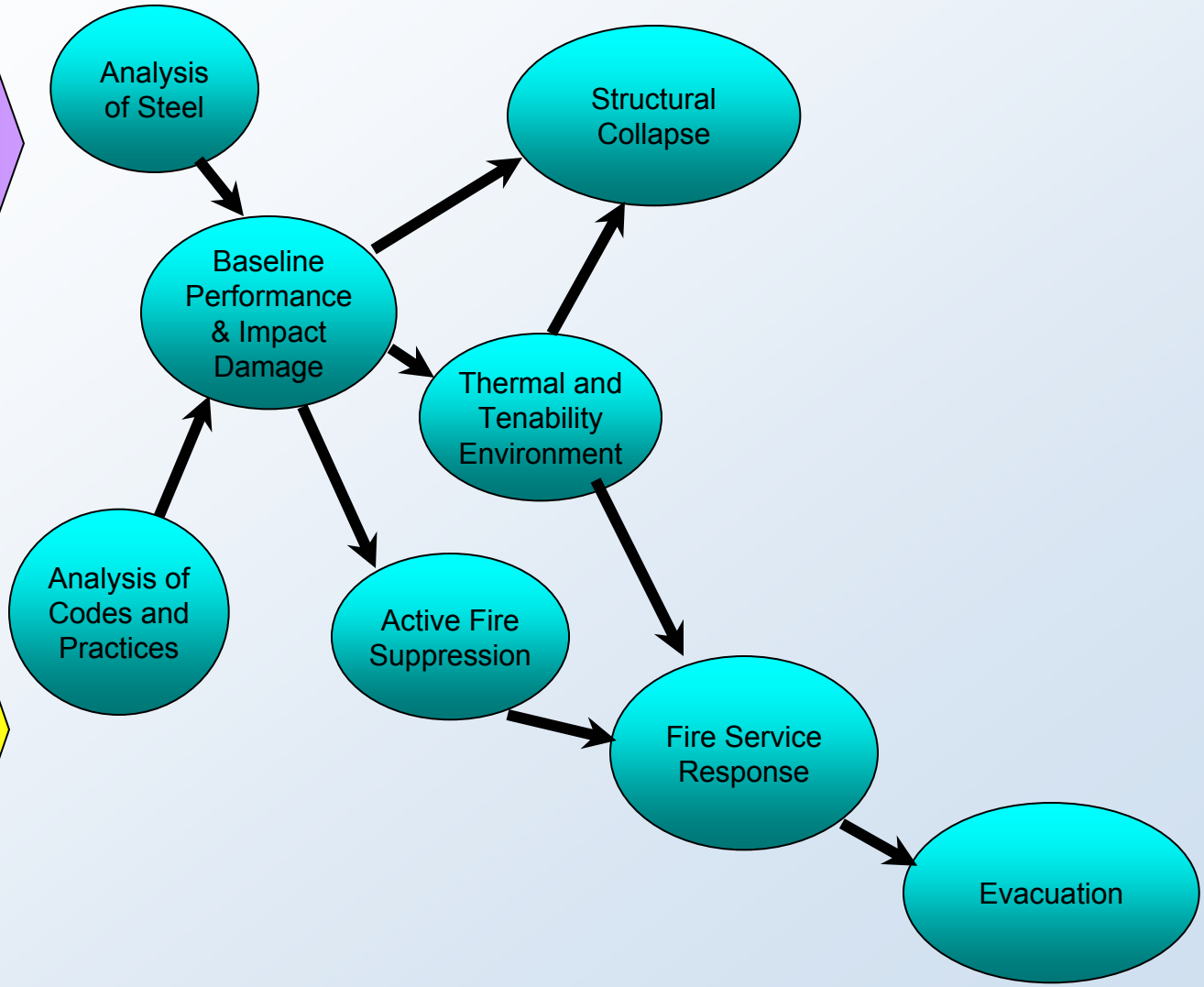
Documents

Video/ Photographic Records

Oral History Data

Emergency Response Records

Recovered Structural Steel



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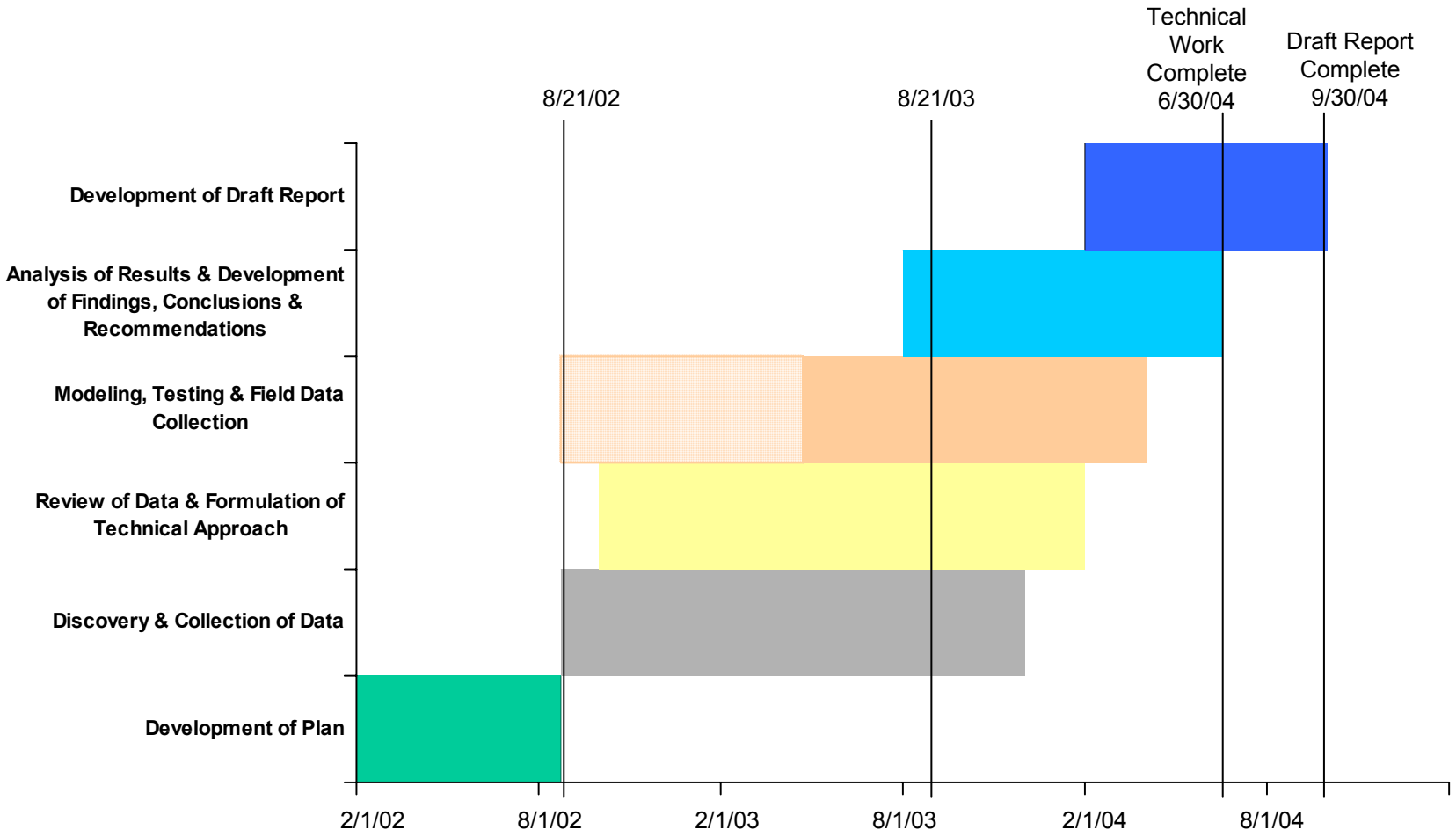
WTC Investigation Status

- 15 months into investigation; good solid progress on all projects
- $16 million investigation; $5.5 million awarded in contracts
- Drawing on talent from NIST, outside experts, and contractors
- Large amounts of data and information received; **summary available at http://wtc.nist.gov**
- Two public updates issued (December 2002 and December 2003); latter being released today
- One technical progress report issued (May 2003); expect to release next technical progress report early in 2004

WTC Investigation Schedule



Challenges Previously Identified

- Massive amounts of data from external sources (affecting projects 1, 2, 5, 6 & 8 most)
- Level of complexity in fire-structure modeling and collapse analysis (affecting projects 2, 5 & 6)
- Scope and scale of occupant behavior, evacuation, and emergency response study (affecting projects 7 & 8)
- Process and time for acquiring outside expertise (affecting projects 1, 2, 6 & 7 most)
- Administrative requirements to ensure strict adherence to laws and regulations such as Paperwork Reduction Act and Common Rule for the Protection of Human Subjects (affecting projects 7 & 8 most)

Selection of External Experts and Contractors

- **Process completed**
  - Solicitations issued: 16 (1 replaced w/consultant)
  - Awards made: 12 contracts
    9 experts (3 solicitations)
- Four others hired as expert consultants
  - V. Junker; K. Malley, V. Dunn, J. Hodgens
- **Excellent group of contractors and experts to augment NIST in-house capabilities**
- NIST, not the contractors and experts, is responsible for determining investigation findings, conclusions, and recommendations
- Contractors and experts complement the team approach that is the essence of the NCST Act

World Trade Center Investigation Contract Solicitations and Awards

WTC No.	Project	Title	Status	Recipient
1	7	Outside Experts for Occupant Behavior and Evacuation	Awarded 9/30/02 and 10/16/02	D. Mileti, G. Proulx, N. Groner
2	5, 6, 7	Fire Safety Engineering Expertise	Awarded 12/23/02	H. Nelson
3	5	Media, Visual and Database Expert with Experience in Obtaining Visual Materials for the World Trade Center	Hired expert consultant	V. Junker
4	3	Document and Evaluate the Steel Recovered from the WTC Towers	Awarded 6/9/03	WJE Associates
5	7	WTC Investigation Survey Administration and Report Delivery: Questionnaires, Interviews and Focus Group Synopsis	Awarded 6/9/03	NuStats, DataSource, GeoStats, MBC Res Ctr
6	2	Development of Structural Databases and Baseline Models for the WTC Towers	Awarded 2/23/03	LERA
7	1	Analysis of Building and Fire Codes and Practices	Awarded 7/25/03	RJA, SKG, RG
8	7	World Trade Center Investigation First Person Accounts of Egress	Awarded 4/15/03	NFPA
9	6	Fire Endurance Testing of the WTC Floor System	Awarded 7/10/03 Modified 8/22/03	Underwriters Laboratories
10	2, 5, 6	Outside Experts for Baseline Structural Performance, Impact Analysis, Structural Response to Fire, Collapse Initiation and Probabilistic Assessment of the WTC Investigation	Awarded 6/16/03, 6/23-25/03, 7/3/03	SOM, D. Parks, K. Willam, Teng Assoc, D. Veneziano/J. Van Dyck
11	2	Analysis of Aircraft Impacts into the WTC Towers	Awarded 9/22/03	ARA
12	4	Analysis of Sprinklers, Standpipe, Pre-Connected Hoses in WTC 1, 2, 7	Awarded 9/22/03	Hughes Associates
13	6	Development of WTC 7 Structural Models and Collapse Hypotheses	Awarded 10/27/03	GMS, CAEA, J. Fisher
14	6	Structural Response of WTC Towers to Fire With/Without Impact Damage	Awarded 10/30/03	SGH, CAEA
15	4	Analysis of Active Fire Alarm Systems, WTC 1, 2, and 7	Awarded 10/21/03	RJA
16	4	Analysis of Smoke Management Systems, WTC 1, 2, and 7	Awarded 10/30/03	Hughes Associates

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Update on Data Collection (1)

- **Significant progress achieved since August 2003, e.g.,**
  - Supporting documents for McKinsey & Company's FDNY study
  - Information on the flammable contents of the aircraft from the airlines and Boeing
  - UL test reports on spray-on fireproofing (W.R. Grace)
  - Port Authority white paper "Salient points with regard to the structural design of The World Trade Center towers"
  - Photos (6194 from over 185 photographers); video clips (5726 from 150 hours of videotape from over 20 sources)
- **NIST continues to seek photos and videos of south face of WTC 7**
- **NYC has agreed to provide access to 911 tapes and logs, and transcripts of about 500 first responder interviews no later than December 31, 2003**
- **NIST has received all of the essential information it needs for the WTC investigation**

Update on Data Collection (2)

- NIST requests for materials that are currently pending or not yet located
  - Original contract specifications for WTC towers (lost in the collapse of the buildings)
  - Construction logs and maintenance logs for WTC 1, 2, and 7 (lost in the collapse of the buildings)
  - Calculations and analyses that supported the original aircraft impact studies (lost in the collapse of the buildings)
  - Descriptions of partitions and furnishings in most of the tenant spaces of WTC 2 & 7 in the fire and impact zones
  - Shop drawings showing connection details of WTC 7
- NIST is making efforts to re-create this information from various sources since much of it was lost when the buildings collapsed
- NIST will pursue other materials that could assist in the investigation, but NIST has received all of the essential information it needs for the WTC investigation

Safety of WTC Towers in Aircraft Collision

- Buildings are not normally designed to withstand the impacts of fuel-laden commercial airliners.
- Safety of the WTC towers and their occupants in an aircraft collision was a consideration in the original design.
- NIST needs information to understand what was done:
  - What was the type and speed of aircraft considered?
  - Where was the impact considered to have occurred?
  - Would the tower remain standing after aircraft impact?
  - What would be the effect of the jet fuel and aircraft contents on fire safety?
  - Would there be loss of life among the tower occupants?

Sources of Available Information

- Port Authority (February 1964), three-page white paper, “Salient points with regard to the structural design of The World Trade Center towers,” dated 2-3-64.
- Port Authority (March 1964), three-page document, “period of vibration due to plane crash at 80th floor.”
- Alternative Insurance Works (2001), World Trade Center Property Risk Report, Prepared for Silverstein Properties, Inc.
- *The New Yorker* (11/19/2001), “The Tower Builder” by John Seabrook, Interview with Leslie Robertson.
- FEMA 403 (2002), *World Trade Center Building Performance Study: Data Collection, Preliminary Observations, and Recommendations.*
- Glanz and Lipton (2003), *City in the Sky – The Rise and the Fall of The – World Trade Center,* Times Books, 2003.

Available Information on Safety of WTC Towers in Aircraft Collision (1)

Type of Aircraft:	Boeing 707 (largest jet aircraft in the air at that time) DC-8
Speed of Aircraft:	600 mph (Port Authority, February 1964) 180 mph (FEMA 403, 2002)
Location of Impact:	80th floor (Port Authority, March 1964)
Structural design:	It appears that the design of the WTC towers considered the impact of 707 aircraft and analysis indicated that such collision would result in only local damage which could not cause collapse or substantial damage to the building

Available Information on Safety of WTC Towers in Aircraft Collision (2)

Fire safety: There are two views on whether the effect of jet fuel and aircraft contents was a consideration in the original building design:

- One view suggests that an analysis was done indicating the biggest problem would be the fact that all the fuel would dump into the building and there would be a horrendous fire.
- Another view suggests that the fuel load, and the fire damage that it would cause, may not have been considered.

Life safety: There are two views on what would be the effect of aircraft impact on occupant life safety.

- One view, which did not consider the fires, suggests that the aircraft impact would not have endangered the lives and safety of occupants not in the immediate area of impact
- Another view, which considered the fires, recognized that a lot of people would be killed even though the building structure would still be there.

- **NIST continues to be interested in available information related to the calculations and analyses that supported the original aircraft impact studies**

Assessing the Most Probable Structural Collapse Sequence (1)

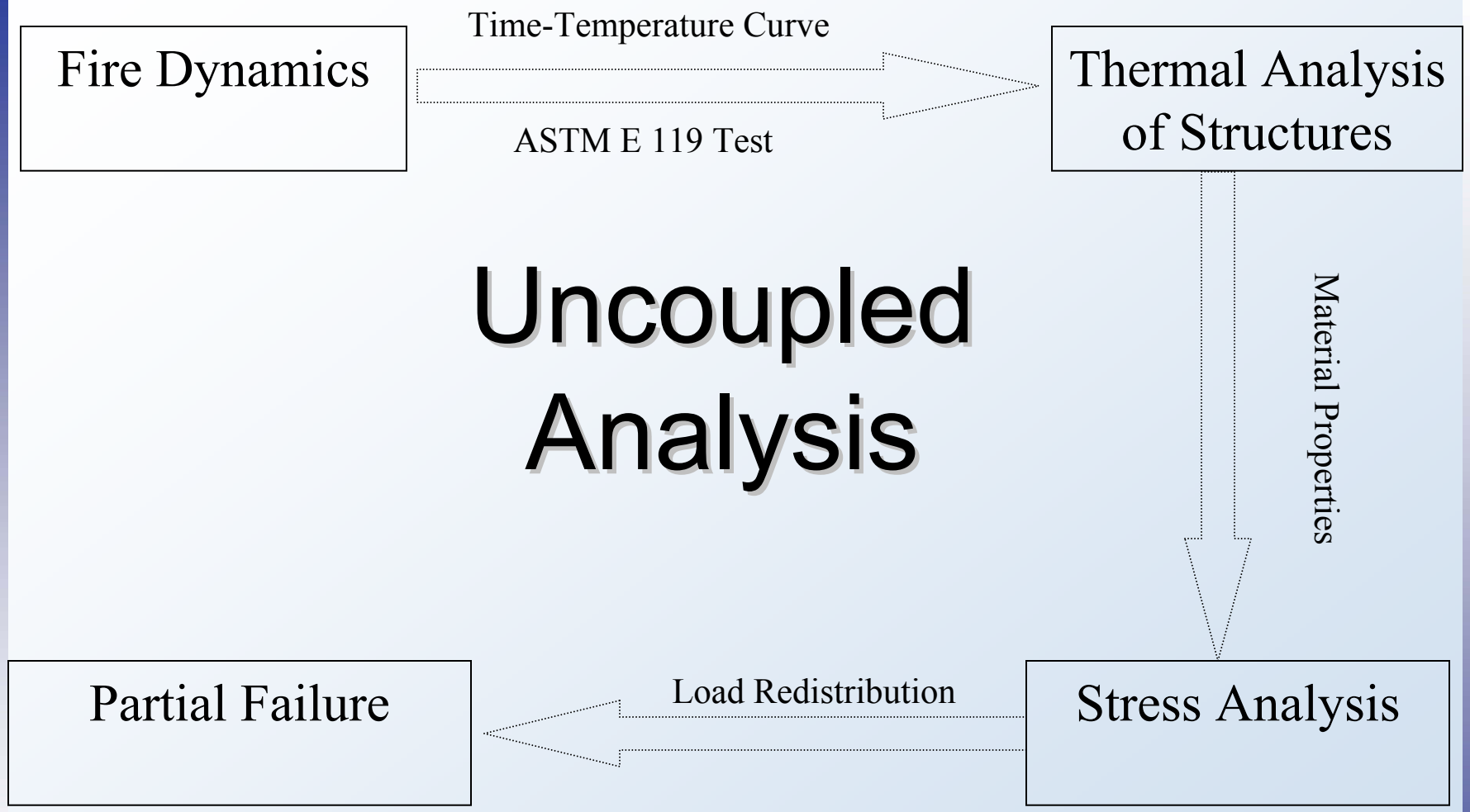
- Overall analysis objectives:
  - What is the most probable collapse sequence?
  - What confidence levels are associated with it?
  - What is the probability of other collapse sequences?
  - What parameters influence the most probable collapse sequence?

- **NIST has developed a comprehensive approach to identify the most probable structural collapse sequence, from aircraft impact to collapse initiation**

- NIST has made significant progress in:
  - Defining the requirements for these complex series of analyses
  - Formulating detailed technical modeling approaches
  - Augmenting in-house expertise with contractors and external experts
  - Commencing technical work in all of these areas

Assessing Most Probable Structural Collapse Sequence (2)

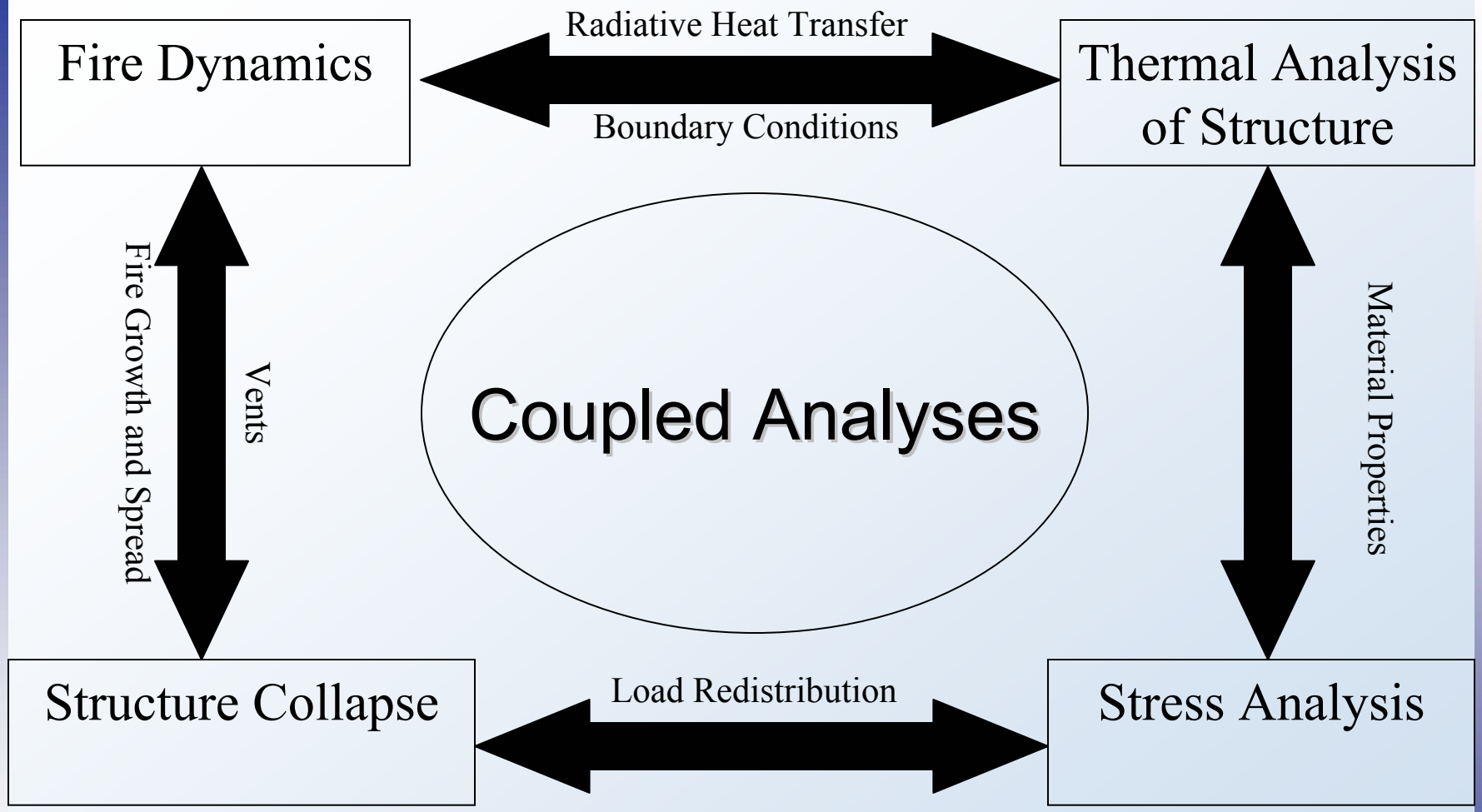
- **NIST is developing a rigorous technical approach to evaluate the role of fireproofing in the collapse of the WTC towers,** considering:
  - As-built condition of the fireproofing prior to September 11, 2001
  - Mechanical and thermal properties of the fireproofing materials
  - Extent to which fireproofing may have been dislodged due to aircraft impact via debris impact and local deformation/acceleration
- NIST is developing a number of simplified modeling approaches to provide insights and bases to evaluate results from detailed models
  - Integration of impact damage, fire dynamics, thermal response, structural response, collapse initiation analyses
  - Performance of connections, components and subsystems
  - Effect of key components and subsystems on structural stability
- NIST is working with commercial software developers to automate conversion of geometry, finite element meshing, materials, and loads information between different computer programs in a seamless manner



Uncoupled Analysis

Current Method:

Deterministic, Linear and Sequential Analysis
of Collapse Induced by Fire-Structure Interaction



Proposed Method:

Probabilistic, Nonlinear, Coupled Analysis
of Collapse Induced by Fire-Structure Interaction

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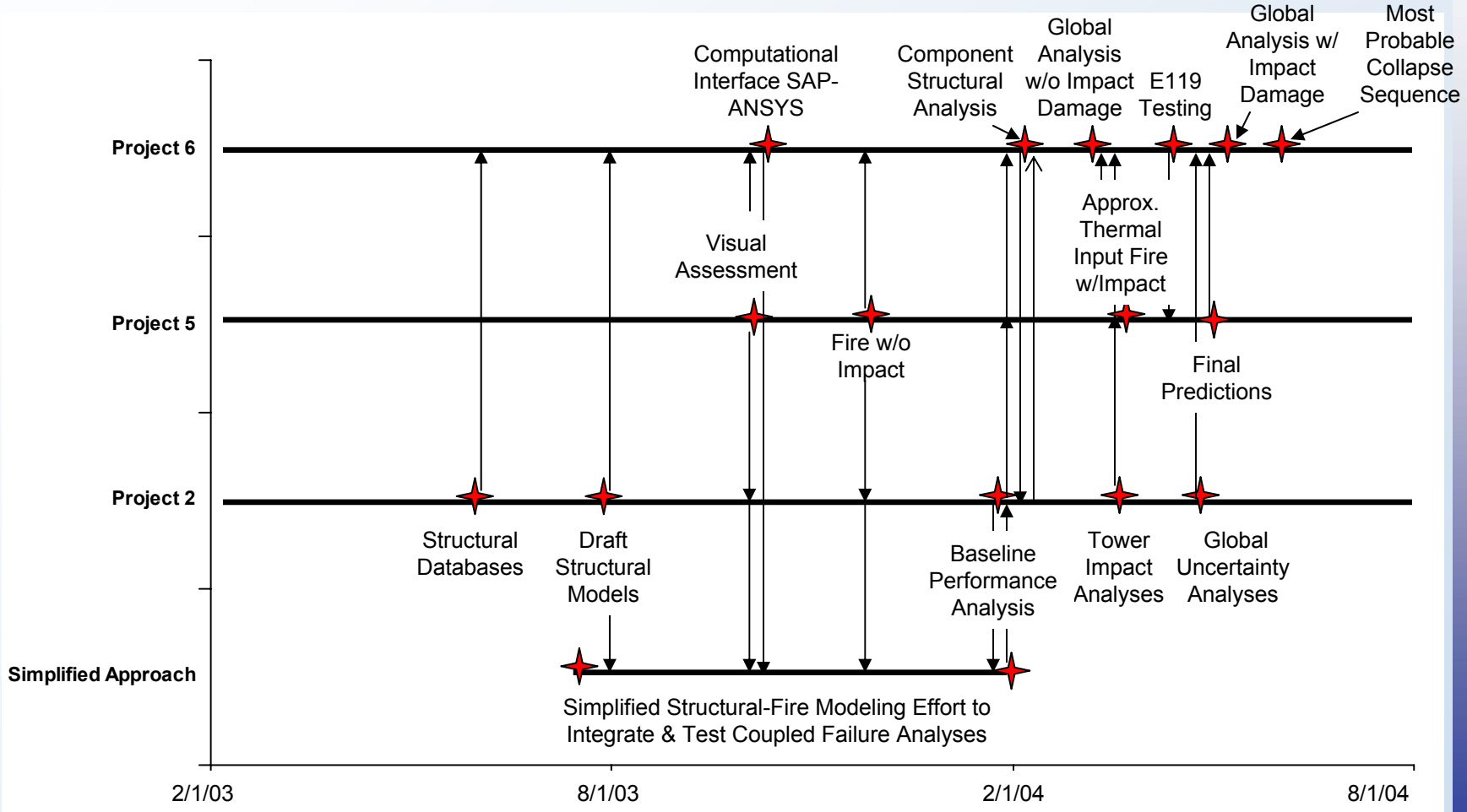
Projects 2, 5 & 6 Interfaces



Update on Analysis of Structural Steel

- NIST has 236 pieces of WTC steel in its possession; **NIST believes the collection of steel from the WTC towers is adequate for purposes of its investigation:**
  - **regions of impact and fire damage emphasized in selection of steel pieces**
  - **NIST has all 14 specified steel grades for exterior panels; 2 specified grades that represent 99 percent of core columns; and both specified grades for floor bar joists**
- NIST is documenting failure mechanisms and damage via an extensive visual analysis of the WTC steel and enhanced image analysis of photographs of the damaged buildings
- **Preliminary results show that the measured room temperature steel strength met relevant ASTM specifications; in many instances exceeding the specifications by 5,000 to 15,000 psi**
- Ongoing work to evaluate the design of the steel building components and system and their performance under impact and fire conditions up until the time of collapse initiation

WTC Fire Model Validation Experiments

- **NIST has completed experiments for validation of WTC fire models**:
  - Fire tests in large compartments to measure the heat release and transfer rate to compartment gases and steel components (steel truss and columns, with and without fireproofing). NIST reported on these tests in May 2003.
  - Shake table experiments to determine the magnitude of impulses that could result in damage to the ceiling tile systems, increasing the accessibility of the fire energy to the ceiling/floor membranes. These tests are now complete.
  - Office work station fire tests, based on descriptions of furnishings used in WTC 1 office space, to input thermo-physical properties to the fire model. NIST reported on these tests in August 2003.
  - Fire tests of multiple (three) workstations to validate model predictions of the sensitivity of fire intensity, duration, and spread to the distribution of combustibles, the ventilation of the fire, and the effect of jet fuel. These tests are nearing completion.

Update on Fireproofing and Fire Rating of WTC Floor System

- May 2003 progress report: NIST has not been able to determine the technical basis for the selection of fireproofing material for the WTC floor system, and the determination of the thickness of fireproofing to achieve the specified 2-hour rating

- NIST found no documentary evidence indicating that a test based on ASTM E 119 had been conducted to determine the fire rating of the WTC floor system. Port Authority informed NIST that "there are no test records in our files."

- **Project specific fire endurance testing was not and is not normal practice but may be conducted when circumstances warrant it, e.g., in a new application.**

- A composite bar joist floor system with spray-applied fireproofing represented an innovative application in the 1960s.
  - Use of bar joists in the floor system of high rise buildings such as the WTC towers
  - Long unsupported span of the floor system (60 ft and 35 ft in the two directions)
  - Role of floor system in ensuring stability of the WTC structural system
  - Floor diaphragm action to transfer lateral (wind) loads to the columns

- **NIST has awarded a contract to Underwriters Laboratories to determine the fire rating of typical WTC floor systems under both as-built and specified conditions**

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Collection and Analysis of Photographic and Video Images

- Visual database now contains:
  - 6,194 photographs taken by more than 85 photographers
  - 5,726 video clips from 150 hours of videotape representing more than 20 sources

- **NIST has determined the exact times for the major events of September 11, 2001 (aircraft strike, building collapse initiation)**

- **NIST has developed detailed mappings for the fire, smoke, and the condition of windows at several specific times for each WTC tower. Work is underway for WTC 7**

- From the analysis of the visual images to date, NIST has identified significant events for WTC 1 and 2 related to aircraft impact, fire development, and building damage

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

- Buildings are not normally designed for fire protection and evacuation under extreme conditions
- **Critical lack of information on which to base evacuation and emergency response practice, standards, and codes in such conditions**
- First-person interviews will provide valuable information to improve public safety during extreme events in tall buildings. Specifically in the following areas:
  - Firefighting in tall buildings
  - Evacuation in tall buildings
  - Emergency communications in extreme events
  - Building design features to support such operations
- **NIST has now received all necessary approvals and has commenced the first-person data collection efforts**
- The personal privacy and confidentiality of individual respondents will be protected to the maximum extent permitted by law

Multiple Data Sources

- Existing published first-person accounts of WTC evacuation; over 725 accounts collected and analyzed
- Communication tapes from Port Authority of NY & NJ and NYPD; 1000 plus hours of taped recordings
- Filings with the Occupational Safety and Health Administration by survivors and families of victims; about 60 written statements
- Documents from Port Authority, FDNY, NYPD, and others on design of egress and emergency communication systems; WTC evacuation history; WTC evacuation planning and drills; emergency response preparedness and operational data
- Photographic and video data on occupant behavior, evacuation, and emergency response
- First-person data collection from survivors, current and retired first responders, and families of victims
- Access to NYC 9-1-1 tapes and logs, and transcripts of about 500 interviews with FDNY employees involved in WTC emergency response activities

Occupant Behavior, Evacuation, and Emergency Response Study

- NIST is developing a detailed chronology of events related to the emergency response and evacuation
- NIST is analyzing the contents of emergency communications data already received to:
  - better define the events of September 11, 2001
  - document the performance of the emergency communication systems
- NIST is using computer egress modeling to better understand the evacuation experience on September 11, 2001:
  - Obtained three existing computer models
  - Supporting information from evacuation history of WTC towers
  - Supporting information from first-person accounts

Analysis of Building and Fire Codes and Practices

- Procedures and practices of interest:
  - Design and construction of WTC towers and WTC 7
  - New and innovative design features, technologies and materials
  - Passive and active fire safety systems
  - Emergency access and egress systems
  - Structural modifications, inspection, and maintenance

- **NIST has completed a preliminary comparison of then current building regulatory and code requirements**
  - Provides context to study specifications and criteria used in the design, construction, operation, and maintenance of the WTC buildings

- **NIST has completed preliminary documentation of the fuel system for emergency power in WTC 7**
  - Fuel tanks, fuel distribution system, control system, fire protection

Investigation of Active Fire Protection Systems

- NIST is investigating the design, capabilities, and performance of the active fire-protection systems in the WTC towers and WTC 7:
  - Sprinkler system, including fire standpipes, pre-connected hoses, water supply
  - Fire alarm systems, including provisions for redundancy and modifications made after the 1993 bombing
  - Smoke management systems, including reviews conducted after the 1993 bombing

- **NIST has completed a review of the history of post-occupancy fire incidents and has identified events that were large enough to activate more than one sprinkler or, if sprinklers were not present, events judged to be equivalent**

Bottom Line

Make all buildings safer for occupants and first responders

Better evacuation systems and emergency response capabilities in future disasters