NIST Special Publication 1000-1

National Institute of Standards and Technology Final Plan: National Building and Fire Safety Investigation of the World Trade Center Disaster

NIST National Institute of Standards and Technology • Technology Administration • U.S. Department of Commerce

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Final Plan
National Institute of Standards and Technology
National Building and Fire Safety Investigation of the World Trade Center Disaster

Goals:

- To investigate the building construction, the materials used, and the technical conditions that contributed to the outcome of the World Trade Center (WTC) disaster.
- To serve as the basis for:
    - Improvements in the way buildings are designed, constructed, maintained, and used;
    - Improved tools, guidance for industry and safety officials;
    - Revisions to codes, standards, and practices; and
    - Improved public safety.

Objectives:

The primary objectives of the NIST-led technical investigation of the WTC disaster are to:

1. Determine why and how WTC 1 and 2 collapsed following the initial impacts of the aircraft and why and how WTC 7 collapsed;
2. Determine why the injuries and fatalities were so high or low depending on location, including all technical aspects of fire protection, occupant behavior, evacuation, and emergency response;
3. Determine what procedures and practices were used in the design, construction, operation, and maintenance of WTC 1, 2, and 7; and
4. Identify, as specifically as possible, areas in building and fire codes, standards, and practices that are still in use and warrant revision.

Guiding Principles:

- Active, comprehensive, independent, and objective technical investigation that is fully informed of the concerns and issues of all interested parties and within the limits of available resources.
- Open and inclusive process in planning and conducting the investigation, and in publishing and disseminating findings and recommendations.
- Contribute to improving standards, codes, and practices to reduce future risks by focusing on:
    - Fact-finding and analysis of the facts, and
    - Validating and verifying existing knowledge.
- Non-technical issues are outside scope of investigation: No findings of fault or negligence of any individual or organization.
- Maintain ongoing liaison with professional community, public, and local authorities.
- Project teams that include NIST staff and external world-class technical experts.

Source of Information for Plan Development:

Formulation of the NIST investigation plan drew upon many sources of information from within and outside NIST. These include external experts and groups (industry, academia, and government), FEMA/ASCE Building Performance Assessment Team (BPAT) members, the Building Performance Study report of this team (FEMA Report 403, May 2002), NIST experts in building and fire safety, and the public-at-large. NIST held a public meeting in New York City on

June 24, 2002 to gather comments and suggestions on the scope of the NIST investigation detailed in this plan. This plan has been refined based on that input, incorporating many of the suggestions received.

Program Context for the Investigation:

The ***building and fire safety investigation*** detailed in this plan is a 24-month study of the factors contributing to the probable cause (or causes) of collapse of the WTC Towers (WTC 1 and 2) and WTC 7 and the associated fatalities and injuries. This program will investigate the building design and construction, the materials used, and the technical conditions that contributed to the outcome of these disasters following the initial impact of the aircraft. What is learned in examining WTC 1, 2 and 7 is expected to benefit new and existing buildings.

Parallel to the investigation is a proposed ***research and development (R&D) program*** to provide the technical basis for improved building and fire codes, standards, and practices. This program addresses work in critical areas such as structural fire safety, prevention of progressive collapse, building vulnerability reduction tools, and equipment standards for first responders. It includes BPAT recommendations for investigation of WTC 3, 4, 5, and 6, Bankers Trust, and peripheral buildings as well as recommendations for future studies to address specific issues of broader scope not covered by the BPAT. The intent is for the findings and recommendations to be introduced into the voluntary consensus process that is used to develop building and fire codes and standards in the U.S. The rate at which the recommendations of the investigation can be implemented will depend on the level of funding available to the R&D program.

An industry-led ***dissemination and technical assistance program (DTAP)*** is the third part of the proposed ***NIST response plan***. The DTAP is designed to provide practical guidance and tools to better prepare facility owners, contractors, architects, engineers, emergency responders, and regulatory authorities to respond to future disasters. The DTAP is an important complement to the R&D effort in gaining acceptance of proposed changes to practice, standards, and codes. In addition, it will address BPAT recommendations for training and education of stakeholders.

The proposed NIST response plan complements, is responsive to, and goes beyond the BPAT efforts. The plan addresses all major recommendations contained in the BPAT report. NIST has also identified other critical issues that need study, especially in areas that impact life safety and engineering practice.

Scope and Rationale for Building and Fire Safety Investigation:

The NIST building and fire safety investigation will focus exclusively on the WTC Towers and WTC 7. The results of this investigation could stimulate major changes in both U.S. building and fire codes and in engineering practice, despite the unique design features of the buildings or circumstances under which they collapsed. The lessons to be derived from the investigation will be applicable to a broad range of buildings types, not just the specific buildings that are studied. These real-life lessons will inform the R&D and DTAP elements of the NIST response plan and be extremely useful to the building and fire communities in considering needed changes to codes, standards, and practices. The following examples illustrate the value of an investigation focused on the WTC Towers and WTC 7.

The WTC Towers and WTC 7 are the only known cases of total structural collapse in high-rise buildings where fires played a significant role. These building collapses provide a unique source of information to understand the complexities associated with the dynamics of building fires and the collapse vulnerability of buildings to fires. Through the analysis of that information, the

investigation will provide an excellent case study to apply and gain experience in the use of general methodologies for fire safety design and retrofit of structures.

In addition, lessons will be learned on:

- The behavior of open-web steel trussed joists to withstand the thermal environment present in large fires. Joists are used in commercial and institutional buildings nationwide.
- The behavior of fireproofing materials and the fire performance of connections used in steel structures.
- Possible mechanisms - not considered previously - that could initiate progressive collapse in buildings as a result of fires and impact loads, and the critical role of pivotal components such as transfer girders and floor diaphragms.
- The mechanical and metallurgical behavior of different grades of structural steel in these buildings (using steel recovered from the WTC site that is being stored at NIST).

There are equally important lessons to be derived for life safety that were outside the scope of the BPAT study.

- The control of fire spread in buildings with potentially large open floor plans, and the effectiveness of compartmentation as a means to isolate fires in such buildings.
- The role of occupant behavior and evacuation technologies and practices for tall buildings, including decision-making and situation awareness, time-constrained evacuation strategies, communications, role of floor wardens and fire safety directors, and issues concerning people with disabilities.
- The role of current firefighting technologies and practices for tall buildings, including emergency response, equipment, pre-planning, and training, and the performance of active fire protection systems such as sprinklers, manual suppression, fire alarms, and smoke management systems.
- Command, control, and communication systems for fire service response.

There are also important lessons to be derived for architectural and engineering practice that were not the focus of the BPAT study.

- The technical evaluation process and practices used to assure safety whenever an innovative system is planned or an alternate method that deviates from existing building and fire codes is used.
- The margin of safety and degree of structural redundancy to accommodate local failures from abnormal loads such as blast, impact, and accidental fires.

The NIST investigation will strive to study the disaster holistically, paying particular attention to the interplay between the building, the occupants, and the emergency responders. The review, analysis, modeling, and testing work will be based upon a solid foundation of technical evidence provided by critical data such as building documents, video and photographic records, oral histories, emergency response records, and recovered structural steel.

Technical Approach:
The technical approach of the NIST building and fire safety investigation will include the following phases over an estimated 24 month period:

- **Identification of Technical Issues and Major Hypotheses Requiring Investigation:** opportunity for public input (e.g., public meeting; website; Federal Register notice) in developing investigation plan; consultations with experts in structural and fire protection

engineering and in construction, maintenance, operation and emergency response procedures of tall buildings); findings and recommendations of BPAT study and technical issues identified by other experts; analysis of inputs to establish priorities for investigation; review by Federal Advisory Committee.

- **Data Collection:** inputs from building owners and operators, local authorities, designers, consultants, and contractors; data and information collected by the BPAT study; building and fire protection design documents, records, plans, and specifications; construction, maintenance, operation records, building renovations and upgrades; video and photographic data; field data; interviews and other oral and written accounts from building occupants, families of victims, emergency responders, building operators, and other witnesses; emergency response records including audio communications; and other records.

- **Analysis and Comparison of Building and Fire Codes and Practices:** analysis and comparisons of codes, standards, and specifications used for WTC buildings; comparison of codes with codes in other jurisdictions; review and analysis of practices used for design, construction, operation, maintenance, repair, renovations, and upgrades.

- **Collection and Analysis of Physical Evidence:** structural steel, material specimens and other forensic evidence to the extent they have been collected or are otherwise available; analysis of metallurgical and mechanical properties of steel to evaluate its quality and to estimate temperature conditions in the buildings before collapse.

- **Modeling, Simulation, and Scenario Analysis:** aircraft impact on structures and estimated damage to interior and core structures and residual structural capacities; role of jet fuel and building contents in resulting fire; fire dynamics and smoke movement; thermal effect on structures and the effectiveness of fireproofing; effect of fire on structural response and vulnerability and the role of connections, flooring system, and core and exterior columns; occupant behavior and response including influence of communications and barriers to egress; evacuation issues including egress, control/fire panels, emergency response, and communications; fire protection system design and vulnerability; hypotheses for structural collapse including evaluation of system vulnerability to progressive collapse; probable collapse mechanisms and associated uncertainties.

- **Testing to Re-Create Scenarios and Failure Mechanisms:** reduced and real-scale tests to provide additional data and verify simulation predictions, especially for the effects of fires.

- **Technical Findings and Recommendations:** preparation of interim and final reports; peer review by established NIST Editorial Review Board; augmented NIST review to include senior management and legal; review of key reports by Federal Advisory Committee; finalize and disseminate via published reports, web, and media.

- **Identify Needs for Changes to Codes and Standards:** identify specific areas in need of change to codes, standards, and practices based on findings of investigation (note: specific recommendations and actions for proposed changes to codes, standards, and practices will be made via the R&D and DTAP programs).

The NIST investigation plan includes eight projects that provide the focus for the technical work. These are:

- Project #1: Analysis of Building and Fire Codes and Practices
- Project #2: Baseline Structural Performance and Aircraft Impact Damage Analysis
- Project #3: Mechanical and Metallurgical Analysis of Structural Steel
- Project #4: Investigation of Active Fire Protection Systems
- Project #5: Reconstruction of Thermal and Tenability Environment
- Project #6: Structural Fire Response and Collapse Analysis
- Project #7: Occupant Behavior, Egress, and Emergency Communications
- Project #8: Fire Service Technologies and Guidelines.

These projects are interdependent, and when considered together will meet the NIST investigation objectives. A detailed description of each of these eight projects is in Attachment 1.

Technical Expertise:
The NIST building and fire safety investigation will include world-class technical experts from both within and outside NIST. External experts will be drawn from academia, practice, and government and used on an as-needed basis in various phases of the investigation. Several of these experts may have contributed to the BPAT study.

Federal Advisory Committee:
NIST will charter a 7-10 member Federal Advisory Committee to provide advice to the NIST Director on all aspects of the investigation, including scope, approach, work plan, schedule, results, findings, recommendations, and interim and final technical reports. The Federal Advisory Committee will provide advice on the objectivity, thoroughness, and integrity of the investigation. Committee meetings will be announced in the Federal Register. The NIST Director will appoint individuals to the committee who are recognized for distinguished professional service, possess broad technical expertise and experience, and have a reputation for independence, objectivity, and impartiality. Members will represent a balance of the diverse disciplines relevant to the investigation, including structural engineering, fire protection engineering, metallurgy, firefighting, human behavior, property insurance, and architecture. Members will be selected to avoid conflicts of interest. They shall not: be current NIST employees, be the recipient of an active NIST grant or contract directly related to the WTC investigation, represent parties affected directly by the investigation, participate in the conduct of the investigation, or participate in litigation on matters directly and specifically within the scope of the NIST investigation.

NIST Secretariat:
The Director of NIST has established a secretariat to coordinate NIST-level activities in support of the investigation and to maintain ongoing liaison with the Executive Branch, the Congress, the public, and the media. NIST recognizes that there will be significant public and media interest in the investigation. NIST has assigned a spokesperson to provide press announcements and coordinate media briefings during the course of the investigation. NIST will also provide information via reports and briefings to the Executive Branch and Congress at their request. The secretariat includes representatives of the Building and Fire Research Laboratory, Congressional and Legislative Affairs, Budget Division, Public and Business Affairs Division, NIST Counsel, Program Office, Acquisition and Logistics Division, Occupational Health and Safety Division, and the Management and Organization Division.

Liaison with the Professional Community, the Public, and Local Authorities:
NIST will maintain ongoing liaison with the professional community, the general public, and local authorities over the course of the investigation through briefings and presentations. NIST has

established a website to communicate information related to the investigation (http://wtc.nist.gov). This information will also be available in print; every effort will be made to ensure that those without internet access can receive the same information by mail. In addition, NIST has assigned a special liaison to interact with the families of building occupants and first responders. NIST recognizes the vital role that those individuals and groups have to play in providing input to the NIST investigation. NIST also believes that it is appropriate and important to keep these families and organizations informed about the progress of the investigation.

Impact and Outcomes:
The NIST investigation aims to establish the probable technical causes of the collapse of the WTC towers after the aircraft impact and WTC 7 and the associated loss of life and injuries. Implementation of the results of the NIST investigation, in conjunction with those of the R&D and Dissemination and Technical Assistance elements of the NIST response plan, will restore confidence by making buildings safer nationwide, enhancing the safety of fire and emergency responders, better protecting building occupants and property, and providing better emergency response capabilities and procedures in future disasters.

The findings and recommendations of the NIST investigation will support and guide future work that will develop and disseminate guidance and tools, assess and reduce vulnerabilities, and produce the technical basis for cost-effective changes in national codes, standards, and practices. A private sector coalition, representing key industry, standards, codes, and professional organizations, has worked with NIST to establish the response plan to meet longer-term needs. The goal of the response plan is to produce cost-effective design and retrofit measures as well as operational guidance for building owners and emergency responders.

Table 1: Outputs for National Building and Fire Safety Investigation of the World Trade Center Disaster

Technical Area	Project #	Outputs
Identification of Technical Issues and Major Hypotheses	**Planning Phase**	• Public Meeting to gather comments on scope of NIST investigation plan. • Implementation Plan for NIST Investigation. • Major Hypotheses and Technical Issues for Investigation
Analysis of Building and Fire Codes and Practices	**1**	• Report(s) on the code provisions, procedures, and practices used in the design, construction, operation, and maintenance of the structural, passive fire protection, and emergency access and evacuation systems of the WTC 1, 2, and 7.
Baseline Structural Performance and Aircraft Impact Damage Analysis	**2**	• Report(s) on the baseline performance of WTC 1 and 2 under design, service, and abnormal loads and the analysis of aircraft impact damage on the structural, fire protection, and egress systems.

Mechanical and Metallurgical Analysis of Structural Steel	**3**	• Report(s) on the mechanical and metallurgical properties and quality of steel, weldments, and connections from steel recovered from WTC 1, 2, and 7.
Investigation of Active Fire-Protection Systems	**4**	• Report(s) on the performance of the active fire-protection systems in WTC 1, 2, and 7 and their role in fire control, emergency response, and fate of occupants and responders.
Reconstruction of Thermal and Tenability Environment	**5**	• Report(s) on the reconstruction of the time-evolving temperature, thermal environment, and smoke movement in WTC 1, 2, and 7 for use in evaluating the structural performance of the buildings and behavior and fate of occupants and responders.
Structural Fire Response and Collapse Analysis	**6**	• Report(s) on the response of the WTC Towers to fires with and without aircraft damage, the response of WTC 7 in fires, the performance of open-web steel joists, and the most probable structural collapse mechanisms for WTC 1, 2, and 7.
Occupant Behavior, Egress, and Emergency Communications	**7**	• Report(s) on the behavior and fate of occupants and responders, both those who survived and those who did not, and analysis of the performance of the evacuation system.
Fire Service Technologies and Guidelines	**8**	• Report(s), building on the work of the work done by the Fire Department of New York and McKinsey & Co., that: document what happened during the response by the fire services to the attacks on the World Trade Center until the collapse of WTC 7; identify issues that need to be addressed in changes to practice, standards, and codes; identify alternative practices and/or technologies that may address these issues; and identify R&D needs that advance the safety of the fire service in responding to massive fires in tall buildings.
Technical Findings and Recommendations	**Reporting Phase**	• Interim and Final Reports of the Investigation, including probable technical causes of the disaster and identification of areas in of codes, standards, and practices that warrant change.

Attachment 1

Description of Investigation Projects

Project #1: Analysis of Building and Fire Codes and Practices

Purpose: To obtain, review, and analyze applicable building code provisions and project documents and to determine the procedures and practices that were used in the design, construction, operation, and maintenance of the structural, fire protection, and emergency access and evacuation systems of WTC 1, 2, and 7, and to provide input to other investigation projects.

Technical Approach: This project focuses on gathering background information that governed the design, construction, operation, and maintenance of the WTC buildings as related to structural and fire safety performance. The major sources of information will be historical records that have been maintained by various entities involved in the design, construction, operation, and maintenance of the structural system, the passive fire protection systems, and the emergency access and evacuation system. In addition, building code provisions that governed the project will be compared with code provisions of other jurisdictions that governed tall buildings at the time of design and construction of the WTC buildings. A summary will be prepared of those aspects of the structural, passive fire protection, and emergency access and evacuation systems that may have bearing on the structural performance, occupant evacuation, and loss of lives on September 11, 2001. This project is divided into eight tasks as follows:

Task 1—Review design calculations and project documents. Available documents related to the original design will be reviewed to establish the design loads and methods used to proportion structural components. Special effort will be devoted to documenting the approval process for those aspects of the structural system used in the WTC towers that were not covered by the provisions of the governing code and to document abnormal loads anticipated at the time of the original design of the WTC towers. Available project and as-built drawings (structural, mechanical, architectural) will be obtained for use by other investigation projects.

Task 2—Review building construction. Available construction documentation (such as construction logs, change orders, test and inspection reports) will be reviewed. Significant events encountered during construction (and over the life of the buildings) that may have impacted the performance of the structural, passive fire protection, and elevator systems will be identified and documented. The architectural configuration will be established for the affected stories of WTC 1 and 2 and WTC 7 on September 11 before the attacks.

Task 3—Review passive fire protection features. Those codes and standards that applied to the passive fire protection features of the WTC buildings will be reviewed. This includes those in effect at the time of construction and those in effect during occupancy. Also included are documents on the passive structural fire protection system used in the buildings such as fireproofing, compartmentation, fire stops, and enclosures around egress paths. The structural integrity and fire safety performance of the enclosure shaft for the elevators and stairs will be studied. The maintenance records of the passive fire protection systems will be reviewed. Relevant modifications made to the passive fire protection systems during the service life of the buildings and after the 1993 bombing will be documented.

Task 4—Review emergency access and evacuation systems. Review the design, operation, maintenance, and inspection of the emergency access and evacuation systems (e.g., stairwells and elevators) in the WTC towers and the condition of these systems at the time of collapse of the buildings. Collect the relevant literature and review existing U.S. and international standards and identify design characteristics and maintenance practices applied to such systems in WTC 1

and 2 that affected their performance on September 11, 2001. Standards and practices for firefighter lifts and FDNY policies will be reviewed to evaluate the potential effectiveness of such technology in improving firefighter effectiveness and reducing firefighter losses.

Task 5—Code comparisons. The New York City, the New York State, and national model codes that were in effect when the buildings were designed will be documented. Specific provisions in those codes will be compared with design requirements for the WTC 1, 2 and 7 buildings. Focus will be on the structural loading criteria and provisions for structural fire protection, active and passive fire protection systems, and emergency access and evacuation. Code provisions will be compared for high-rise construction in other code jurisdictions with those that governed the design of the WTC towers. Current model code provisions will also be compared with those then in effect that governed the design and construction of the WTC buildings. In addition, provisions for code enforcement will also be compared.

Task 6—Review maintenance records. A review will be conducted of maintenance and renovation that may have affected the structural system and the passive fire protection system. The objective is to develop the most accurate representation of the structural systems, including the condition of the structural fire protection, as they existed in the portions of the buildings affected by aircraft impacts on September 11, 2001.

Task 7—Document structural modifications following the 1993 bombing. The structural modifications that were made after the 1993 bombing will be reviewed to determine whether they may have affected the structural system of the WTC buildings.

Task 8—Report preparation. The results of this project will be synthesized into a chapter to describe the design, construction, and maintenance of and modifications to the WTC buildings. The structural configuration, passive fire protection systems, and emergency access and evacuation system at the time of the attack will be described. In addition, the internal condition of the architectural and mechanical systems will be documented with input from other investigation projects. The project staff will contribute to drafting the final investigation report for review by the Federal Advisory Committee.

Outputs and Estimate of Time-to-Completion(1):

1. Interim report that documents the design basis for the WTC buildings and describes the process by which the innovative structural system was approved and the abnormal loads from aircraft impact anticipated in the original design of the WTC towers (6 months).

2. Interim report that summarizes pertinent construction data for the WTC buildings (9 months).

3. Interim report that documents code provisions related to high-rise construction and structural fire safety (9 months).

4. Interim report that documents maintenance and modifications that may have affected the structural and passive fire protection systems within the affected regions of the buildings. This includes modifications resulting from the 1993 bombing (10 months).

5. Interim report on regulations and practices related to the passive fire protection features systems in the buildings (9 months).

6. Interim report on the design, operation, maintenance, and performance of emergency access and evacuation systems in the WTC towers (6 months).

7. Draft chapter for final report that describes the design, construction, operation, and maintenance of and modifications to the structural, passive fire protection, and emergency access and evacuation systems, and that documents the probable conditions of the buildings at the time of the attacks on September 11, 2001 (16 months).

(1) Estimated time-to-completion is from start of investigation.

Project #2: Baseline Structural Performance and Aircraft Impact Damage Analysis

Purpose: To evaluate the role of the structural system design and the abnormal loads from aircraft impact on the collapse of the WTC towers by: (1) developing reference structural, mechanical, and architectural (SMA) models of the WTC towers, (2) establishing baseline performance of each of the towers under normal design loading conditions (gravity and wind), (3) estimating probable damage to the SMA systems of the towers due to aircraft impact, (4) comparing differences between anticipated and actual abnormal loads posed by aircraft impact, and (5) estimating the structural reserve capacities of the towers to accommodate abnormal loads under service conditions and the reserve capacities after aircraft impact.

Technical Approach: This project focuses on establishing the performance of the WTC towers under normal design loads, estimating the probable damage to the structural, mechanical, and architectural (SMA) systems, and evaluating the effect of the aircraft impact on the reserve capacity of the WTC towers. These damage estimates are required for reconstructing the fire and smoke environment and for analyzing structural fire response and collapse. In addition, a comparison will be conducted between the response and damage to the towers due to the impact of the Boeing 767 aircraft and the abnormal load condition of a Boeing 707 aircraft impact as considered in the original design. This project will also evaluate the reserve capacities of the towers immediately after impact. This project is divided into six tasks as follows:

Task 1—Develop SMA models of the two towers. The structural plans for the two towers will be studied to select appropriate structural modeling strategies for the different response analysis objectives. The models will need to recognize the special features of the structural system such as the floor diaphragms systems consisting of open-web steel trussed joists and a composite slab, the exterior prefabricated spandrel beam and column elements, and the variety of connection details used in the towers. The models will have varying levels of complexity ranging from frame elements for the entire structural system to detailed finite element meshes of shell elements for the structure in the vicinity of the level of impact. These models, after third-party review, will be used by other investigation projects dealing with the structural performance of the towers. To simplify modeling efforts, a database will be developed for the two towers with geometries, dimensions, and material properties of the various structural members. CAD models will be developed to represent mechanical and architectural systems. Mechanical models will include HVAC, elevators, and water supply systems while architectural models will include interior layouts, stairways, fire suppression systems, etc.

Task 2—Analyze the structural models of the towers under design loading and service loading conditions, estimate the structural reserve capacities, and evaluate the effectiveness of the floor system to prevent column buckling. Estimate the resistance of the stairwell construction to pressure loads.

Task 3—Simulate the Boeing 767 aircraft crashes into the towers to estimate the extent of damage to SMA systems. The analysis of the aircraft crash will be performed at various levels of complexity ranging from energy and momentum conservation calculations to state-of-the-art,

three-dimensional, and large-deflection finite element analyses of both the aircraft and the towers. The simulations will account for the speed, direction, and mass and stiffness distribution of the aircraft. This task will use WTC tower steel properties, including high strain rate properties, obtained from the project on Metallurgical and Mechanical Analysis of Structural Steel. The primary purpose of this task is to provide estimates of the probable damage to structural systems - including floors and exterior tube and interior core columns, and the load redistribution provided by the outrigger truss system - rather than the damage done to the aircraft. Therefore, the level of complexity of the aircraft model will be selected to achieve this analysis objective. The simulation of the aircraft crash into the towers will account for the several sources of uncertainty pertaining to the towers and the aircraft to obtain uncertainty bounds for the results. Structural models of the damaged towers will be developed for use in subsequent analyses.

Task 4—Analyze the towers for the abnormal loads from an impact of a Boeing 707, flying at the speed assumed in the design, to estimate the extent of damage and the reserve capacity after impact. The results of this analysis will be compared with information that may be available on the damage estimated in the original design of the towers. A comparison will be conducted between the results of tasks 3 and 4 to evaluate the differences in the response and damage between the anticipated design case and actual aircraft impact into each tower.

Task 5—Determine the structural reserve capacity (or margin of safety against collapse) within a probability based framework under existing service loads following the loss of exterior and core columns and floors due to the aircraft impact. This task will help to determine the mechanism by which the towers remained standing immediately after the aircraft crashes and prior to collapse, and specifically to evaluate the structural integrity after the crashes.

Task 6—Report preparation. The results of this project will be synthesized into a chapter to describe the baseline structural performance of each of the towers under design and service load conditions, estimates of damage to the SMA systems due to aircraft impact, and the reserve capacity of the structural components under normal design loads, abnormal design loads, and subsequent to damage by aircraft impact. The project staff will contribute to drafting the final investigation report for review by the Federal Advisory Committee.

Outputs and Estimate of Time-to-Completion:

1. Estimation of the damage to the towers. Models for Boeing 767 and 707 aircraft obtained (4 months).

2. Reference structural, architectural, and mechanical models of the towers. Third-party review of SMA models (6 months).

3. Interim report on estimation of the local and global response of the towers to aircraft impact including damage to structural, architectural, and mechanical systems (14 months).

4. Reference structural models of the damaged towers (13 months).

5. Interim report on the baseline performance of the two towers under service and design loads (gravity and wind) (16 months).

6. Response analysis of the WTC towers to actual and anticipated abnormal loads from aircraft impact (15 months).

7. Interim report on estimation of the structural reserve capacity of the towers under normal design, abnormal design loads, and immediately after aircraft impact (17 months).

8. Draft chapter for final report that describes the baseline structural performance of the towers under design and service load conditions, and estimates damage to the SMA systems due to aircraft impact and the reserve capacity of the components of the tower structures damaged by aircraft impact (18 months).

Project #3: Metallurgical and Mechanical Analysis of Structural Steel

Purpose: To analyze structural steel available from WTC 1, 2, and 7 for determining the metallurgical and mechanical properties and quality of the metal, weldments, and connections, and providing these data to other investigation projects.

Technical Approach: This project is divided into six tasks as follows:

Task 1—Collect and catalog the physical evidence (structural steel components and connections) and other available data, such as specifications for the steel, the location of the steel pieces within the buildings, and the specified steel properties.

Task 2—Document failure mechanisms and damage based on visual observations of recovered steel, especially for available columns, connectors, and floor trusses. Possible factors contributing to extreme erosion seen on some parts of the steel columns will be studied.

Task 3—Determine the metallurgical and mechanical properties of the steel, weldments, and connections, including temperature dependence of properties. The grades of steel will be identified in the columns, welds, spandrels, trusses, truss seats, and fasteners. The identification will include composition, microstructure, mechanical, and impact properties. This project will provide steel property data, including models of elevated temperature behavior for relevant steels, to estimate damage to the structural steel members from aircraft impact, evaluate structural fire response, and study the initiation and propagation of structural collapse in the project on Structural Fire Response and Collapse Analysis.

Task 4—Correlate determined steel properties with the specified properties for construction of the buildings. The quality of the steel used in the buildings will be compared with that specified.

Task 5—Analyze the steel metallographically to estimate maximum temperatures reached. It is recognized that high temperature exposure before the collapse may be difficult to distinguish from exposure during post-collapse fires.

Task 6—Report preparation. The results of this project will be synthesized into a chapter to describe the results of the metallurgical and mechanical analysis of the structural steel available from the WTC towers and WTC 7. The project staff will contribute to drafting the final investigation report for review by the Federal Advisory Committee.

Outputs and Estimate of Time-to-Completion:

1. Catalog of available structural steel and relevant specifications (4 months).

2. Documentation of failure mechanisms and damage from visual observations (4 months).

3. Interim reports on the metallurgical and mechanical properties of the steel and connections, including temperature dependence of properties.

a. *Data to support model development*—identification of steel in the columns, welds, spandrels, trusses, truss seats, and fasteners based on composition, microstructure, room temperature tensile properties, and impact properties (partial results in 4 months, complete in 12 months).

b. *Data to support aircraft impact modeling studies*—high strain rate mechanical properties and impact properties of columns, spandrels, bolts, and welds on columns (partial in 4 months, complete in 14 months).

c. *Data to support models of steel frame performance in fire*—creep and high temperature tensile properties of columns, bolts on columns, trusses, truss seats, and bolts or welds associated with truss seats (partial results in 4 months, complete in 12 months).

d. *Data to support models of steel during collapse*—high strain rate room temperature tensile properties of truss seats and associated bolts and welds (partial results in 5 months, complete in 16 months).

e. Models of elevated temperature deformation as a function of load, temperature and time history for relevant steels (some steels in 6 months, complete in 16 months).

4. Estimation of maximum temperatures reached by collected structural steel (complete in 12 months).

5. Database of microstructural changes with temperature in the various classes of steels for future use by building and fire communities (16 months).

6. Comparison of steel properties to applicable material specifications (12 months).

7. Draft of chapter for final report that describes the results of the metallurgical and mechanical` analysis of the structural steel available from the WTC towers and WTC 7 (18 months).

Project #4: Investigation of Active Fire Protection Systems

Purpose: To document and evaluate the performance of the installed active fire protection systems in the World Trade Center Buildings 1, 2, and 7 and assess their role in fire control, emergency response, and the fate of occupants and responders.

Technical Approach: This project is divided into nine tasks as follows:

Task 1—Establish contacts with the Port Authority, Silverstein Properties, their contractors and consultants to obtain information relevant to this project.

Task 2—Develop a comprehensive set of questions to collect information from building operators, first responders, building occupants, and families of victims on the operation of and damage to the fire safety systems on September 11, 2001. These questions will be coordinated with other investigation projects, in particular those for building and fire codes, occupant behavior and egress, and fire service technologies and guidelines.

Task 3—Document the performance of active fire protection systems during significant fires in WTC buildings 1, 2, and 7 prior to September 11, 2001.

Task 4—Document the design, installation and normal operation of installed active fire protection systems, including sprinklers, fire alarm, smoke management systems, pre-connected hoses, and communication system for building occupants in WTC buildings 1, 2, and 7. Review available fire inspection reports.

Task 5—Document the design and capacity of the water supply to the fire sprinkler systems. Review the redundancy and defense-in-depth of the water supply system.

Task 6—Estimate the limits of performance for fully functional sprinkler systems as installed in the buildings.

Task 7—Analyze the design of the active fire protection systems relative to applicable building code provisions and standards at the time of installation. The maintenance, modifications, and inspection records for these systems will be reviewed. Modifications made after the 1993 bombing incident will be documented.

Task 8—The information collected in tasks 1-7, along with other information developed in projects, will be reviewed and analyzed by NIST staff with the assistance of other fire protection engineers with expertise in the operation and capabilities of active fire protection systems. The analysis will establish the facts regarding the performance of these systems in WTC 1, 2, and 7. NIST staff will interpret and analyze these facts and document the findings.

Task 9—Report preparation. Synthesize the results of this project into a chapter to describe the installed active fire protection systems in WTC 1, 2, and 7, and the performance of these systems on September 11, 2001. The project staff will contribute to drafting the final investigation report for review by the Federal Advisory Committee.

Outputs and Estimate of Time-to-Completion:

1. Compilation of information on performance of active fire protection systems in previous fires in WTC Buildings 1, 2, and 7 (3 months).

2. Comprehensive set of questions for collecting information on the operation of and damage to fire safety systems on September 11, 2001 (3 months).

3. Interim findings on the design, installation, and maintenance of and modifications to active fire protection systems present in WTC 1, 2, and 7 (6 months).

4. Completion of estimates of the performance limitations of fully functional sprinkler systems of the type and capacity installed in the WTC buildings (8 months).

5. Synthesis of collected information that will be used to establish the facts and analyze the performance of the active fire protection systems (12 months).

6. Draft of chapter for final report that describes the installed active fire protection systems in WTC 1, 2, and 7, and evaluates the performance of these systems on September 11, 2001 (18 months).

Project #5: Reconstruction of Thermal and Tenability Environment

Purpose: Reconstruct, with assessed uncertainty limits, the time-evolving temperature, thermal radiation, and smoke fields in World Trade Center Buildings 1, 2, and 7 for use in evaluating the behavior and fate of occupants and responders and the structural performance of the buildings.

Technical Approach: This project is divided into seven tasks as follows:

Task 1—Develop guidance on the initial conditions for modeling the fires, the rates of fire spread, and the floors on which the structural collapses appear to have begun through the acquisition of available and relevant photographic and video images of damage to the three buildings, review of accounts from occupants and responders (via project #7), and the cataloging and analysis of such images and accounts.

Task 2—Gather data on the internal construction materials, furnishings and contents to characterize the types of combustibles and estimates of the mass loading and to compare them with data from prior surveys of similar occupancies. Other fuel sources in WTC 7 will be identified and documented. The extent of the dispersed aviation fuel in WTC 1 and 2 will be estimated based on input from the Baseline Structural Performance and Aircraft Impact Damage Analysis project.

Task 3—Compile existing data on the fire performance of floor, wall, and ceiling systems and on the nature of openings (ducts, shafts, etc.), complemented by additional measurements as needed, to determine air access for combustion, to identify fire paths for intercompartment fire spread, and to identify those paths that were capable of contributing to the collapse of the buildings.

Task 4—Determine the thermal properties of the structural insulation systems and the effects of vibration, impact, and shock on their thermal performance. Use this information to estimate the thermal environment on the outside surface of the protected structural members. Also included will be the extent to which the coatings were in place on September 11 and any indication of whether chemical interaction between the insulation materials and the steel at elevated temperatures could have contributed to degradation of structural performance in the time available.

Task 5—Extend the capabilities of NIST's Fire Dynamics Simulator (FDS), using knowledge gained from the previous tasks, to reconstruct the temperature, thermal radiation, and smoke fields within the three buildings (including floor spaces and stairwells) as a function of time and location. Reduced-scale experiments will be used to guide and evaluate the accuracy of key FDS sub-models.

Task 6—Use FDS to simulate fully involved fires in the three buildings, with and without the initial damage from the aircraft or incident debris, for evaluating the extent that damage affected the thermal environment experienced by the structure. Parameter variations in the re-creation of the fires will enable characterization of (as appropriate to each of the three buildings) the mode and locale of fire ignition; the roles of jet fuel and building contents, ventilation system, compartment damage, pressurized core, and fire protection system on growth and spread of fire; the rate and extent of fire spread; and the extent of hot, smoky, and toxic conditions. Uncertainty will be estimated for the results of the analyses. The effectiveness of compartmentation in controlling fire spread in these buildings will be analyzed.

Task 7—Report preparation. The results of this project will be synthesized into a chapter to describe the time-evolving temperature, radiation, and smoke fields in WTC 1, 2, and 7, the effectiveness of compartmentation in controlling fire spread in these buildings on September 11, 2001, and the associated uncertainties. All experiments, model assumptions and operations, and reconstructions will be documented. The project staff will contribute to drafting the final investigation report for review by the Federal Advisory Committee.

Outputs and Estimate of Time-to-Completion:

1. Acquisition and analysis of photographic and video images of damage to WTC buildings 1, 2, and 7 (3 months).

2. Compilation of data on construction materials and systems, furnishings and contents, and other fuel loads (4 months).

3. Evaluation of the thermal performance of structural insulation system(s) (8 months).

4. Completion of experiments to guide FDS sub-model development (10 months).

5. First prediction of the fire dynamics in one of the WTC towers (12 months).

6. Evaluation of pathways for fire ventilation and for compartment-to-compartment fire growth in the three buildings (14 months).

7. Completion of reduced-scale demonstration experiments (15 months).

8. Final predictions, with uncertainties, of the time-varying temperature, thermal radiation and smoke fields in WTC 1, 2, and 7 (16 months).

9. Draft chapter for final report that describes the time-evolving temperature, radiation, and smoke fields in WTC 1, 2, and 7 and the effectiveness of compartmentation in controlling fire spread in these buildings on September 11, 2001 (18 months).

Project #6: Structural Fire Response and Collapse Analysis

Purpose: To determine the response of structural components and systems to the fire environment in WTC 1, 2, and 7, and to identify probable structural collapse mechanisms.

Technical Approach: This project is divided into seven tasks as follows:

Task 1—Evaluate the response of floor and column systems under fire conditions. The following sub-tasks will be performed:

a. Develop structural model of floor truss and slab system including supports (i.e., connections to columns). Obtain information from project on Baseline Structural Performance and Aircraft Impact Damage Analysis.

b. Develop structural model of both interior (core) and exterior column system for the floors of interest. Obtain information from project on Baseline Structural Performance and Aircraft Impact Damage Analysis.

c. Obtain thermal environment time-histories. Consider both standard fires (e.g., ASTM E-119 and ASTM E-1529) and real fires based on fire dynamics simulations.

d. Obtain thermal and mechanical properties of steel truss and connections as well as steel columns sections at elevated temperatures.

e. Obtain thermal insulation properties of spray-on fire proofing.

f. Estimate, using transient thermal analysis, the time-temperature relationship for the floor truss and column systems. Consider both unprotected and protected steel.

g. Evaluate, using thermal-mechanical analysis, the time-dependent structural response of the floor truss system using the thermal environment time-histories determined in "c", including support reactions (connection forces), and the column system for the estimated service and fire loads.

Task 2—Evaluate the response of the WTC towers under fire conditions, without and with aircraft impact damage. The following sub-tasks will be performed:

a. Develop structural model of floors of interest (location and number of floors to be determined) to evaluate the response of the WTC towers without aircraft impact. Obtain information from project on Baseline Structural Performance and Aircraft Impact Damage Analysis.

b. Develop structural model (including aircraft damage) of floors of interest (impact floors and floors above that are involved in fire). Obtain information from project on Baseline Structural Performance and Aircraft Impact Damage Analysis.

c. Obtain thermal environment time-histories. Consider both standard fires (e.g., ASTM E-119 and ASTM E-1529) and real fires based on fire dynamics simulations.

d. Estimate, using transient thermal analysis, the time-temperature relationship for the structural components for the estimated service and fire loads. Consider both unprotected and protected steel.

e. Evaluate, using thermal-mechanical analysis, the time-dependent structural response of the floors of interest using the thermal environment time-histories determined in "c". Include the effect of load transfer from damaged zones to the remaining structural elements, the composite floor system, and the connection of the floor system to the columns.

f. Identify components critical to collapse initiation. Estimate the nominal safety margin for each critical component as a function of time.

Task 3—Conduct tests of structural components and systems under fire conditions. In the course of the investigation, it may be necessary to physically re-create the predicted thermal environment in the buildings and measure the structural response of components such as floor truss seat connections, floor truss assemblies, and exterior prefabricated column-spandrel elements. Such tests would be used to validate analytical models and to provide response data that are otherwise unavailable.

Task 4—Evaluate failure hypotheses for the WTC towers. The following sub-tasks will be performed:

a. Identify candidate hypotheses for initiation and propagation of collapse.

b. Evaluate hypotheses for collapse initiation and propagation, including the role played by floor diaphragms, connections, and transfer trusses and girders.

c. Estimate uncertainty for probable collapse initiation and propagation mechanisms.

d. Identify most probable collapse mechanism(s).

Task 5—Report on the performance of open-web steel trussed joist systems in fire. The past performance of open-web steel joist systems in fire will be investigated. This study will include fire incident reports, and insurance investigation reports. Test reports (ASTM E119 or others) of steel joist systems in fire will be obtained and evaluated. Data obtained both domestically and, where possible, internationally will be included in the investigation. The results of this review will be compared with the floor system comprised of open-web steel trussed joists used in the WTC towers.

Task 6—Analyze the response of WTC Building 7 under fire conditions. The following sub-tasks will be performed:

a. Develop model of WTC 7 structural system.

b. Obtain fuel loads for various tenants and internal building operating systems (e.g., power generation) from project on Reconstruction of Thermal and Tenability Environment.

c. Obtain thermal environment time-histories. Consider both standard fires (e.g., ASTM E-119 and ASTM E-1529) and real fires based on fire dynamics simulations.

d. Obtain properties of steel at elevated temperatures from project on Metallurgical and Mechanical Analysis of Structural Steel.

e. Estimate, using transient thermal analysis, the time-temperature relationship for the structural system.

f. Evaluate, using thermal-mechanical analysis, the time-dependent structural response of the structural system, including transfer girder system, for the estimated service and fire loads.

g. Identify most probable collapse mechanism(s), including the role played by transfer girders. Estimate the margin of safety for each critical component as a function of time.

Task 7—Report preparation. The results of this project will be synthesized into a chapter to describe the response of structural components and systems to the fire environment in WTC 1, 2, and 7, and to identify probable structural collapse mechanisms. The performance of open-web steel trussed joist systems in fire will be documented. In addition, the role of pivotal components such as floor diaphragms, connections, and transfer girders in collapse initiation will be documented. The project staff will contribute to drafting the final investigation report for review by the Federal Advisory Committee.

Outputs and Estimate of Time-to-Completion:

1. Evaluation of the response of floor system under fire conditions (9 months).

2. Evaluation of the response of column system under fire conditions (12 months).

3. Evaluation of the response of the WTC towers with no aircraft impact under fire conditions (16 months).

4. Evaluation of the response of the WTC towers with aircraft impact under fire conditions (17 months).

5. Report on the performance of open-web steel trussed joist systems in fire (6 months).

6. Completion of design, construction, and testing of critical components (16 months).

7. Evaluation of the response of WTC Building 7 under fire conditions (17 months).

8. Draft chapter for final report that describes the response of structural components and systems to the fire environment in the WTC 1, 2, and 7, and the probable structural collapse mechanisms. The performance of open-web steel trussed joist systems in fire and the role of pivotal components such as floor diaphragms, connections, and transfer girders in collapse initiation will be documented (18 months).

Project #7: Occupant Behavior, Egress, and Emergency Communications

Purpose: To determine the behavior and fate of occupants and responders - both those who survived and those who did not - by collecting and analyzing information on occupant behavior, human factors, egress, and emergency communications in World Trade Center Buildings 1, 2, and 7, and evaluating the performance of the evacuation system on September 11, 2001.

Technical Approach: This project is divided into six tasks as follows:

Task 1—Gather baseline information on the evacuation of the WTC buildings on September 11, 2001 through a comprehensive, systems-oriented, and interdisciplinary data collection effort focused on occupant behavior, human factors, egress, and emergency communications (including instructions given, interpretation of instructions, and response to instructions). This will involve the collection of new data from people affected by the WTC attacks (e.g. building occupants, building operators, and first responders via direct accounts from survivors and families of victims), especially those who had to evacuate the buildings. Experts in human behavior and statistical sampling will be used to develop a data acquisition strategy that considers various data collection methods such as interviews and questionnaires. Inputs and suggestions will be obtained from groups with an interest in the content of the data collection effort. Additionally, written accounts, transcripts of (emergency) communications, published accounts, and other sources of egress related information will be obtained, in coordination with other data collection efforts for the investigation.

Task 2—Collect archival records from prior WTC evacuation incidents (e.g., 1975 fire, 1977 blackout, 1980 bomb scare, 1990 power outage, and 1993 bombing) and practice evacuations, including oral history data from floor wardens and fire safety directors. These records will be compared and contrasted with the September 11th incident evacuation. Changes made to the evacuation procedures following the earlier incidents and in recent years will be evaluated in the context of the experience on September 11, 2001.

Task 3—Document pre-event data for WTC Buildings 1, 2, and 7. This information includes, but is not limited to, physical aspects of building egress components, such as stairs (width, number, location, vertical continuity), evacuation lighting, back-up power, elevators (number, operational before and after impact, role in evacuation), and active fire protection systems (sprinklers, manual suppression, fire alarms, smoke control). Building plans, emergency plans, type and frequency of evacuation drills, occupancy level and distribution on the morning of September 11th, and communications will also constitute pre-event data. This information will provide a baseline for evaluating the performance of the egress system.

Task 4—Store the information collected in task 1 in a database. Additionally, information from third-party sources, such as television interviews and newspaper articles, as well as other relevant published material will be analyzed, examined, and assembled in the database.

Task 5—Analyze the data to study the movement of people during the evacuations, decision-making and situation awareness, and issues concerning persons with disabilities. A timeline of the evacuation will be developed using the results of these analyses together with other data sources. This timeline will be compared with the timeline of the structural response, the development of the interior conditions (fire and smoke), as well as activation of the active fire protection systems. The characteristics of the WTC evacuation designs and protocols will be evaluated, including the performance of stairs and elevators, emergency communications, and the temperature and smoke conditions. The designs will also be compared with building code requirements and practices for tall buildings in other major cities worldwide. The observed evacuation data will be compared with results obtained using alternate egress models to better understand occupant behavior and identify needed improvements to existing egress models. In addition, the evacuation experience will be compared with previous evacuation incidents in these buildings. The results of the analyses will be reviewed in the context of occupant protection practices for tall buildings, including the consideration of full evacuation and phased evacuation strategies.

Task 6—Report preparation. The results of this project will be synthesized into a chapter to describe the occupant behavior, egress, and emergency communications in WTC 1, 2, and 7, and the performance of the evacuation system. The project staff will contribute to drafting the final investigation report for review by the Federal Advisory Committee.

Outputs and Estimate of Time-to-Completion:

1. Completion of data collection strategy (4 months).

2. Collection of archival data and pre-event data (4 months).

3. Completion of data collection effort and database development (9 months).

4. Completion of analysis of occupant behavior, egress, and emergency communications as defined in task 5 (17 months).

5. Draft chapter for final report that describes the occupant behavior, egress, and emergency communications in WTC 1, 2, and 7 and the performance of the evacuation system (18 months).

Project #8: Fire Service Technologies and Guidelines

Purpose: To build upon work already done by the Fire Department of New York (FDNY) and McKinsey & Company by: (1) fully documenting what happened during the response by the fire

services to the attacks on the World Trade Center, up to the time of collapse of WTC 7; (2) identifying issues that need to be addressed in changes to practice, standards and codes; (3) identifying alternative practices and/or technologies that may address these issues; and (4) identifying R&D needs that advance the safety of the fire service in responding to massive fires in tall buildings.

Technical Approach: This project is divided into four tasks as follows:

Task 1—Collect emergency response data in cooperation with FDNY to document first responder fatalities, command and control procedures, and equipment performance. Records of interest include dispatch logs, recorded radio communications, run logs from surviving responding units, 911 records, data recorded by the FDNY, Port Authority (PANYNJ) operations, and the New York City Police Department (NYPD), and fireground positioning of emergency apparatus. Information will also be sought on operations and function of communications systems, on-site emergency information systems, fire alarm panels, elevator control panels, standpipes and fire hoses, and other pre-positioned emergency equipment. In coordination with project #7, oral history data will be collected from witnesses, those in control of emergency operations, and surviving first responders to the extent their oral history has not already been documented. Technical experts will review and conduct a fact-based analysis of the data.

Task 2—Interpret the factual analysis to determine the effect on responder successes of factors such as:

- the influence of building design (e.g., height, stairways, elevators, smoke control systems) on fire service command and control procedures, life saving operations, and safety of rescue personnel;
- the influence of aircraft impact damage and fuel run-off on fire service command and control procedures, life saving operations, and safety of rescue personnel;
- the impact of systems failures (e.g., communications systems, water supply, sprinklers, standpipes) on fire service command and control procedures, life saving operations, and safety of rescue personnel;
- building occupant egress as related to fire service operations;
- the ability to fight large fires on the upper floors of tall buildings;
- the impact that the 1993 bombing of the WTC had on codes, standards, and procedures that affected first responders in tall buildings;
- pre-planning, training, and standard operating procedures (including command and control) at the time of the incident;
- fire fighter accountability, location and tracking,
- fire and emergency response protocols for tall buildings;
- the resources available for initial situation assessment and incident management, and practices for determining the possibility of structural collapse; and
- communications and coordination of response activities with other authorities at the incident.

Task 3—Identify alternative emergency response practices and technologies that may advance the safety and effectiveness of first responders, such as: knowledge/information systems for command and control decisions; elevator use by firefighters; firefighter tracking systems; interoperability of communication systems (occupants, firefighters, police, EMS); fire growth and smoke hazard prediction; structural safety monitoring, assessment and prediction; and simulation tools for training.

Task 4—Report preparation. The results of this project will be synthesized into a chapter to describe: the actions of the fire service and performance of their equipment; identify available alternatives related to fire service technology, training, and operational procedures; and identify R&D needs in support of their capability to protect the public, themselves, and vital physical infrastructure during extreme events. The project staff will contribute to drafting the final investigation report for review by the Federal Advisory Committee.

Outputs and Estimate of Time-to-Completion:

1. Documentation of the activities of the fire service and the injuries and fatalities of all emergency responders up to the point of the collapse of WTC 7 (8 months).

2. Documentation of the successes of the emergency responders in preserving life and property, and the factors that may have limited that success (14 months).

3. Identification of the key factors where R&D may improve the capability of responders to protect the public, themselves, and vital physical infrastructure during extreme events (16 months).

4. Draft chapter for final report that describes the actions of the fire service and their equipment; identifies available alternatives related to fire service technology, training, and operational procedures; and identifies R&D needs in support of their capability to protect the public, themselves, and vital physical infrastructure during extreme events (18 months).